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NEW TECHNOLOGIES AND GLOBAL INDUSTRIALIZATION

Prospects for Developing Countries

Prepared by the

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PREFACE

From 4-7 April 1989 an Expert Group Meeting on the impact of new technologies on developing countries' industrialization prospects, strategies, and policies was held by UNIDO in Vienna. The meeting's major objectives were:

- first, to analyze and assess changing and emerging international patterns of industrialization stemming from new technological developments;

- second, to outline specific industrial strategy options and policy measures for developing countries in response to these developments; and

- third, to strengthen co-operation among developing countries in terms of monitoring international technological developments and designing joint approaches in industrial policies.

This report presents the major background studies which served as a basis for discussions during the meeting. In addition to a general policy issue paper, the reader will find specific technology case studies on the industrial strategy and policy implications of recent technological developments in telecommunications, microelectronics (exemplified by the textiles/clothing and the machine tool industry), biotechnology and new and advanced materials.

A summary report of the main findings and recommendations of the April 1989 meeting was published earlier and is available upon request from UNIDO.[1/]

1/ Expert Group Meeting on Prospects for Industrialization Policies in Developing Countries Taking into Account the Impact of Developments in the Field of New and High Technologies, Vienna, 4-7 April 1989, Report, PPD.118 (SPEC.), 24 May 1989.

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CHAPTER ONE

New Technologies and Industrialization. Main Policy Issues for Developing Countries.

by the Secretariat of UNIDO

I. INTRODUCTION

This introductory chapter seeks to assess the role of new technologies in determining future patterns of international competitiveness. It further attempts to establish the principal importance and scope of industrial policies in creating the proper preconditions in developing countries to respond to and introduce new technologies and to maximise their benefit for the overall economy. The chapter provides a broad analysis of the interlinkages between emerging new industrial technologies and industrialization prospects and policies of developing countries. The nature of some key new technologies is briefly analyzed and major impacts are assessed. Major areas for policy attention are then discussed in more detail.

It is considered essential to put the issue of new technologies into the broader perspective of the preconditions required for effective generation, absorption, diffusion and application of industrial technologies. One of the main objectives of this chapter is therefore to demonstrate that the emergence of new technologies does not imply a redefinition of the industrial policy agenda but rather presupposes a targeted and imaginative use of the current set of industrial policy measures.

In the context of this chapter, the term 'new technologies' is meant to encompass advances in the areas of telecommunications, microelectronics, biotechnology and new materials. Although these technologies are very heterogeneous in nature, the chapter by necessity will remain general in its outlook and conclusions. Detailed specific information on the various technology areas under consideration is provided in separate case studies presented in the following chapters.

There can be no doubt that the dramatic technological changes taking place at present do affect all developing countries in one way or another. The challenge of new technologies, however, takes on a different face in each developing country. Different levels and patterns of industrial development will shape both the short- and medium-term relevance of new technologies and the capacities to respond to resulting threats and/or opportunities. This means that since the conditions, applicability and impact relating to the new technologies vary in different developing countries, the conclusions drawn in this chapter can not be equally relevant for all.

The new technologies under consideration are characterized by varying degrees of maturity. While some are approaching the end of their infancy stage (this appears to apply to quite some industrial applications of microelectronics) others such as the development of new materials and certain advances in biotechnology are in a truely embryonic stage. Accordingly, this chapter will to some extent be exploratory in nature. Throughout, emphasis will be on the formulation and accentuation of problems and issues, not on their solution.

II. TECHNOLOGY AND INDUSTRIALIZATION: THE SETTING

Industrial technologies are both an outcome of the industrialization process and one of its main driving forces. The introduction of new technologies can be seen as one of several important factors which directly and indirectly change the context and modes of international industrial production, thus being among the key determinants of the international division of labour. Given the accelerating pace of technological development in industry, there is an urgent need not only to identify incipient technological breakthroughs but above all, at an early stage, to analyze their short- and long-term implications for the worldwide industrialization process and to reassess the validity of crucial assumptions underlying developing countries' current industrial strategies.

In doing so, it is important to put the technology dimension into perspective, i.e. to recognize its essential yet only partial role in shaping industrial strategies. Developing countries in particular are facing a multitude of adjustment pressures on their economies resulting from inter-related external factors such as financial constraints and uncertainties; changing trade policies of major trade partners; subsidization and other support measures for industry in competing countries; large and unpredictable price fluctuations in world markets; exchange rate variations etc. It is in this overall context that the impact of new technological developments needs to be seen.

In the advanced industrialized countries where technological developments in industry have been concentrated, new products are continuously introduced which either substitute or supplement existing products. New production processes are being applied which have higher productivity and/or different factor proportions, higher flexibility and different economies of scale. In place of some materials traditionally supplied by developing countries, new materials are being introduced. These innovations in turn lead to changes in production costs, quality, timing, etc. and thus to changes in the competitive system both at the micro and at the macro-economic level.

As a result, adjustment pressures on developing countries have increased and so may, with some notable exceptions, their technological dependence. Obviously, the pursuance of the industrialization process will force these countries to participate in one form or another in the international technological race. With the race accelerating in speed and in costs, many developing countries will face great difficulties to follow: only a few may succeed in keeping abreast in highly selected areas of technology. For the majority of developing countries, new technologies will have to be acquired from abroad rather than developed domestically. Restricted property rights and high technology transfer prices will constrain this acquisition. So will prevailing scarcities in financial resources and human skills.

This implies that the industrial policy of developing countries should be focussed on establishing the preconditions of an efficient technology-creating system. In a dynamic perspective it is the international gap in technology-generating capacities more than the gap in the present utilization of certain sophisticated technologies which should be addressed by policy-makers.[1] The point to make in this context is that technology is not (or only under exceptional circumstances) exogenously given to an economy. Rather it is the industrial policy and production structure framework which largely establishes the conditions under which technologies are generated/applied and the specific types of technologies chosen.

Process technologies are applied in industrial enterprises with a view to increase productivity or to better respond to other market requirements. As a means of production, they come both embodied, i.e. in the form of industrial machinery and equipment, and dis-embodied, i.e. in the form of know-how, experience, managerial and organizational skills.[2] This is an extremely important point to recognize: it means that each technology - and above all new sophisticated ones - is to be seen as an integrated hardware-software package with the interaction of these two components greatly determining its costs and benefits. This has obvious implications also for the issue of technology import as will be discussed below.

Closely related to the above, it is currently to be observed that industrial services are assuming an ever greater importance. This is true in a double sense First, new sophisticated production technologies can only efficiently be operated within an overall system of support services such as telecommunication; advanced repair and maintenance services; computer software specialists; and R&D inputs. Second, at the company level the 'service content' of manufacturing is increasing, e.g. through the use of computer systems for design, quality control, inventory handling, etc. Indeed, "information technologies have created a symbiosis between development in the manufacturing and the services sectors". (UNCTAD 1988, p. 257). Two brief further comments are in order in this regard. First, the services emphasized above are knowledge-based in nature and productivity-raising in their effects. They represent highly productive inputs to the production system and have nothing in common with the traditional notion of services being low-skill, low-productivity activities. Second, and following straight from the previous point, these services are directly industry-related. A recent OECD study concludes that more than 50% of all market-oriented services in OECD countries are of a directly production-related nature (OECD 1987). Hence, while it appears to be true that the advanced industrialized countries are gradually becoming service economies, it is certainly grossly misleading

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1/ This point is specifically elaborated upon in Chapter Five: Industrial Applications of Biotechnology. Implications for Industrial Policy in Developing Countries (by Martin Fransman).

2/ The role of organizational innovation is particularly emphasised in Chapter Three: Technological and Organizational Change in the Global Textile-Clothing Industry. Implications for Industrial Policy in Developing Countries (by Kurt Hoffman). See also section III.4.a. of this chapter.

to equate this with a trend towards a post-industrial economy. In the words of a much debated recent study: "Manufacturing Matters" (Cohen/Zysman 1987), i.e. a strong manufacturing base will remain the backbone of industrial development in the years to come.

III. THE NATURE OF NEW TECHNOLOGIES AND IMPLICATIONS FOR THE INTERNATIONAL DIVISION OF LABOUR

1. The general nature of new technologies

For a term as broad as "new technologies" there is obviously no watertight definition available. What can be observed at present is that the international technology-driven competition has grown, development cycles of both new products and new processes have become shorter and comparative advantages of both countries and companies are subject to relentless change. In this overall process of industrial change some dramatic technological advances such as microelectronics and bioengineering have emerged which are commonly referred to as 'new' technologies. These new technologies exhibit certain characteristics with regard to the nature, scope and direction of their impact on industrial development as briefly described below:

- Nature of impact: The major new technologies are transformational in nature, i.e. they have drastically changed the conditions under which industrial goods are being produced. Microelectronic innovations are a case in point. Not only have they triggered off a whole wave of new products (e.g. in consumer electronics) but above all they have had a profound impact on industrial production processes. CAD/CAM, CNC control units, CIM and FMS are but a few acronyms which have become common language in modern manufacturing.[1/]

- Scope of impact: Closely related to the above point, the new technologies can be characterised as pervasive, i.e. in their application they cut across many sub-sectors of industry (and not only industry). Conventional classifications of industrial sub-sectors and activities therefore tend to become less meaningful or blurred. This is the case e.g. in machine tool production which now includes as much electrical as non-electrical engineering and in food processing and pharmaceuticals production in which similar new biotechnologies are developed and utilized.

- Direction of impact: Though implicit in what has been said so far it needs to be specifically pointed out that the new technologies tend to work in favour of increased homogeneity of industrial production processes. Industrial equipment will become more similar across various branches (at least regarding components such as control units, design systems, etc.). This in turn has significant implications for human resource development in general and training in particular, as will be discussed below (see section IV.2.b).

1/ CAD/CAM = computer-aided design/computer-aided manufacturing; CNC = computer numerically controlled; CIM = computer-integrated manufacturing; FMS = flexible manufacturing systems.

In the developed countries and the most advanced developing countries the introduction of new technologies entails changes in many key parameters of industrial development with far-reaching repercussions on corporate strategies, structural change, trade and investment patterns and overall competitiveness. In these areas, some traditional notions and ways of thinking will have to be buried as has become obvious for example in the debate on 'flexible automation'. Only 10 to 15 years ago, flexibility and automation were conceived of as antagonistic and the idea of achieving increased flexibility via automation would have been considered a contradiction in terms. With the advent of microelectronics-based CAD/CAM systems this is no longer true; the rules of industrial production have been partly rewritten.

The following sections provide a brief overview of the major areas of new technologies before section IV turns to policy issues relevant for developing countries in responding to the technological challenges.

2. Telecommunications and microelectronics: Advances in the transfer of information

There can be no doubt that advances in the field of microelectronics and telecommunications occupy a central position in the incipient industrial-technological transformation taking place at present. Indeed, both areas are to be seen in a sense as the two sides of the same coin: while microelectronic equipment permeates industrial production technology, telecommunication facilities are the matching industrial infrastructure required to reap system or networking benefits.[1/] Computer-based systems provide a common language which - as is often said - is transported by telecommunication on the highways of the information age minimizing transaction time.

Economic historians have always emphasized the crucial role of time in economic and technological progress.[2/] Indeed global competition is now more and more a competition on time and less simply on price c. An example very much to the point is the long-distance interfacing of US West Coast design studies with CAD facilities in Hong Kong to reduce the lead time required between design and manufacture of garments.

Recent technological developments in telecommunications have taken place in exchange technology, transmission equipment and peripherals alike:[3/]

1/ 'Télématique' is the pertinent French term to combine the two aspects.

2/ The first industrial revolution was primarily a revolution in the means and methods of production; hence it depended essentially on the exact measurement of time. Lewis Mumford, for example, holds the view that it was the invention of the clock more than that of the steam engine which kindled the first industrial revolution.

3/ The following draws on Chapter Two: Technological Change in Telecommunications. Implications for Industrial Policy in Developing Countries (by Kurt Hoffman)

- digital exchanges are being introduced which are solid-state (without moving parts) implying fewer breakdowns and less maintenance requirements than conventional electromechanical switching systems;

- transmission equipment is revolutionized by fibre optics and laser transmission systems which are superior to conventional systems in terms of greater capacity, speed, flexibility and resistance to interference;

- peripheral equipment now comprises a broad range of 'intelligent' terminals and telephones, key systems, mobile radios and a variety of new office equipment.

With these wide-ranging innovations, telecommunications even more than before is becoming a critical element of any country's industrial infrastructure. Consequently, any development strategy which in anyway is dependent on international linkages for finance, technology, goods and services and/or involves the local participation of foreign firms in any sector of the economy will face considerable and growing difficulties in the future if an adequate, digital-based telecommunications system is not in place.

Within the developed countries, the basic telecommunications infrastructure has long been in place, telecommunications services are used as an integral part of the productive effort in the economy and there is a wide range of domestic enterprises able and willing to supply both services and equipment under competitive conditions.

Many developing countries, however, lack the basic telecommunications infrastructure and a viable domestic equipment and service supply sector that exist in the industrialized countries. Consequently, and in contrast to developed countries, the predominant policy concern and objectives of developing countries in relation to telecommunications must be to build up the basic telecommunications network and to respond to the needs of a growing economy.

The diffusion of microelectronics is closely related with telecommunications because of important synergetic effects. Of all new technologies the industrial application of microelectronics is by far the most advanced. Microelectronic technology has been introduced in a wide range of industrial processes involving both the transfer and processing of information and the control of machinery. Leaving aside microelectronic innovations in the sphere of administration and co-ordination (office automation equipment) the two major areas of application so far have been computer-aided design (CAD) on the one hand and computer-numerically-controlled (CNC) machines on the other. This will be briefly exemplified below by the cases of both the clothing industry and the machine tool industry.[1/]

1/ For details see Chapter Three and Chapter Four: Technological Change in the Machine Tool Industry. Implications for Industrial Policy in Developing Countries (by Staffan Jacobsson).

So far the clothing industry has shown a considerable 'resistance' to automation pressure. Its central production stage, viz. the assembly of pieces of cloth, has remained largely a domain of labour-intensive operations on traditional or programmable sewing machines. However, in the pre-assembly stage, CAD systems have been rapidly advancing and are now widely used for pattern making, grading and marking on the basis of stored 'rules'. The main benefits are a quick response to changing market requirements, a shorter turnaround time in grading and marking and considerable improvements in fabric utilization.

As regards the international diffusion of CAD systems in clothing manufacturing the overwhelming majority of them has been installed in industrialized countries: By 1985, only approx. 10 CAD systems out of a total of 700 were to be found in advanced developing countries (Hoffman, 1985a). The same broadly holds true for CAD diffusion in other industrial sectors. It has been significant only in very few developing countries and territories (including Brazil, Hong Kong, India, Republic of Korea, Mexico, Singapore, Taiwan Province of China) which have either promoted their indigenous electronics industry, established a domestic automobile production or moved into high-technology-based clothing exports. (Kaplinsky 1987)

The machine tool branch has since the 1970s become a particularly strong producer and user of NC and CNC machinery. For example, in the leading OECD producing countries of metal-cutting machine tools the share of NC machine tools has risen from one quarter to two thirds within just a decade (1976-86). In the same period the share of CNC lathes in total lathe production went up from one third to almost four fifths of the total. Here again, a considerable diffusion gap exists between most developed countries and the few advanced developing countries which are significant users of NC-machine tools. However, in terms of density (number of NC machine tools per employee in the engineering sector) at least countries such as the Republic of Korea and Singapore now have achieved levels in the order of 50% of the density in the UK, the USA or the FRG.

These illustrative references are supported by evidence from many other fields of industrial activity. Hence, it appears safe to conclude that in the field of microelectronics there is "little basis for drawing a general conclusion that [the developing countries] are closing the technological gap with the industrially advanced economies". (Kaplinsky 1987, p. 63)

3. Biotechnology and new materials: Advances in the transformation of matter[1/]

Biotechnology and new and advanced materials are very much in an incipient stage as far as their industrial applications are concerned. Hence, their implications for future patterns of industrial development are less clear cut and more difficult to assess.

1/ For details see Chapter Five and Chapter Six: New and Advanced Materials. Implications for Industrial Policy in Developing Countries (by Lakis Kaounides).

Biotechnology can be defined as the use of biological organisms (or their constituents such as cells and DNA) for the transformation of inputs into commercial outputs. In this sense, evidently, biotechnology or bioprocessing has a very long history ranging from fermentation to, more recently, the introduction of new plant varieties within the so-called Green Revolution.

Around the mid-1970s, however, a 'new' biotechnology took off. Scientific breakthroughs (mainly in recombinant DNA and cell fusion) have provided new powerful tools which in turn have greatly enhanced the potential of biotechnology for commercial applications. The new techniques enabled new combinations of genes to be created and the functions of biological organisms to be modified.

In this process, significant interlinkages were created between advances in biotechnology and those in microelectronics. On the one hand, new information processing technologies are having an impact on the efficiency of biotechnological processes. Examples are to be found in the use of microprocessors and computers in automated control of bioreactors and DNA synthesizers. On the other hand, biotechnology is beginning to have an effect on information processing although this effect is not yet as great as the other way round. For instance, one area of application for protein engineering is in the field of biosensors and biochips where integrated circuit technology is fused with protein engineering technology.

In general, however, the translation of scientific and technological advances into commercial applications (products or processes) has not lived up to initial expectations (Venkataraman 1987). Only a few marketable products have so far been created from the 'new' biotechnology, inter alia because lead times for product development, including testing and approval, tend to be very long and often unexpected problems emerge in the process of scaling-up. Examples of commercial biotech-offspring include the anti-cancer agent interferon, human insuline and growth hormones in the field of pharmaceuticals as well as tissue culture, sugar-substituting sweetners and the cloning of oil palm plants in the area of agro-industry.

The latter two developments are already having substantial effects on the international sugar market and on the vegetable oil market. The gradual substitution of non-sugar sweetners for sugar has contributed to a further oversupply and low prices in world sugar markets; high productivity oil palms will lead to shifts in cultivation (e.g. away from rubber into palm oil because of higher yields) and may eventually also result in price decreases for all vegetable oils.

New and advanced materials are another high tech field of great significance which is expected to develop its full impact on industrial development and competitiveness towards the late 1990s. Increasing attention is now being paid to recent scientific and technological developments which have led to the creation of highly engineered advanced materials. These comprise a number of distinct yet connected clusters of materials such as engineered plastics, advanced ceramics, composites, advanced metallic alloys and superconductors.

The quintessence of progress made in such interlinked fields as physics, mathematical modelling, computer science and advanced instrumentation is that material scientists can now intervene directly at the microstructure of materials. Consequently, it is less and less the availability and properties of specific materials which constrain the development of end products. Rather, one can now in many cases start from the required properties and performance elements of a product and then develop and process tailor-made materials for the particular application. From this, a vastly accelerated rate of materials and product innovation follows as well as rapid obsolescence in existing products and processes, and reduced life cycles for new materials. No single material will dominate the market for long periods, as used to be the case in the past.

Furthermore, it is likely that the materials which will dominate industry in the 21st century, will be 'materials systems'. Composite and laminate materials systems tailored for specific applications and environments will gradually displace monolithic or homogeneous materials, such as metals.

The early incorporation of such materials into new products and processes confers higher value added, leads to improved competitive positions and accelerates market penetration. Hence, a successful advanced materials sector will increasingly contribute to maintaining or acquiring international competitive advantage. Many governments have already recognized the potentially harmful effects on output, employment and trade of falling behind in advanced ceramics, polymers and composites.

Moreover, the advent of advanced materials may significantly influence industrial location decisions in the future, particularly when seen in a broader perspective. The introduction of computer-based manufacturing systems, together with just-in-time inventory control and total quality management, imply a tendency towards proximity of materials suppliers to industrial end users. Indeed, advanced materials have in some cases been developed specifically to eliminate import dependence on critical production inputs. It may thus be expected that e.g. the demand for some metals will be negatively affected as advanced materials gain a stronger foothold in the developed countries' industries in the future.

4. Main conclusions for future industrial development patterns

a. General lines of development

Based on the brief analyses provided above an attempt can be made to arrive at some more general inferences. These will - sometimes implicitly - be shaped primarily by developments in microelectronics and automation technology which have left their mark already quite firmly on international industrial structures and economic relations.

First, the introduction of new technologies is bringing about a change of the major determinants of global industrial competition. The implications of this change for developing countries have been and will continue to be profound. In many branches of industry comparative advantages based on the intensive use of low cost labour are being eroded or lost due to progressive automation in industrialized countries. A further implication is the tendency of the raw materials intensity of industrial production to decline[1] thus jeopardising the long-term development prospects of raw materials producers and exporters.

At the same time, it appears that a certain technology obsession - coupled with doomsday predictions for the developing countries - which was prevalent in the early 1980s, is now giving way to more realistic and differentiated assessments. It has become clear that the barriers for adoption of new technologies have been underestimated whereas the immediate impact of their diffusion in specific sectors has been overestimated. This is not to say that the current changes in the international division of labour are to be belittled; however, the sometimes feared 'relocation back North' of industrial capacities has so far not taken place on a massive scale[2] - although it can be observed that the strong redeployment wave of past decades from North to South is now tapering off. This means that the time needed by all actors to adjust to the new technological setting can be used by developing country governments to design appropriate policy responses and measures.

Second, and particularly important for the design of policy responses, it needs to be recognized that the new automation technologies in developed countries have been introduced for different reasons in the various industrial branches and often at a different diffusion pace in companies within the same industrial branch. The most obvious motive, given the nature of factor endowments in industrialized countries, has been the pressure to reduce production costs. In the high-wage context of developed countries, automation can result in reducing the total unit cost of production by saving labour and increasing the labour productivity.

However, the cost argument has often been complemented - and sometimes indeed been superseded - by other considerations. The two most significant ones have been product quality and flexibility of production. Product quality is the overriding concern e.g. in the manufacturing of precision tools and professional instruments. In these areas the use of CNC-machinery has effectively become an industrial standard. The use of conventional machinery would inevitably lead to exacting requirements and close tolerances not being met, rejection rates being comparatively high and eventually competitiveness being lost. Flexibility has become a must in many industrial branches such as metalworking and engineering products (where approx. 80% is small batch production) and particularly in garments manufacturing where more frequent fashion changes demand flexible adjustment and quick response.

1/ This is partly due to more efficient materials utilization in the context of CAD/CAM systems and partly due to biotech-induced substitution effects and the advent of new and advanced materials.

2/ This is the clear result of the most comprehensive empirical study so far undertaken on the subject. The study covers the investment behaviour of Federal Republic of Germany companies in the following industrial branches: textiles, clothing, shoes, precision instruments, optics and electronics. (Jungnickel 1988).

Indeed, this emphasis on flexibility, quality and a built-in capacity to quickly adjust to changing customer needs can be said to constitute the central characteristic of the new technologies. This explains why organizational innovations have to go along with the introduction of new hardware. The much heralded Japanese success has at least as much been caused by new management styles as by new machinery: quality circles, group technology, just-in-time inventory planning and multi-skilled production workers are some of the basic determinants.

Third, and directly linked to the flexibility issue, economies of scale are gradually eclipsed by economies of scope (Cohen/Zysman 1987, Chapter 10). In the past, automated industrial equipment was dedicated to a very specific task such as for example, the production of a specific component. Changes in this dedication were either impossible or involved extremely time-consuming and costly adjustment of the equipment. In the context of high minimum efficient sizes of production high volumes of standardized products were required to achieve sufficiently low unit costs: this is the essence of economies of scale. With the application of microelectronics, however, automation has become programmable or flexible. This implies that the trade-off between automation and flexibility is less sharp than it used to be. CNC machinery can be programmed to perform a variety of tasks, e.g. producing different machine components or assembling different products. This flexibility permits the move from one-product to multi-product manufacturing. To recover high investment costs it is no longer required to have large production series of the same product but to efficiently utilize the equipment for flexible small batch production of a variety of products: this is the essence of economies of scope.

Fourth, the emergence of new technologies has tended to be accompanied by increased entry barriers for new companies seeking to start production in the industrial branches concerned. Such barriers refer first of all to the access to and the ability to operate the new technologies; further to capital requirements, R&D capacities, marketing networks and other factors. Entry barriers appear to be less of a problem in the field of biotechnology which is very research-intensive yet not particularly capital-intensive. Hence, many developing countries possessing the core scientific capabilities and a supportive overall industrial infrastructure - two exacting conditions, to be sure - will be able to enter the biotech market in specific fields. The situation is different, however, with regard to the production of flexible automation equipment where the barriers for new companies are tremendous. Advantages of great size apply in areas such as financing, research and development, marketing and distribution which are of eminent importance. A forceful corporate concentration process is underway in these branches in most developed countries both at the national level and increasingly crossing national boundaries.[1/]

1/ An illustrative example of an extremely powerful industrial conglomerate firm is the Swedish-Swiss ASEA-BBC group. It employs R&D staff of some 12,000 people and has annual expenditures on R&D exceeding e.g. those of the entire industry of a country like Austria.

This is not to say that medium-sized companies are essentially bound to loose out in competition. On the contrary, they do possess a number of crucial advantages over industrial giants. It seems, however, that they can only compete successfully if they join forces in areas such as financing, R&D, marketing and others (the policy implications of this are dealt with in section IV.2.c.).

b. Feeling the winds of change: Emerging trends in foreign direct investment flows

At present, fundamental changes are occurring in the determinants and international patterns of foreign direct investment (FDI) flows, partly due to technological factors. The implications for developing countries are far-reaching. Hence, it appears worthwhile to briefly review some of the main trends in this area (Lütkenhorst 1988).

Recent years have shown a distinct tendency for FDI towards stronger intra-OECD countries flows. This trend has been caused, inter alia, by increased FDI in EC countries (anticipating the 1992 Common Market), the rise of Japan as major source of FDI,[1/] the high foreign indebtedness of many developing countries and the gradual shift of FDI towards higher technology areas.

Developing countries as a whole now appear to be running the risk of marginalization in an intensified process of globalizing industrial production. Real FDI flows to developing countries have decreased substantially as has their share in total FDI outflows from developed market economy countries. Since 1975 this share has exhibited a clear downward trend from a peak level of 41.8 per cent to only 16.8 per cent in 1986. At the same time, a strong shift has taken place in the geographical distribution of FDI flows with Latin America giving way to South-east and East Asia as a major recipient area. It is in the latter region that notable exceptions to the general curtailment of FDI flows to developing countries can be found.

Specifially regarding manufacturing FDI in developing countries, far-reaching changes in investment motives and investment strategies are to be observed at present. One of these is the diminishing significance of inter-country differentials in labour costs as key investment incentive. This has two quite different aspects which need to be clearly distinguished from an analytical point of view:

- First, differences in production costs in general and labour costs in particular - though continuing to be a relevant factor - in many cases have ceased to be a sufficient precondition to induce FDI flows. Other qualitative investment determinants beyond direct production costs have come into play which will be discussed in more detail below.

1/ Due to both the strenth of the yen and frequent trade disputes a growing share of Japanese FDI is now targeted at the USA, car manufacturing joint ventures being a case in point.

- Second, even if production costs should continue to be the decisive factor in shaping investment decisions, the labour cost share in these does not weigh as heavily as it used to in the past. The advanced degree of industrial automation stemming from microelectronic-led innovations has drastically reduced the share of labour costs in total production costs. Consequently, we are witnessing a gradual "uncoupling of manufacturing production from manufacturing employment". (Drucker 1986 p. 775). In the UK to quote but one telling example, labour costs now represent not more than 10 per cent of the average ex-factory costs for all consumer electronic goods; they account for as little as 5 per cent in the case of 14" colour TV sets (Milne 1988).

In this process of labour costs losing in significance other investment determinants become more important instead - and these are of a more qualitative nature. Whereas the "first round" in establishing a global industrial production network involved labour-intensive goods requiring only simple technologies (e.g. clothing, shoes, toys, simple consumer electronics), worldwide industrial restructuring is now proceeding into branches such as automobiles, electrical machinery and machine tools. These industries tend to use more sophisticated technologies which accordingly place higher demands on potential investment locations.

With FDI in developing countries moving gradually away from export production of simple consumer goods based on routine assembly operations and venturing into technologically more sophisticated production lines, a premium is put on risk diversification; investors in more advanced areas of manufacturing (for example machine tools) will primarily opt for strategic locations which allow them to serve export markets while, at the same time, tapping a large domestic market of the host country. "Large potential markets such as Brazil, Mexico, and China are being tapped by foreign investment, locating there to take over the expansion of new segments of consumers. In sum, the target is still the world market, but the strategy of multilocation is increasingly more important vis-à-vis the export-platform strategy" (Castells 1986, p. 306).

Another essential investment requirement is the availability of highly skilled labour able to operate top-of-the-range machinery, often of a CNC type. Low wages cannot by themselves substitute for non-existing engineering skills and hence it is cheap skilled labour that foreign investors are after. This means that the performance of developing countries in attracting FDI will in the future be crucially dependent upon the successful upgrading of existing skills. In the present case, on-the-job training cannot be the solution as the prior availability of skilled labour itself figures prominently among investment incentives. Seen from this angle, the attraction of FDI essentially becomes a race against time for most developing countries. The question is "whether the training of technical labour could be done rapidly enough, and on a scale large enough to foster a second stage of "off-shore" productive decentralization from the North's industrial basis". (Castells 1986, p. 305)

Finally, the overall industrial environment of a host country is of great importance. In a recent survey of Japanese small- and medium-sized enterprises having invested abroad, the "technology support" of a host country (encompassing the skill level of the labour force, infrastructure provision and the availability of necessary support industries) was found to be the first ranking determinant of investment decisions, placed even above such important factors as exchange rate stability and political stability (Phongpaichit 1988). Admittedly, the now frequently used term "support industries" is not a well-defined concept; yet it is quite obvious what it basically refers to. The foreign investor in areas such as transport equipment, machinery or electronics is vitally interested in an existing network of industrial products and related services. This concerns areas such as essential spares; subcontracting opportunities for parts and components; maintenance services; and increasingly the assistance of computer software specialist needed to adjust complex machinery or to accommodate specific buyers' requirements.

A recent UNIDO study on the FDI behaviour of machine tool producers confirmed the need to go beyond labour cost considerations and found the concept of "proximity" to be crucial: "proximity to suppliers of high quality materials and components, proximity to a labour force to some extent trained by the machine tool industry itself and proximity to buyers, many of whose orders are of a 'custom-made' type. These are system requirements, external benefits which can be reaped by the firm" (UNIDO 1987, p. 26). Accordingly, the absence of such system advantages in many developing countries will effectively act as a barrier against attracting FDI in a wide range of industries.

The above "tour d'horizon" of recent trends in FDI flows to developing countries testifies to an increasing complexity with regard to major investment determinants. Key factors in steering what has become a thinner flow of FDI to developing countries are skill levels, market size, the existence of an efficient industrial support network, the availability and quality of a variety of support services as well as advanced telecommunication and information-processing facilities. Whereas previously a certain physical infrastructure (transport facilities, energy and water supply) was often sufficient to attract FDI, now a highly developed human and technological infrastructure is required as well and is becoming increasingly important. Low wages undoubtedly continue to be an asset, but no longer a panacea. The rules of the game have changed and in the late eighties "locational patterns primarily intended to reduce the costs of unskilled labour ... are more the result of historical practices rather than of immediate concern" (Ballance 1987, p. 259) Manufacturing FDI flows to developing countries thus may be expected to keep concentrating on only a few advanced developing countries which meet the requirements outlined above while the vast majority of Third World countries will be left high and dry (Mohs 1985).

IV. NEW TECHNOLOGIES AND INDUSTRIAL COMPETITIVENESS: THE POLICY LINK

1. Why is policy crucial?

Developing technologies is one thing, achieving industrial competitiveness is another. The former provide opportunities and powerful tools to achieve the latter. However, transmission mechanisms are needed to translate technological potential into actual economic benefits. This is where economic policy in general, and industrial policy in particular enter the picture. They influence the forms and conditions, the costs and benefits of applying new technologies.

The speed of generating and diffusing new technologies and the efficiency of applying them depend on a broad range of coherent policies. System advantages are essential to fully reap the benefits of sophisticated production technologies. These system requirements relate, first of all, to the level of individual manufacturing enterprises. Here it is essential that various high-tech components be effectively integrated. An example would be a garment producing company introducing a CAD system, CNC-cutters, a computer-based production monitoring system and a link-up to an electronic point of sale system (EPOS) at the retail end.

Second, system requirements are also pertinent at the level of an industrial branch or the industrial sector as whole. Industrial networks need to be established to provide for crucial input-output links and complex interconnections including a number of high-tech related industrial services.[1/]

Third, and most importantly, there are system requirements working at the level of the whole economy. To meet these requirements essentially is a policy task and will have significant repercussions on the efficiency of lower level systems (industrial sector, branches and companies). Key elements of these overall system prerequisites are a harmonious interplay of private and public sector institutions; effective co-ordination between research and industrial sector needs; human resource development efforts in line with prospective industrial-technological trends; the provision of adequate amounts and forms of industrial finance, etc.

Given the broad array of policies which impinge upon technological innovation and, in turn, on industrial competitiveness important implications can be discerned for the determinants of a country's comparative advantage. With high technology products being increasingly traded on an intra-industry basis, comparative cost advantages have lost their 'political innocence'. The high-tech areas of international trade which are rapidly gaining significance are determined neither by the availability of natural resources ('Ricardo goods') nor by relative factor endowments ('Heckscher-Ohlin goods'). Trade in

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1/ "Advantage in a national economy is embodied not simply in the capacities of specific firms but in the web of interconnections that establishes possibilities for all firms." (Cohen/Zysman, op. cit., p. 102). See also Pérez 1988.

high-tech products has been said to be the sphere of "arbitrary comparative advantage" (Cline 1982). This means quite simply that the patterns of specialization emerging now in particular areas of industrial production are not primarily the result of factor endowments and relative factor prices but more the result of political intervention: "In a very real and immediate way, a nation chooses its comparative advantage." (Reich 1983, p. 782).

This applies not only in the stricter sense that specific lines of technological development are given priority and are deliberately promoted/subsidised. It also applies in the broader sense that, in view of the increasing significance of human capital as a factor of production, a country's educational system and entire social infrastructure determine its overall competitiveness more strongly than ever before. This is a situation where the opportunity costs of refraining from political action are ever greater; a premium is placed on the earliest possible promotion of potentially competitive technologies and products.

National policy-makers will find themselves in a formidable dilemma situation: often there is considerable pressure to take policy decisions (e.g. on the introduction of an advanced telecommunications system) as early as possible since in the course of time policy will become more and more constrained by technological imperatives. This implies, however, that policy decisions often are to be taken in a state of highly insufficient knowledge. While this dilemma can never be entirely eliminated, it could obviously be reduced by early access to knowledge about technology options.[1/] A close monitoring of international technological trends thus is essential.

2. Major policy areas

In the past national policy-makers have tended to focus their attention more on the generation of technology (domestic or imported) than on its diffusion. However, unless the internal generation process of technologies can be shown to have substantial spillover effects or other long-term economic benefits, the source of the technology appears to be less important than its efficient application. A fortiori, this applies to new and high technologies which only very few developing countries have the capacity to generate themselves.

The design of policies and measures aimed at promoting the diffusion of technology in a country's industrial sector therefore assumes increasing importance. Again, as this paper is concerned with identifying and exploring issues and not with working out strategies for specific countries, the analysis will have to remain general in nature. Also it needs to be emphasized that below only some selected policy areas are dealt with which are specially relevant for technological innovation in industry.

1/ Paul David refers to this dilemma as the "narrow policy windows paradox". Policy is confronted with the task to prevent the "windows of opportunity from slamming shut before the information needed for policy is available." (David 1986, p. 5).

a. Development 'climate'

The ability to apply new technologies is not so much determined by measures which are specific to the various technologies involved but rather by the overall entrepreneurial, managerial and technological capabilities of a country. Such capabilities develop over time; they are usually built up in the course of the industrial development process. Well designed and coherent industrial policies can play a major role in this process; at the same time, even good resources and skill endowments can be ruined by bad policy.

New technologies are not being introduced in a vacuum. The more mature technologies have already been efficiently mastered, the easier it will generally be to effectively utilize new technologies. This being so, there are obviously vast differences among developing countries regarding the preconditions to apply new technologies which result in disparities in their technology absorption capacity. Furthermore, in any given country, the diffusion of new technologies is uneven between different companies reflecting variations in management, industrial organization, skill availabilities, etc.

Admittedly, the required concentration on creating a conducive overall development 'climate' is a difficult task in times of economic crisis and the concomitant external and internal pressures which many developing countries are facing at present. Yet the question is if the isolated introduction of advanced technologies in specific areas can yield broader benefits unless it is sustained in the long run by an overall atmosphere of innovativeness. Essential elements in this are:

- Stability and continuity: Frequent policy changes tend to generate a feeling of insecurity on the part of economic actors and prevent the formation of stable long-term expectations so crucial for the willingness to undertake long-term industrial investments.

- Strategic vision and policy commitment: A central role to be played by the government in developing countries is to design an industrial strategy, indicate sectoral priorities and formulate objectives with a view to provide guidelines for company decision-taking. Experience has shown that a strategic vision (i.e. a notion of a country's preferred future industrial structure) coupled with a corresponding policy commitment is required to encourage private risk-taking.

This 'strategic vision' is not at all to be equated with rigid economic planning. It can be applied to quite different economic systems. The important point is to provide an overall direction and orientation for private decisions which often involve long-term, costly and risky commitments.

b. Human resource development

Human resource development is the appropriate starting point in discussing more specific policy areas relevant for the development and application of new technologies: "The first element in the successful diffusion of technology is the role of investment in human capital (Ergas 1987, p. 233).

Human resources did not always receive the strong attention they deserve as crucial determinant of economic development. Specifically in the sixties and early seventies a widespread fallacy was to explain economic development basically in terms of capital and technology inputs and to treat the concomitant development of human resources largely as a residual - as such considered more a social concern than an economic variable. Meanwhile however, it has become widely accepted that it is human beings and the skills they command which are decisive to promote development and that investment in human capital can in fact yield higher returns than does real capital formation.

There is an increasing awareness now that it is the education and skill level of the labour force which largely determine a country's competitive strength and resilience, its capacity to adjust to new sophisticated technologies and to reduce the economic and social costs of the adjustment process. This has been a clear lesson from successful countries, both developing and industrialized. It is now widely recognized that the successful industrialization of the East Asian newly industrializing countries has been largely caused by the early priority given to the development and upgrading of human resources. Investments in expanding and improving secondary and higher education have taken a large share of public expenditures. A cornerstone in their human resource development strategies have been efforts to organize an efficient country-wide vocational training system. Indeed, the quality of vocational training more than anything else is the decisive factor in coping with technical change and in applying new technologies. Even countries with a strong scientific elite will meet difficulties in diffusing new technologies unless they have given equal priority to their vocational training system.

The utilization of new technologies based on computers and micro-electronics is rapidly gaining in significance. This has the effect of making production systems much more similar accross various industrial branches than they have been hitherto (UNIDO 1986). The implications of this tendency for a rational organization of vocational training are far-reaching and call for increased co-operation between industry and government.

Under the conditions of increasing convergence of industrial technologies training for industrial activity that make use of the new technologies can clearly yield economies of scale in the sense that a general technical training can easily be adapted for use in specific industrial branches. This implies that sooner or later industry will obtain benefits in strict cost terms through participating in general training courses in the use of new technologies. The financing of such training could, of course, come both from industry associations and the public purse; the benefits for government would be those of supporting industry in its efforts to remain internationally competitive.

Furthermore, this type of training tends to maximize the mobility of semi-skilled staff and thus create more opportunities for dynamizing the industrial sector as a whole. This point is especially relevant given the emphasis in many, particularly Asian developing countries towards the creation of supporting industries and close networking of service and producing enterprises. For the most part the smaller firms which grow up to meet the needs of more complex industrial structures are created by people who previously acquired industrial experience through working in already established larger enterprises. It might be expected that this kind of pattern will also be observed in relation to new technologies in the coming years.

A high level of general technical training thus appears to be conducive to strengthening the position of smaller firms. The same is true for a standardized system of examinations and certificates (Ergas 1987). The more technical competence is visible from standard certificates the more will inter-firm mobility be encouraged and the less important will be internal labour markets. This would again favour smaller companies in their recruitment of skilled labour.

Moreover, in a wider perspective the human resources needed for industrial development should be seen not only in terms of the operational functions of manufacturing but also in terms of essential overall supporting functions for industry such as research & development, marketing, technological extension and productivity services, engineering and financial consultancy, government planning and administration.

c. Small and medium enterprises

Small and medium enterprises (SME) have a very important role to play in any country's industrial development. They are a major supplier of industrial employment and a crucial element in industrial networking, e.g. as specialized producer of part and components which otherwise would need to be imported. Furthermore, it has come to be increasingly recognized that SME are a valuable and significant source of technological innovation. Examples abound that the existence of efficient SME adds to the resilience and responsiveness of a country's industrial sector whenever challenged by external shocks (such as drastic price changes; changing consumer preferences or new production technologies).[1/]

Accordingly, there is evidence that above a certain minimum threshold smaller companies tend to be more dynamic innovators than bigger ones. At the same time, as was argued in section III.4.a. above, many new technology areas are characterized by high entry barriers in areas such as research and development, finance, marketing, distribution channels, etc. The implication is that the high potential of SME in developing or utilizing new technologies can only materialize if it is strengthened by a number of joint support functions (Sercovich 1987). These could range from information services (including market research) to joint research programmes, the formation of export consortia, collective bargaining with suppliers of production inputs, joint negotiation with financial institutions, etc. Many examples for such initiatives can be found in industrialized countries in terms of regional initiatives of smaller companies either in the same industrial branch (e.g. clothing manufacturers in Italy) or across different branches of industry (e.g. the Fosieby industry group in Sweden).

1/ One example of this is the successful adaptation of the Italian and Japanese clothing industry to competition from developing countries (see Chapter Three).

While the organizaion of SME co-operation along these lines is essentially a task for the enterprises concerned and would require their continuous commitment and active participation, government policy can play a valuable catalytic role in this regard. For example, training and awareness courses could be organized to draw attention to new technological options and seed money could be provided to initiate viable forms of co-operation.

It is noteworthy in this context that the Republic of Korea - long known for its emphasis on large industrial conglomerates - in the early 1980s switched to a policy of promoting SME (Lütkenhorst 1989). The reasons given for this remarkable policy swing related above all to weaknesses in the production of more sophisticated industrial components (e.g. electronic instrumentation and control systems) on which the country has remained highly import-dependent. A 10-year Long-Term Promotion Plan for Small and Medium Industry was adopted in 1982. Special measures in favour of SME, inter alia, include the so-called Industrial Systematization Project (seeking to establish close links between small parts manufacturers and large producers of final goods), special support for export-oriented SME and a Technology Support Centre for Small and Medium Industries (UNIDO 1987a). The latter includes among its facilities a Precision Machinery Technology Centre providing a wide range of services to SME (e.g. special courses for engineers to handle NC-machinery; factory-level technical advice for production management; adaptation of imported precision machinery).

d. Institutional support

Institutional aspects have been emphasized above in connection with the organization of vocational training and regarding technological and other support extended to SME. Indeed, it is hard to overestimate the role played by an efficient institutional network in promoting the development and diffusion of technologies in developing countries (for the following discussion see also Dahlman 1988).

On the one hand, experience shows that competitive pressure in open markets is among the most powerful mechanisms to induce changes in products and processes and respond to opportunities offered by new, more efficient technologies. On the other hand, in many developing countries only insufficient information is available on the nature and range of new technologies on offer as well as on the terms and prices of acquisition. Furthermore, the developmental role of new technologies typically implies disparities in the perceived private and social returns of their introduction. Government policy and public institutions thus are needed to complement and reinforce the market mechanism. Some of the more important institutions - in addition to those already dealt with in previous sections - are discussed below.

Collecting and assessing information is one important area. In view of the skills required for the related activities, the costs involved and the relevance of specialized technology information for a wide range of industries, many developing countries have established centralized technology information agencies often as a joint government-private sector effort. Such institutions have the task

- to collect, process and provide information on existing industrial technologies, including sources and prices of technology supplies;

- to monitor and assess emerging technological trends, particularly as regards their impact on structural change in industrial production;

- to link technological information with market intelligence so as to enable producers to take preventive action in line with prospective market trends.

Obviously, another important area calling for institutional measures is the gradual building up of domestic R&D capacities. While in most developing countries public research institutes and laboratories are in place, their research orientation leaves much to be desired. More often than not, research programmes follow academic basic research interests which remove them from the more immediate needs of their country's industries (or, for that matter, of other productive sectors of the economy). What is often lacking is the close interaction of R&D institutions and industry. Industrial companies are to be encouraged to demand research services; universities and other research institutions in turn should pursue more industry-related research. The lack of such co-operation appears to be a result partly of traditional attitudes, partly of weak communication links between the actors concerned and partly of the overall lack of integrated industrial production systems in many developing countries. Transfer agencies - i.e. agencies concerned with the commercialization of research results and the design of industry-relevant research programmes - could play a key role in overcoming some of these barriers.

Reference can again be made to the case of the Republic of Korea. At an early stage in the country's industrialization specialized public research institutes with a strong industry orientation were created. They were complemented from the outset with a number of institutions - or sometimes departments within the research institutes themselves - with the mandate to identify and promote commercial applications of research results (for details see UNIDO 1987b).

Following the experience of developed countries, the establishment of so-called science parks could yield substantial benefits for some more advanced developing countries which have already acquired certain capabilities in research-intensive industrial production. Science parks are special industrial zones at the periphery of universities or other research centers intended to host research-intensive manufacturing activities such as bioengineering or advanced electronics.[1/] However, the establishment of

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1/ The development of special zones focussing on high-tech industrial development is a fairly recent trend in many, mostly industrialized countries (OECD 1987a). Terminology is not yet well-established; the following distinctions, however, appear appropriate (Currie 1985):

- innovation centres: restricted space intended primarily to induce establishment of small high-tech companies and newly established ones in the initial phases of operation;

- science parks: larger areas of land suitable for knowledge-based firm of differing sizes and stages of development; research-intensive manufacturing is permitted and encouraged;

- research parks: similar to science parks, but permitting manufacturing only up to prototype level.

high-tech industrial zones or science parks is a long-term commitment often bearing fruit only after an incubation period of up to 10 years.

Also it needs to be emphasized that the successful operation of a science park has a number of important preconditions. In addition to the more obvious ones - availability of highly skilled personnel; an attractive site with an excellent infrastructure - this includes the existence of venture capital institutions willing to finance high risk, non-standard projects.

The number of science parks so far established in developing countries is extremely small. The most prominent example is the Hsinchu Science-Based Industrial Park in Taiwan Province of China, which testifies to the possibility of rapid progress in a realistic planning framework. Founded only in 1980, the Hsinchu Park has attracted more than 70 research-based companies (some 40 per cent locally owned), predominantly from the electronics industry. In 1987 these companies generated a total production value of approximately US $700 million. The main objectives in establishing the Hsinchu Park were to speed up industrial restructuring towards more knowledge-intensive production, to create proper jobs for highly skilled local workers and to promote domestic entrepreneurship. The Hsinchu Park occupies a total area of 2,000 hectare of which approximately 10 per cent have been designated duty-free; this limited area of 200 hectare may thus be considered a science-based export-processing zone (UNIDO 1988).

Finally, an important though often neglected institutional requirement is an effective system of industrial standards and quality control. Standardization results in the reduction of transaction costs, particularly for decentralized industries; it is crucial for any production of high-tech components and absolutely indispensable if these are to be exported. It has been argued in fact that in the case of Japan the early introduction of national certificates linked to industrial standards has encouraged enterprises to adopt firm-level quality control systems which in turn has rendered possible the successful expansion of the sub-contracting system (Dahlman 1988).

V. SELECTED ISSUES FOR DISCUSSION

1. Acquisition of technology

Throughout this chapter reference has been made to developing countries, sometimes as generators of new technologies, sometimes as users of new technologies. The question if an individual country should rely on imported new technology or should seek to develop and produce advanced technology domestically indeed touches upon a key industrial strategy decision. The answer depends entirely on the specific country and the specific technology in question and would have to take into account numerous demand and supply related factors, such as size and structure of domestic demand; the potential to tap export markets; skills required and available for product development and subsequent manufacturing; competitive situation and prices in the world market; economies of scale and of scope; and many others. Nevertheless, in what follows some comments of a more general nature are offered.

The experience of many countries has clearly demonstrated that the efficient assimilation, adaptation and diffusion of imported technology can yield substantial long-term benefits (Dahlman 1988). Furthermore, it does not preclude the later domestic development of the same or even more advanced technologies. Accordingly, the sequential aspect in absorbing technology needs to be stressed. The external sourcing of advanced technology may be considered a logical first step. As these technologies are increasingly diffused and utilized in a country's industrial sector, they create both learning effects and a broader market which also domestic producers will subsequently seek to tap.

An important issue to be considered in this context is the trend towards increasing specialization and intra-industry trade worldwide. Given that any concept of total self-sufficiency in high technology areas would be anachronistic, to what extent is it reasonable to favour domestic production over imports? Is there a trade-off between rapid and efficient diffusion on the one hand and the generation of domestic production capabilities on the other? For example, some advanced developing countries have indeed achieved higher self-sufficiency ratios in the production of NC machine tools than most industrialized countries. What are the implications for user industries[1/] and for the industrial development process as a whole?

It should also be noted that the acquisition of technology from abroad is a demanding and complicated process in itself. Specialized knowledge is required on the available options, their prices, properties, advantages and disadvantages. Furthermore, it may be possible to acquire the same or similar technologies through different forms such as direct foreign investment, licensing, turnkey projects, purchases of capital goods and/or purchases of technical advice (Dahlman et al. 1987). Whatever the mode of acquisition a monitoring of the terms of technology transfer is needed in areas such as royalty payments, technology depackaging and restrictive business practices. National technology registries have been established for this purpose in many developing countries and have contributed to improving the bargaining position of domestic companies acquiring technology from abroad.

2. The technology gap

While many of the economic implications of new technologies are still subject to debate there are some indisputable truths as well. Among these is the fact that the impact of the incipient technological revolution will be felt in one way or another by all developing countries regardless of their level of development or their economic system. Not all, however, appear to be well equipped to adequately respond to the challenges facing them and only a few are in a position to generate frontier technologies themselves.

1/ A negative impact could be higher prices (as compared to the world market) and a relatively narrow range of available types of machinery (see Chapter Four)

The determinants of different countries' capacity to respond to technological challenges are manyfold and appropriate industrial policies and strategies are not among the least important. Apart from industrial policy measures, as dealt with in section IV.2., some of the more obvious determinants would include the size of a country's domestic market; the level of economic development (as measured by GNP per capita); the level of industrial development (as measured by MVA per capita and the share of MVA in GNP); the degree of industrial internationalization (as measured by the share of manufactures in total exports or GNP); and many others.

In particular, the present mix of industrial production has significant implications for both technological adjustment pressures and technological adjustment capacities. Developing countries producing a diversified range of industrial products for different export markets will find themselves permanently forced to adjust products and processes to changing quality requirements, price and cost structures. In these cases, high adjustment pressure and the need to acquire comparative advantages will itself contribute to the gradual build up of adjustment capacities. Conversely, countries whose industrial activities are dominated by resource-based goods (natural comparative advantage) are typically facing a lower pressure towards technological upgrading and, consequently, are not stimulated to innovate. If these countries are confronted with sudden and drastic technological changes (as may be increasingly the case due to the development of new materials), they will hardly be prepared to meet the resulting challenges.

This situation may lead to the following scenario. The more advanced developing countries endowed with efficient promotional institutions and highly skilled human capital are given powerful new tools to increase their competitiveness (by combining their wage cost advantage with latest machinery) and may even gradually 'catch up' with the industrialized countries.[1/] At the same time, many other developing countries (the least developed countries in particular) would further fall behind in the industrialization race. For instance, it has been argued in this chapter (see section III.4.b.) that foreign direct investment in manufacturing will concentrate even more than in the past on relatively few leading developing countries. In consequence, the poorer developing countries will find themselves in a vicious circle: Left aside by foreign investors because of their not meeting the requirements for technologically more advanced production, they will be largely excluded from the only realistic source of technological upgrading, viz. foreign investment.

1/ Carlota Pérez sees world industry in a period of transition from the old paradigm (mass production of standardized products) to a new paradigm (flexible small-batch production of customer-specific products). In the transitional period developing countries are considered to face a "temporary window of opportunity" if they are blessed with "a reasonable previous level of productive capacity and externalities and a sufficient endowment of qualified human resources in the new branches of engineering." (Pérez 1988a, p. 93).

If the scenario outlined above really applies, then a situation of increasing technological gaps will result. And this may in effect be particularly the case between developing countries. Moreover, the accentuation of R&D disparities could induce additional 'brain drain' further depriving the poorer developing countries of their already limited human resources.

This is not to deny that possibilities for technological leapfrogging do exist in some areas and also least developed countries can avail themselves of these opportunities. Advances in telecommunications are a case in point. Given that (a) a highly efficient telecommunications system has become a basic element of a country's industrial infrastructure and (b) the introduction of such a system is not a continuous process but takes place only in discrete intervals, there is no choice but to jump to the most advanced equipment available. In general, however, the potential for technological leapfrogging has tended to be overestimated. Jumping into high-tech areas does not provide a solution to lacking skills and weak supporting infrastructures; it is further complicated by vested interests and sunk investments which in most industrial branches are more relevant than in the area of telecommunications.

3. International co-operation

To promote and/or respond to technological changes in industry in the 1990s will require, more than ever before, substantial financial, organizational, managerial and research & development resources which go beyond the capabilities of single companies and often even single countries. A pooling of resources and sharing of experience are required in many areas to both coordinate and enhance national technological efforts. In the developed countries the trend towards joint programmes, projects and institutions in selected high-tech areas is becoming ever stronger. For instance, the European Communities (EC) have in recent years initiated joint technology research efforts in telecommunications (Research and Development in Advanced Communication Technologies for Europe, RACE), major industrial technologies (Basic Research in Industrial Technologies for Europe, BRITE) and biotechnology (Concertation Unit for Biotechnology in Europe, CUBE).

Likewise, international co-operation may contribute to strengthen the position of the developing countries in the international system. Co-operation potential exists both among developing countries and between developing and industrialized countries.

The regional and sub-regional level appears to be a logical starting point for co-operation among developing countries, in particular where economic co-operation and integration arrangements already exist such as the Association of Southeast Asian Nations (ASEAN), the Andean Pact, the Gulf Council for Economic Co-operation (GCC) or the Southern African Development Co-ordination Conference (SADCC). The ASEAN countries for example adopted a Plan of Action on Science & Technology for Development as early as 1981 with manufacturing industries, transportation and communication being among the priority areas (for details see Chee Peng Lim 1987). Furthermore, efforts are underway to arrive at a harmonization of ASEAN industrial standards. In general, technology-related regional co-operation among developing countries can cover a broad range of issues. These would include, inter alia, the joint monitoring of emerging trends in key technology areas;[1/] efforts at establishing joint telecommunications systems (e.g. satellite communication) or at least technical compatibility for countries in the same sub-region; exploring the potential for technology specialization schemes; or joint approaches at regulating specific technology areas such as bioengineering. Among the many advantages of such regional co-operation efforts would be a visible political commitment of member governments to promote specified priority areas of new technologies as well as increased market transparency for companies already involved or interested in these areas.

In addition to regional co-operation further attempts could be made to fully explore the potential for co-operation at the interregional level. It appears that in the past this potential has remained partly unexploited. The identification of common issues and challenges facing countries in different developing regions can lead to fruitful interaction and co-operation and should be considered an area for priority attention in the future.

As regards co-operation between developing and industrialized countries, the field of education and training appears to be most relevant. For example, ASEAN and the European Communities (EC) have recently agreed on a two-year programme of scientific and technological co-operation which includes the provision of fellowships to ASEAN scientists, engineers and technical experts for training in EC countries. The important point obviously is to provide highly qualified training without causing brain drain. For example, within a scheme recently introduced in Indonesia the Government provides for education and training abroad which subsequently are 'paid back' through work in Indonesian ministries, research institutions or industry for a specified time period.

VI. CONCLUSIONS AND OUTLOOK

The industrial application of a number of interrelated new technologies, inter alia, leads to shorter product cycles, more rapid changes in production processes, greater uncertainties and hence an overall need for high flexibility of production and openness to innovation. Innovativeness in turn is closely related with entrepreneurship. More than before developed countries are applying policies and institutional measures to promote both innovation and entrepreneurship as vehicles for keeping the lead in the technological race. Various public support measures are taken particularly in the pre-production stages in order to reduce risks and costs and to facilitate investments in new technologies and their applications.

1/ There are obviously economies of scale involved in collecting the relevant information and regional bodies could e.g. prepare briefings for countries too small or lacking the resources to do so themselves.

UNIDO for its part has recently directed its efforts towards the regionalization of the so-called Technological Information Exchange System (TIES). Examples are the establishment of the Sistema Andino de Información Tecnológica (SAIT), the Asian TIES Network and the African TIES Network.

Undoubtedly these measures contribute to enhancing the prospective competitiveness of industries. Developing countries need to review these policies and institutional measures and utilize the experience for their own industrial transformation. The increasing R&D and skill intensity of industrial production may force developing countries to concentrate their scarce resources in these respects.

Does this entail a further expansion of regional disparities and other developmental disparities in the emerging new industrial structures in developing countries? Will developing countries be moving even further towards "dual societies" with islands of high tech production and highly developed infrastructures in a sea of stagnant development? Will these islands or advanced centres be more linked with other international centres than with the rest of the national economy? Can these possible threats be halted through active regional policies?

The complexity of industrial technology is increasing. This suggests that decisions at corporate and policy-making levels are also becoming more and more complex regarding the choice, sources, terms and conditions, up-to-dateness etc. How can individual and groups of developing countries meet these demands?

Obviously, as one basic precondition, industrial data and information systems are assuming a greater role for industrial production efficiency and adaptability and for organizational efficiency. Whereas the technological development itself will provide possibilities to install such data systems, for the developing countries this means,

- significant increases in hard- and software investment;
- increased skill requirements for data processing, etc;
- organizational changes within the national economies so as to enable the various actors to synchronize efforts and quickly respond;
- increasing regional and national markets for information-related products and services, constituting opportunities for developing country producers - in competition with developed countries.

Skill intensities are increasing in industry and in supporting services. New educational and vocational training approaches need to be developed to meet these needs, to be cost-efficient and flexible. Can various types of systems be elaborated and can some of these be operated at a subregional or regional basis? What new international co-operation modalities can be found between developing and industrialized countries?

In the past developing countries' comparative advantages were primarily to be found in labour-intensive, low-skill, raw material-intensive and standardized series of product groups. The current trends indicate an erosion of these assumptions and increasing challenges to the built-up structures. A critical issue is thus to determine the modes, pace and policies for industrial restructuring towards a different production structure. What indeed are the future competitive strengths of various types of developing countries? What are the ways of identifying these and to create comparative advantages?

Technology advances are spurred by close interaction between the research, finance, policy, administration and production centres in an economy. Developing countries are generally lagging behind in such networking. An important issue is therefore the restructuring of their institutional machinery. Which measures are conducive to eliminate overlaps and to create a streamlined, efficient institutional set-up? Can successful approaches of some developed and developing countries in this regard be adopted in others as well?

Industrial strategies and policies which merely aim at breaking existing technology barriers are based on a static concept. In fact, policy-makers are faced with a 'moving target' in the sense that technological innovation takes place continuously and new barriers arise all the time. The main objective thus should be to promote national technology-creation and technology-diffusion capabilities. To what extent can this be achieved within national efforts? What is the role to be played by regional, inter-regional and international co-operation? Is there a danger that co-operation may become more biased towards already advanced research-endowed countries so as to yield better results and provide feedbacks and mutual benefits? Are the least developed countries threatened to be bypassed in this process?

To conclude, it can be pointed out that new technologies neither automatically re-establish an overall industrial superiority of developed countries nor do they provide across-the-board opportunities for developing countries to leapfrog into a high-tech future. Technological innovation does not provide ready-made solutions to any country's industrial development. It generates tools, however powerful they may be, to increase productivity and improve human well-being. Whether the inherent potential of technological advances is translated into successful industrial development is largely a question of economic and social organization: Policy matters.

CHAPTER TWO

Technological Change in Telecommunications. Implications for Industrial Policy in Developing Countries

by Kurt Hoffman*

I. INTRODUCTION

The telecommunications sector has been fundamentally and pervasively transformed by the Information Technology (IT) revolution. The rapid and widespread diffusion and application of digital micro-electronic technology through the whole of the telecommunications sector has given rise to a plethora of new products and services that have proved to be far superior to those based on electro-mechanical technology. The characteristics of these products - lower costs, more features, greater reliability - has led to a tremendous expansion of the worldwide market for telecommunications despite the restraining effects of global recession through the first half of this decade. After expanding annually at more than 12 per cent for nearly a decade, by 1986, global sales of telecommunications equipment had reached US $109 billion and by 1995 are expected to be close to US $240 billion annually, in current prices.

In parallel with this, the pervasive applicability of microelectronics throughout the whole of the electronics "complex" of industries - computers, office equipment, components, telecommunications, etc. - has provoked the convergence of these industries, gradually eroding traditional market boundaries. This has led to a rush of new entrants in the telecommunications equipment industry that is severely challenging the established manufacturers. Competition within the sector is now technology-based be it aimed at protecting existing markets or at gaining access to new, rapidly growing markets.

These trends in technology and industrial structure have in turn stimulated a dramatic upheaval in established regulatory practices in what was once, because of its alleged characteristics as a "natural" monopoly, a highly regulated largely monopolistic sector. Pressures from users to gain rapid access to the new array of services have led to pressures from new producers to be allowed to supply this burgeoning demand.

In the face of this, the regulatory structure in place in most developed countries has been or is being completely overhauled. Monopoly public sector enterprises are being privatized; close, even collusive, relationships between public sector procurement agencies and monopoly private suppliers are being broken up and much more competition is now being allowed in both equipment and service supply.

The same pressures for deregulation and liberalization are at work internationally with regard to international flows of telecommunications

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equipment and services. Established regulatory practices at the international level are being assailed by proponents of open markets and greater competition. The whole machinery of international telecommunications regulation is being forced to respond to what are essentially technology-induced pressures for change.

Among all sectors of importance to the long-term economic development prospects of developing countries telecommunications in the one most profoundly affected by new IT. In turn it is increasingly recognized that a modern, efficient telecommunications system is one of the most critical elements of the industrial infrastructure. This importance has been enormously enhanced by the central role of digital telecommunications as the "highways of the Information Age". Because of this and because of the pervasive nature of the impacts mentioned above, developing countries are faced with policy implications across a very broad range of fronts. These include not only policy issues relating to the development of the sector and the regulation of the domestic supply of telecommunications services but also industrial policy in its broadest sense, trade policy and strategies for attracting foreign investment.

There is a general presumption that the IT revolution has had largely negative implications for developing countries. The technological frontier is seen to be moving away from the position of most countries at a rapid rate; technology-based barriers to entry are thought to have made most sectors impenetrable except for a few advanced countries; traditional wage-based international competitive advantages are allegedly being eroded by automation in the North.

Whether or not this pessimistic perspective is justified in other sectors is open to question. In the case of telecommunications, it is certainly <u>not</u> legitimate. Technological change in telecommunications has led to developments which on the whole are rather positive for developing countries. Yet there is little appreciation that this is the case or why developments in this sector should be positive when they appear negative everywhere else.

These positive aspects will not, of course, automatically translate into pervasive benefits for developing countries. Policies and strategies need to be designed that exploit the opportunities that are open to developing countries in telecommunications. Such policies in turn must be based on a comprehensive understanding of the full range of technology-led changes in telecommunications - in products and processes, in industry structure and in approaches to domestic and international regulation.

This chapter attempts to provide an overview of the main developments in telecommunications and their policy implications. It starts in section II with a brief review of the current situation with regard to telecommunications in developing countries and examines the arguments as to why telecommunications is seen as so important to long-term development prospects. This may seem obvious - but in fact most developing countries have massively <u>underinvested</u> in telecommunications, primarily because many governments has failed to appreciate both the qualitative importance of telecommunications and the scale of the quantitative benefits that derive from investment in the sector.

Section III turns to the technological changes that have transformed the sector and sets out the broad general implications for developing countries.

Section IV examines the technology-induced and developed country-led pressures for change in domestic regulatory practices in developing countries and reviews the policy implications of these. The analysis centers on the fact that there is a critical difference between the policy agenda embraced by the advanced countries in response to change in telecommunications and that faced by developing countries.

Within the developed countries, the basic telecommunications infrastructure has long been in place, telecommunications services are used as an integral part of the productive effort in the economy and there is a wide range of domestic enterprises able and willing to supply both services and equipment under competitive conditions. Given the prior existence of conditions that would allow the operation of an efficient market, their policy moves towards a more open market situation are premised on the view that the social and economic benefits arising from telecommunications will best be attained by achieving the maximum possible degree of market freedom.

With a few exceptions, most developing countries lack the basic telecommunications infrastructure, a viable domestic equipment and service supply sector and the conditions necessary for a properly functioning market that exist in the industrialized countries. Consequently, and in contrast to developed countries, the predominant policy concern and objectives of developing countries in relation to telecommunications must be developmental in character. This implies the formidable task of building the basic telecommunications network and of responding to the needs of a growing economy. This section discusses the logic and the reality of introducing changes in the regulatory environment in developing countries where developmental needs are foremost and where there are many factors at work that distort market operation.

Section V discusses how technological and structural change have opened up new opportunities for local production and local learning in telecommunications technology and explores the policy implications in the area of negotiation, technology transfer and local capacity development. Section VI deals with the possibilities for regional collaboration and the necessity for compromise at the international level to ensure that developing countries extract the maximum possible advantage from the expansion of global economic activity stimulated by changes in telecommunications technology. Section VII concludes the chapter with the presentation of some general conclusions.

II. TELECOMMUNICATIONS: A CRITICAL ELEMENT OF INDUSTRIAL INFRASTRUCTURE

There has long been a presumption in the development field that there is a strong positive correlation between the level of communications and the pace and degree of economic development. Starting with the classic work carried out by sociologists such as Rogers, Schramm and Lerner and carrying on through UNESCO's well known correlation study in 1979, sociologists and development economists have sought to show that the expansion of communications possibilities between social groups and economic entities helped create the necessary social and political conditions for dynamic development to proceed (Lerner 1964; Rogers 1976; Schramm 1964; UNESCO 1979; for a recent review see Saunders 1985).

However, despite this body of knowledge and presumption in favour of the role of communications in the development process, the reality has been that investment in the telecommunications infrastructure by developing countries has historically been accorded a relatively low priority. Two broad sets of reasons have been put forward to explain this. First, despite the availability of macro studies which showed a correlation between indicators of communication such as telephones/1000 people and GNP, it was very difficult to enumerate and quantify the national economic and social benefits of telecommunications investment relative to investment in other sectors and activities such as food production, water, power, schools, hospital and roads.

Thus the entities responsible for telecommunications administration in developing countries - often known as postal, telegraph and telephone agencies or PTTs - faced great obstacles in trying to convince their finance and planning ministries to give priority to telecommunications investment. They simply were not able to provide sufficient economic justification for what would inevitably be very large capital expenditures (because of the "lumpy" nature of telecommunications investment) with a very long lead time and very diffuse benefits compared to other infrastructural investments.

Secondly, there was a strong perception, particularly in countries who reached independence after the second World War, that telecommunications services conferred direct benefits only upon a narrow and privileged portion of the population (i.e. foreign and upper income groups). Telephones were therefore considered an expensive luxury - although it was recognized that the telephone system could be financially profitable since the state had the monopoly power to impose high tariffs.

Consequently, the telecommunications network, while exploited as a source of surplus, was not viewed as a legitimate candidate for major investment on equity and developmental grounds. There are notable exceptions, however, as some countries such as the Republic of Korea, Taiwan Province of China, Brazil, Ethiopia and El Salvador have, particularly in recent years, made a determined effort to upgrade their telecommunications and allocate more resources to it. However the number of countries able to maintain this performance consistently is relatively low compared to those countries where performance has been poor.

As a result, the telecommunications sector in most developing countries has suffered from massive underinvestment relative to both demand and economic return. The scale of this underinvestment is manifest in various ways. In many countries, subscriber density is extremely low ranging from a high of 40 telephones per thousand people in Latin America to only 7 per 1000 in Africa, with large areas often averaging less than 1 telephone per thousand people. Demand exceeds supply for even standard telephones by a large margin in most countries and the wait for getting an initial connection can often stretch above five years to even ten years or more. (This section is based on information in ITU 1985; Wellenius 1987; Agi 1987.)

Most of the services that do exist are concentrated in urban centers - in Brazil in 1985, 70 per cent of the telephone lines were in cities accounting for only 20 per cent of the population while in Thailand in 1981, 89 per cent of the administrative districts containing 75 per cent of the population had no telephones. And for those areas where services do exist, the quality of service on offer is often extremely low with heavy call congestion at all times, a high percentage of unmet and broken connections (frequently well above 50 per cent for even local calls, over 90 per cent for international calls) and long periods where there is no service available at all due to equipment failure and poor maintenance.

While the social hardships imposed by these conditions are substantial, the economic costs are even greater due to major efficiency losses throughout the economy. Though making macro estimates of these costs is nearly impossible, there is micro evidence available which indicates they are extremely high. There can be little doubt that lack of access to basic telecommunications service is a key constraint on industrial development and overall economic advance.

The shortcomings of the telecommunications system in developing countries are no doubt well known. From a policy perspective, however, it is much more important, to emphasize that recent and ongoing research carried out by the International Telecommunications Union (ITU), the World Bank and others is now yielding incontrovertible evidence that not only is there a direct positive relationship between economic advance and the availability of basic telephone services but that telecommunications investment can be fully justified on economic and social grounds. For example, a detailed review of the results of 10 recent telecommunications sector development programmes partly financed by the World Bank in Africa, Asia and Latin America showed that they averaged an 18 per cent economic rate of return overall, rising to 36 per cent if consumer surplus is counted in.

Looking specifically at the rural sector, the returns to investment in rural telecommunications frequently exceed these averages. One example comes from the introduction of long distance telephones in the Amazon region of Peru in the late 1970s which resulted in substantial cost savings and increased revenue in river transportation; in another region of the same country, the use of telex for reservations in a rural tourist town, increased hotel occupancy from less than 50 per cent to more than 70 per cent; in Sri Lanka in the late 1970s, telephone access to market information allowed farmers to place their produce at 80-90 per cent of Colombo prices compared to 50-60 per cent before.

More central to our concerns, a similar and even more impressive body of evidence is accumulating with respect to the returns to telecommunications investment which services the industrial sector. This is important because telecommunications services are used in developing countries mainly for commercial reasons - in 1980 in Thailand, 62 per cent of telephone lines were connected to business subscribers with about 90 per cent of telephone calls (including 50 per cent of those from residential subscribers) related mainly to productive and distribution activities.

An ITU study in Kenya identified nine mechanisms through which the efficiency of business firms could be improved via access to more extensive reliable telecommunications services - through facilitating business expansion, sales price increases, improved purchasing decisions, reduced inventories, savings in vehicle use, reduction of down time, reduced distribution costs and lower managerial and labour costs (Communications Studies and Planning International 1983). Cost-benefit analyses carried out in the Philippines and Costa Rica using samples of 200-300 small firms and measuring economic gains againt telecommunications investment costs established benefit-cost ratios of 25:1 and 48:1 respectively (Jonscher 1986).

Quite apart from this growing body of evidence on the economic benefits arising from telecommunications investment, it is now well documented that, as referred to above, telephone systems remain highly profitable activities even when run poorly.[1/] Taken together, this evidence about firm-level gains supports theories rooted in the economics of information which, a priori, argue that communication, by reducing uncertainty, increases the probability of economic units making correct decisions and achieving their goals at least cost.

In short, it is clear that in developing countries, access to telecommunication services is a crucial factor affecting the performance of both individual economic units and of markets; the telecommunications infrastructure is critical to industrial development. Even on their own, these are powerful arguments, calling for developing countries to devote a much greater share of investible resources to the telecommunications sector.

The issue cannot rest here however. The IT-driven technological revolution that has completely transformed telecommunications has, as will be shown below, strengthened enourmously the arguments in favour of increased telecommunications investment. Much more importantly, these developments have made the question of policy and strategy with regard to how these investments programmes should be designed and implemented into one of the critical challenges facing all developing countries no matter what their level of development. These are the main issues being explored in section III.

III. RECENT TECHNOLOGICAL DEVELOPMENTS IN TELECOMMUNICATIONS

The convergence of telecommunications, microelectronics and computer technology has provided a completely new technological base for the telecommunications sector. Old systems have been superseded, previously discrete items of equipment have merged in function and form, and entirely new components, products and services have been developed. The future possibilities arising from the revolution in digital telecommunications could yield great benefits to all countries.

However, a major consequence of these developments is that developing country telecommunications planners are now faced with the difficult task of making choices between a plethora of technical options in relation to system design, component selection and choice of supplier - with all of these choices needing to be made in an environment of considerable uncertainty because of the rapid pace of technological change and constraints of resources. Moreover the planners' problems are compounded by the emergence of unprecedented pressures for change in the way that the telecommunications supply network is organized and managed.

1/ For example, the telecommunications sector will transfer $2.1 billion (60 per cent of gross revenue) to the Moroccan Government over 1987-1994 as value added tax, income tax and import duties. The Brazilian Government received nearly $900 million from telecommunications in 1986 alone. See Wellenius 1987.

Making the right policy decisions is contingent upon having a competent understanding of the nature and scope of the technological changes taking place and of their broad implications. This is the object of this section which starts with a brief overview of technical developments across the three main elements of technology - exchange, transmission and peripheral equipment. The implications of these changes in telecommunications technology in relation to the question of local production of telecommunications equipment and service availibility are then introduced. A more detailed exploration of the policy issues arising from these developments is then undertaken in sections IV and V.

1. Exchange technology

Conventional telecommunications systems are based on a standard set of telephones connected by two pairs of copper wire, routed through an electromechanical switching system. Analogue electrical signals are transmitted between the exchanges via coaxial underground and undersea cable. Exchange or switching systems are thus at the heart of both public and private telecommunications systems. Massive investments in R&D during the 1970s by the leading telecommunications companies have led to the development of fully electronic, stored programme controlled (SPS) digital switching systems.1/

Digital exchanges are solid-state (no moving parts) and thus less susceptible to breakdowns and require less maintenance than conventional systems. Software control allows continuous adaptation of the exchange to new traffic conditions without changing the hardware. Digital exchanges also work at a much greater speed than analogue systems, with greater technical efficiency and at greater levels of capacity. Continued price reduction in semi-conductors means steadily declining real prices in exchanges so that large capacity public exchanges are roughly one-half the cost of equivalent analogue systems and further cost reductions are expected.

Not surprisingly, digital exchange technology is now widely accepted as being both technically and economically superior to conventional systems for use in both developed and developing countries. Virtually all manufacturers have switched to the production of digital exchange equipment away from analogue equipment, which of course is still the mainstay of telecommunications networks in developing countries.

This is not a negative development but a positive one. Unlike other aspects of IT, the advantages open to developing countries in the installation and use of digital exchanges are probably greater than those open to developed countries. Most developing countries are only in the relatively early stages of installing and expanding the basic telecommunications systems, while the developed countries are generally still very heavily committed to existing analogue systems. Thus they are faced with the very costly prospect of replacing their entire communications network - while developing countries can literally "leapfrog" directly into digital systems (Hobday 1985 and 1986).

1/ British Telecom is reported to have spent over $1 billion in R&D expenditure in order to develop its "System X" digital exchange system.

2. Transmission equipment

As in exchange technology, the pace and scope of technical change in transmission technology has been rapid and widespread. Coaxial cable technology, once the dominant terrestrial transmission medium is now being challenged on a number of fronts. Microwave transmission systems exhibiting greater efficiency and capacity due to pulse code modulation (PCM) and time division multiplexing (TDM) transmission techniques are becoming favoured choices for medium capacity lines and difficult terrains - with costs falling on an average of 11 per cent annually in recent years. Likewise radio telephone using Very High Frequency (VHF) and Ultra High Frequency (UHF) systems also does away with the need for physical conductors in rural areas.

Fibre optics and laser transmission systems boast considerable advantages over conventional systems in terms of greater capacity, speed, flexibility, resistence to interference (thus cutting down on the need for boosters) and significantly reduced installation costs (e.g. the costs of laying submarine cables have been cut by 75 per cent). Steadily reducing prices for fibre optics and recent success in overcoming technical problems means this technology will diffuse rapidly in the early 1990s for medium and high capacity routes.

Likewise, microelectronics-based minituarization has made the use of satellite communications technology much more economically viable for both public and private networks. With satellite communications systems, cost reductions due to technical change have averaged roughly 40 per cent per annum per data/speech channel since the early 1980s thus bringing this transmission technology to the forefront in terms of suitability for developing countries.

As with exchange systems, the trend towards digital transmissions systems is a very favourable one for developing countries. By stepping over intermediate technologies, developing countries can avoid more costly and less efficient transmission methods and move straight into a digital transmission infrastructure. Not only are these less costly than previously, but digital systems can simultaneously transmit voice, data, text, TV and various other forms of information using the same hardware. Developing countries using digital transmission equipment can arrive more cheaply and more easily at the same starting point for the transmission and use of the full range of information based goods and services as the developed economies.

3. Peripheral equipment

Peripheral equipment is equually being driven by the convergence of computer and telecommunications technology. The range of intelligent terminals and telephones, key systems, mobile radios, modems and a variety of office equipment (such as word processors, multifunction micro-computers, electronic messaging and other types of workstations) has expanded rapidly. Importantly in peripherals, the convergence process is leading to the development of single devices capable of acting as a terminal for text, data and other "non-voice" services as well as being used as a telephone.

The rise in private applications and the integration of telecommunications with other IT activities means that demand is growing to link these peripherals with telecommunication systems. Thus many other peripheral products are needed both to provide an interface with the public network, and to integrate electronic systems within firms and institutions.

Once again the developing countries start off absolutely equal with the developed economies in terms of their ability to potentially benefit greatly from this explosion in peripheral equipment both because of lower unit costs and because of greater sources of supply.

4. Integrated digital network

As is obvious from the above, technical change has generated improvements in all segments of telecommunications equipment - improvements that can be directly beneficial to developing countries. While these components can be introduced piecemeal into an existing analogue network, their full potential can only be realized when they are used as building blocks in a totally digital network designed to integrated standards (ITU 1985).

Such a network can carry many different types of services in addition to voice traffic. The advantages of a fully integrated network lie in its flecibility, scale economies in terms of different services carried as well as capacity and transmission resilience particularly at peak service periods. Computer monitoring within exchanges and on transmission loads allow the whole network to be controlled as system. The flexibility inherent in the technology also allows for simplification in the physical design of the system, in the production of its components and in its installation and maintenance, all aspects which are important features from the perspective of developing countries.

5. The broad implications of technological change in telecommunications

The spread of radical technological change in telecommunications has been pervasive, perhaps more so than in any other sector. These changes have reached a "critical mass" and accelerated into a true revolution that has a number of implications for all countries and for telecommunications policy in those countries. Below three aspects of these implications that are particularly important for developing countries are singled out (Nulty 1987).

(a) Lower barriers to entry in production and more sources of supply. An important but often unrecognized dimension of the ongoing changes in the telecommunications sector is that there have been equally fundamental changes in production technology. These changes have direct economic implications as they often result in lower unit investment costs due to the lowered costs for basic network components such as cable, exchange termination assemblies, multiplexers, switches etc. on a per bit transmitted basis.

They have also affected profoundly the international structure of the telecommunications equipment supply industry since start-up costs in some segments have dropped from millions of dollars to hundreds of thousands because of the availability of standardized integrated circuits and system software. This situation has positive implications for developing country planners both because it increases the range of choice among suppliers and because it expands the "room for maneouvre" enjoyed by the host country in any negotiations with foreign suppliers.

Moreover, changes in production technology have also opened up a new range of opportunities for local involvement in the design and supply of equipment which could in turn lead to the development of local skills and expertise in digital technology. Hence these technology-induced opportunities for local learning could have major long term and pervasive benefits for developing countries that would go well beyond the telecommunications sector. This is a unique opportunity that simply is not open to most developing countries in relation to virtually any other segment of IT. This issue will explored in much detail in section V.

(b) <u>Changing cost structures for all other industries</u>. Rapidly dropping unit costs and the proliferation of alternative communications options are transforming the cost structures of all industries as the cost of processing and transmitting information has declined sharply relative to the costs of other factors. For example, in 1983, it cost US $14,000 per month to lease the US half of a private transatlantic voice channel. In 1987 that cost was less than US $5000.

These cost reductions are leading to the extension of "telematics" into more and more areas - in merchandising via integration of point-of-sale systems with inventory and purchasing; in manufacturing via worldwide integration of production with inventory and orders, or via centralized computer-aided design systems directing machine tools halfway around the world; in transport where the worldwide dispatch of planes, ships, trucks or trains can be centrally co-ordinated and optimized.

These systems, by making information low cost and transportable, not only alter the cost structure of industry but are facilitating a major shift towards production that is more <u>knowledge-intensive</u>. Hence, the international competitiveness of conventional manufacturing industry is becoming more and more dependent on access to information and to systems that allow its low-cost, rapid processing and transport within the firm or across the world.

(c) <u>Creation of new services and new ways of delivering traditional services</u>. Information technology coupled with technological change within the telecommunications sector has had a profound impact on the service sector and on the role of services in economic development in all countries. The question of services and their implications for developing countries are now widely discussed. Four dimensions deserve special attention in the context of telecommunications.

First, traditional service industries (banking, insurance, consulting and engineering, tourism, shipping, publishing, etc.) are now able to offer a greater range of services, at greater speed and at lower cost via sophisticated peripherals connected to greatly expanded international telecommunications networks. In turn, their competitiveness has also become intimately dependent upon access to telecommunications networks.

For example, it is now possible for a book or article to be written in one country, mocked up in a second, typeset by computer in a third, proofread in a fourth and then transmitted by satellite for printing anywhere in the world. Since all of the labour intensive elements of this process can be carried out in low wage countries (if the necessary facilities are available), book publishers going this route gain a significant cost advantage over those who do not. Similarly in the 1990s, to participate in international finance - whether as a major borrower, investor or banker - requires continuous access to digital, voice and data telecommunication information systems that connect all the world's financial centers on a 24 hours basis.

Second, a whole new category of data services and supplying industries in areas such as data processing, software, and data bases have come into being each specially adapted to the specific needs of the user. For example, US judicial opinions are abstracted and entered into an electronic data base by clerical workers in Korea, stored in a US based privately controlled system and accessed by lawyers all over the world - because such knowledge is essential for doing business in the US market: similar data bases exist for tourism, agriculture, medicine, pesticies, etc.; Pakistan produces architectural drawings for architects working in Stockholm on a construction project in Saudi Arabia; computer programmers in India can write software for Texas Instruments in Dallas; and keypunch operators in Barbados and Jamaica can service data processing operations anywhere in the world.

The above represent new services that are distinguished by their "divisibility", rapid growth and, significantly, represent new export opportunities for developing countries. There has also, of course, sprung up a huge amount of international telecommunications traffic involving intra-firm transborder data flows (TBDF) and service flows whose presence and growing importance has attracted a great deal of attention and comment (for a succinct review see Aronson 1988). The most well-known of the concerns expressed about TBDF (and an important policy issue for developing countries) relate to the difficulties involved in exerting national control over sensitive data flows.

Third, economies of scale have emerged in the provision of access to flows of data, knowledge and services on a national and international basis. The reason for this is that although the cost of initially creating a digital telecommunications network - nationally or globally - is quite high, once installed, the marginal cost of adding another service or transmitting additional data is quite low. Thus barriers to entry faced by suppliers trying to enter different markets are either raised or lowered depending upon whether or not they are able to "plug-in" to an existing information grid via the telecommunications network. This characteristic also means that even if some developing countries do not require sophisticated services, once a digital system is installed, they will subsequently be able to introduce new services at little extra cost.

Unlike the net positive benefits accruing to developing countries as a result of improvements in telecommunications technology as discussed above, developments in telecommunications-related services appear to have both a positive and a negative side, and again there is a vast amount of discussion on the pros and cons surrounding this issue.

Most of the worries arise from (a) the extra competitive advantages enjoyed by foreign firms, particularly TNCs, who have mastered information technology and have access to knowledge, data services and communications systems not available to domestic producers, and (b) the difficulty of exerting national control over private sector data flows with financial and/security implications for the host economy.

On the other hand, the potential advantages to developing countries arising from this transformation and proliferation of telecommunications-related services are also numerous ranging from new export opportunities in labour-intensive service provision, the arguably lower barriers to entry in many conventional industries and the greater access to more knowledge at much lower cost.

Obviously, the arguments presented above forcefully underline the point made in the first section about the critical importance of a telecommunications infrastructure to overall economic growth. More to the point, there can be little doubt that the rapidly increasing information and knowledge intensity of production and competition demands that the telecommunications infrastructure in all countries must be digitally based or at least moving as rapidly as possible in that direction.

The current and, more importantly, the longer term competitiveness of domestic producers will depend centrally on this precondition. Consequently, any development strategy which in anyway is dependent on international linkages for finance, technology, goods and services and/or involves the local participation of foreign firms in any sector of the economy will face considerable and growing difficulties in the future if an adequate, modern, digital-based telecommunications system is not in place.

Accordingly, the telecommunications investment decision is clearly not just a question of arranging adequate finance nor does it primarily involve only technical issues that are best left to the national PTT to sort out. Telecommunications policy now constitutes a critical set of strategic decisions with widespread and long-term implications for industrial development and economic progress for the country as a whole.

The next chapter looks at the question of how developing countries can best organize, regulate and administer the provision of telecommunications services within the domestic market. As will be shown, technological change has unleashed enormous pressures on developing country PTTs and governments to reform and restructure their domestic regulatory environment so that the full potential of the new technology and the new services can be positively exploited by domestic producers.

IV. TECHNOLOGY-INDUCED DOMESTIC REGULATORY REFORMS WITHIN A DEVELOPMENTAL CONTEXT

The new technological reality in telecommunications has had two major consequences for national PTTs in all countries who have been responsible for telecommunications services - and who had previously enjoyed a monopoly position in virtually all aspects of telecommunication supply and administration.

First, access to modern, reliable telecommunications systems has become an absolute economic necessity for all major productive interests operating in an economy whether they are domestic or foreign controlled. Second, there has been a proliferation of different means of access to telecommunications services and the costs of this access have been substantially lowered.

These technology-induced changes in the operating environment have led to the build up of enormous pressures upon PTTs - from users for easy access to the entire range of services via the lowest cost system; and on the supply side, where due to ease of entry and lowered unit costs many alternative sources of supply for both telecommunications systems and services have emerged in direct competition to the services and activities of national PTTs.

These pressures on PTTs first emerged in the US (where technological change in telecommunications first began to emerge) some 15 years ago and they eventually led to a dramatic and well-publicized wave of deregulation and divestiture of the public (and private) monopolies such as AT&T which had previously strictly controlled access to telecommunications and the services available to users. In recent years the same process has been at work in the UK and Japan via the privatization of British Telecoms and NTT and in Europe where much greater competition has been introduced in the provision of services and facilities.

There is now ample evidence that the same pressures that forced liberalization in these countries are at work in the developing countries. Large users in both the private and public sector (often including other branches of government, the military, railroads, power sector and other state enterprises), are conspicuously unsatisfied customers in many developing countries, often going ahead and setting up their own facilities without the permission or support of national PTTs.

There is little if anything the PTTs can do about this since aggressive private suppliers of equipment, systems and services are vigourously seeking new customers in developing countries and as the examples show they are finding any number of willing customers. Consequently, PTTs have been increasingly forced to condone this practice and it is now the case that medium and large scale users in both urban and rural areas are building local switched (mobile or fixed) radio-telephone systems connected to satellites for international, or private lines for national connections.

Moreover, many of these systems have spare capacity which can and is being leased back for use by the national PTT such as is happening with the high-capacity optical fibre, "back-bone" network being built by the Indian railways.

As the evidence alluded to above suggests, many national PTTs in developing countries are finding it difficult to cope with the new demands generated by technological change. Yet the internal pressures for some kind of fundamental change in the situation will continue to grow every day. Unfortunately for the PTTs, it is equally clear that there are also major external pressures being placed upon developing countries to take steps to restructure and reorganize their telecommunications policies and systems of regulation.

These pressures are coming from bilateral and multilateral development agencies such as the World Bank involved in providing financial support for domestic telecommunications projects in many developing countries. They are also being applied by national governments of the developed countries who are using their power within international North-South fora and policy bodies such as the International Telecommunications Union (ITU) and the GATT to press for reform of developing country positions vis-à-vis telecommunications issues at both the national and international level. These external proponents of reform draw a good deal of their ammunition from the allegedly highly successful experience of telecommunications sector reforms undertaken in the developed countries, particularly the US and UK.

Two points need to be recognized about the current situation with regard to the arguments for domestic regulatory reform with developing countries. First, there is little doubt that in many developing countries a reform of the domestic regulatory regime and indeed of the nature and role of the national PTT is necessary to allow the full development potential of telecommunications to be realized. This issue cannot be ignored nor can it be treated separately from any discussion of the other policy issues that have arisen as a result of technological change in te ecommunications.

Second, it is also the case that the arguments and the rationale being used by both internal and external proponents of reform are far too narrowly cast and often largely ignore both the different objectives of telecommunciations policy in a developmental context and unique problems this context implies, particularly when compared to conditions in the developed countries.

Since it is this explicit comparison between the experience of developed countries and the problem of developing countries that in a very real sense has set the context for much of the recent debate over sector reform in developing countries, we shall first look at the arguments and evidence put forward relating to open-market policies, before considering the policy choices open to developing countries in this area.

1. Issues of telecommunications regulation in developing countries

Observers and analysts, looking outward from a perspective informed by the recent experience of the US and other countries, not surprisingly often seek explanations for the problems of Third World telecommunications in the extent and nature of state involvement in the sector. Five sets of reasons are commonly advanced as to why state participation may have caused the observed difficulties (Wellenius 1987; Saunders 1985).

First, as already argued, it is felt that governments fail to understand that investment in telecommunications is crucial to economic progress. Consequently, expansion and improvement of the telecommunications system is given low priority.

Second, the national PTTs are felt to be constrained by government interference in many areas of management and policy. As a result they lack managerial and administrative independence; senior management is frequently shifted in response to political changeover; investment authority is rooted in civil servants; they face restrictions on hiring, promoting and firing and so on.

Third, the PTTs commonly lack the financial independence needed to resolve the perennial problem of underinvestment. They are often not allowed a tariff structure that reflects costs, with pricing being largely dictated by conventional public utility financial criteria - i.e. both connection and service charges are alleged to be excessively low, on economic grounds. This reduces domestic surpluses for reinvestment - even though governments are quite prepared to allow PTTs to make net contributions to their cash starved treasuries. In addition, though the foreign exchange cost of investment is high (50-60 per cent of total costs), PTTs are barred from participating in capital markets and are thus forced to compete with other public enterprises for extremely limited capital resources.

Fourth, it is argued that the management and organization of the PTTs themselves are often very poor, resulting in high expansion and operating costs and a variety of efficiency problems in other areas such as maintenance and repair.

Finally, Third World PTTs are perceived as enjoying a similar, if not greater, degree of monopoly power than PTTs in developed countries. Entry into the industry is strictly regulated to protect the PTT and private bypass arrangements are stringently opposed. Being almost totally insulated from competition or public accountability, they have little incentive to improve performance or innovate. This in turn creates ample opportunities for grossly inefficient administrative procedures that are subject to "irregularities".

Given that the difficulties caused by these problems are greatly exacerbated by radical technological change and the growing demand by large users for early access to new services, it should not be surprising that serious questions are being raised about the ability of PTTs to cope efficiently and adequately with the new context in which they find themselves.

Fundamental changes in the extent and nature of state involvement in the telecommunications sector in developing countries are being called for at many levels and specific aspects of operation but they all point in the same direction: Less and even no state involvement in telecommunications and the introduction of much greater competition in all aspects of service and equipment supply.

This argument has been frequently made, historically and currently, in response to state management of other facets of the economy in developing countries. However, it is being put forward in relation to the telecommunications sector with great passion and conviction because of the alleged success of deregulation in the US, in Europe, particularly in the UK, and in Japan. In light of this, it is instructive to consider briefly this experience.

2. <u>Selective examples of liberalization and privatization in developed countries</u>

The recent experience of developed countries with regulatory reform in the direction of liberalization and privatization has been mixed. The most important positive aspect is that new suppliers have moved quickly into the market to offer the consumer a much broader range of products and services than was available previously. This expansion of consumer choice has undoubtedly benefitted both individual users and the economy as a whole since availability of new telecommunications products and services has stimulated a higher level of economic activity. Another positive aspect is that national PTTs have been forced to place much greater publicly visible emphasis on improving customer service. Direct competition in the supply of services has also led them to expand their levels and rate of investment in new technology well beyond their original plans.

At the same time, the moves towards liberalization and greater reliance on market forces have not always (or yet) had the intended results. For example, liberalization moves in Western Europe and Japan have still left their national PTTs in enormously powerful positions, quite capable of resisting further erosion of their position. Moreover, despite being publicly pro-competition, some governments are quite adept at using non-tariff barriers to prevent or inhibit foreign competition in domestic markets (Naraine 1985). This is quite clear in the recent major conflict that arose between the UK and Japan over the efforts of Cable and Wireless Ltd. to gain a foothold in the Japanese telecommunications market through direct investment. Though Japan is often singled out as being particularly guilty of restricting market access, Cable and Wireless probably would have had just as much trouble gaining access to US, French, Dutch or West German markets - or vice versa.[1/]

A similar example but one that relates to data services involves regulations of the West German PTT, the Bundespost, that prevent subscribers to foreign information services from having direct access to international leased lines - some intermediate data processing must be undertaken in the FRG before the information can be made available to subscribers over the local switched network. Such policies reinforce the Bundespost's monopoly, increase its revenues and protect domestic data processing firms (Feketekuty/Hauser 1984).

Furthermore, as the UK experience with the privatization of British Telecoms shows, such moves do not necessarily lead to the predicted widespread domestic social and economic benefits. Indeed in the UK case, privatization appears, so far, to have beenfitted only a narrow range of high income consumers and users, cost the economy billions of dollars, led to poorer (not better) public service, and further undermined the international competitiveness of large segments of the British equipment supply industry. These problems are documented in the academic literature, by advocacy organizations and almost daily in the national press. This suggests that the UK experience is hardly the shining "jewel in the crown" of regulatory reform that most advocates of privatization make it out.

1/ Vaitsos 1987 provides an extensive discussion of how developed countries use non-tariff barriers to maintain markets in key IT sectors closed to foreign competitors.

3. Comparing the logic of regulatory reform with the conditions in developing countries

If such problems and unintended outcomes arise in a developed country context where the institutions are competent, markets are supposed to work and effective monitoring can be carried out, then what of developing countries?

The net outcomes might be positive. But one could argue just as strongly (with considerable evidence from similar experiences in other sectors) that those features of underdevelopment that in effect define the operating context in developing countries - limited technological and managerial competence in the private sector, inequitable income distribution, a barely functioning market, lack of monitoring capacities and the inefficient manner in which PTTs cope with any sort of complexity - could result in a much worse situation for all parties.

More generally, the context in which developing countries are having to respond to pressures for liberalization and cope with radical technological change is very different from that facing developed countries when they built up their networks. Pressures on PTTs to be competitive and responsive, particularly in profitable areas, were brought to bear upon developed countries after their networks were in place; while developing countries have to face these powerfully "disintegrative" forces well before their networks and local supply industry have become fully established (Nulty 1987)

Three points follow from this. First, even though the problems faced by PTTs in the two groups of countries may seem superficially the same, the causes of these are likely to be substantially different. Second, public and private sector institutions in developing countries are relatively "immature" and exhibit low levels of administrative, managerial, financial and technological competence. There is no guarantee that the responses of these entities to being given the freedom to design and implement market-oriented reforms will actually solve the problems they face.

This, for instance, appears to be the case in the Philippines where telecommunications services are now largely provided by private enterprise after privatization explicitly modelled on the US example was carried out. Growth has been insufficient to meet development needs, the available poor and costly service is concentrated within a few urban areas, and a government review of the situation is now in progress. Similarly, two private firms in Panama allowed to offer international telecommunications services in competition with the public sector are to be absorbed back into the public sector because of poor performance and "irregularities" (Wellenius 1987).

Third, it cannot be assumed that market-oriented reforms even if introduced will actually have the effects intended, let alone address the equity and welfare concerns of the developmental state because these changes will be occurring within a wider social and economic context that acts to distort the working of the market and the distribution of benefits and burdens across different segments of society (the Latin American experience is discussed in Mattelart and Schmucler 1985).

(a) The equity effect of raising capital by subscription. Consider the solution often put forward to overcome the revenue shortages which is that existing and new subscribers make a "capital" contribution via much higher connection and monthly rental fees than are charged normally. Exploration of this proposal for the Indian case showed that to meet minimum revenue levels for planned investment purposes in the Seventh Investment Plan entirely from internal sources, the annual bill to subscribers would need to be more than doubled from $350 to $750. This might seem a reasonable price to pay for a better service from the perspective of western observers or upper income groups in developing countries - but how many Indians could afford it? The answer is: not many. When applications charges of less than $10 were first tried, the waiting list was reduced by 100,000; and when charges were again increased from $80 to $400 the waiting list was reduced by 400,000. If subscribers were in effect now asked to make a capital contribution of $2,400, the waiting list would probably disappear altogether by eliminating all but the wealthiest fraction of city dwellers - hardly an equitable outcome (Chowdary 1986).

(b) Problems caused by lack of an effective "user" capacity in local firms. Other problems arise when we move to the question of market-oriented solutions to make better and more equipment and services available locally. Many of the proposals for increasing the range of services (particularly new data services) available by allowing private suppliers, acknowledge that many of these would be provided by foreign firms. In this case, the mere availability of more services this would bring about is deemed a positive development - yet it ignores the likely negative impact on local providers of services and a variety of other issues associated with data dependency, revenue generation, predatory pricing by foreigners, etc. that generally fall under the category of transborder data flow concerns.

A different set of problems could surface because of the character of local users who are to benefit from the availability of the new services brought into being by liberalization. It is often assumed that all users will be equally able to competitively exploit the new services. Such an assumption might hold in the industrialized countries - but is of questionable merit in many developing countries.

Many potential local users, particularly smaler, domestically owned firms, will lack the skills and other requirements necessary to take advantage of the new services. If they are competing against foreign firms who can exploit these services, then they might be forced out of business, causing a net loss of employment and income to the economy. There is evidence that this is precisely what is happening in the tourist sector in many smaller Third World economies (Poon 1987).

A new international dimension of this problem is exemplified by the role of the Caribbean and Asian economies in the booming US offshore data processing business. Both foreign and domestic firms in these countries are setting up low wage but highly labour-intensive facilities (in what have come to be known as 'teleports') in order to 'key-in' analog data of various sorts (ticket information, manuscripts, etc.) provided by US firms (airlines, publishing houses, insurance companies). The local firm then sends the digitized results back to the US over newly installed digital telecommunications networks.

The US firms certainly benefit from lower unit costs and the developing countries do gain some employment and foreign exchange benefits. But they get little less from what are essentially 'footloose' and 'enclave' activities that have few, if any local linkages, often require government subsidies to attract them in the first place and can, of course, be closed down without warning and moved to a lower cost country.

The governments and entrepreneurs justify these activities on the grounds that because they involve the new technology, they will provide an entry into the IT age. But in fact, there is virtually no skill or technology transfer involved in these white collar sweatshops nor, as cost effective optical character recognition technology will soon be available to US firms, may there be much of a long-term future (Posthuma 1987).

Certainly some countries are benefitting from being able to participate in the expansion of the international market for services from a domestic base - the rapid growth in exports of software from India and Singapore are cases in point. However, these are countries whose governments have already invested substantially in the prior creation of software capabilities. If this process is to occur in the large number of other countries where this prior investment in capabilities has not taken place, then steps must also be taken to create conducive local conditions that go well beyond relying on market forces in the telecommunications sector to bring about downstream linkages - a policy point taken up again below.

Finally, as hinted at above, there is a need to distinguish between the type of country involved when discussing issues of regulatory reform. Those developing countries best equipped to handle the pressures of regulatory reform and to capture its benefits will be the more advanced countries. Their basic needs in telecommunications are close to being met; they enjoy a considerable degree of local supply; they have competent managers in the public and private sector; and, a reasonably well developed absorptive capacity. Moreover, there is a reasonable chance that the public good and national economic welfare would be increased if appropriate reforms were to be introduced.

However, as one moves down the line towards the poorer countries, these conditions are less likely to be met, the inequalities existing everywhere in the Third World and distort the market will by greater, and the possibilities grow that poorly planned regulatory reforms will lead to unexpected, unintended and negative outcomes.

4. Policy options for regulatory reform

With those qualifications in mind a closer look is taken below at policy proposals for reform of the domestic regulatory regime that relate specifically to industry. These broadly fall into three areas - opening up the market for the provision and maintenance of equipment and services by domestic and foreign suppliers; the total recasting and reduction of government control over PTTs and their ability to set tariff structures and obtain investment capital so that PTTs can operate along lines closer to a commercial business; and alongside of this loosening of state ties, the pervasive reform of PTT structure, operations and management.

a. Moving towards greater openness and flexibility in the provision of equipment and services

For a large number of developing countries, five areas have been identified as being broadly suited for either a reduction in state involvement or a reform of current policy and practice by the PTT:

(i) the supply of telephones, PABXs and other subscriber equipment by local and/or foreign suppliers. Provided technical specifications are met, such moves theoretically widen the choice and lower the price to users while also greatly reducing load on PTTs;

(ii) the establishment of separate business networks (e.g. involving fixed station cellular radio telephone) to meet urgent demand and provide high quality voice and/or data transmission. These services should be highly profitable because they are so important to industry and should be able to attract private financing. Moreover they will aid in preserving or creating competitive advantage, and in attracting foreign investment in productive sectors with a high foreign exchange earnings potential;

(iii) the provision of value added services, such as electronic mail and computer data bases, inventory monitoring, banking networks, etc.;

(iv) allowing private or state operators of dedicated networks to offer services to other users thereby using up space capacity but within a framework established by the PTT. In some cases it might well be possible to use the exchange of telecommunications capacities among users to promote economies of scale and technological innovation so that static losses (due to equipment duplication) could be offset;

(v) allowing the contracting out of activities habitually carried out (often poorly and slowly) by the PTT. This would include civil works and maintenance on outside plant, cable ducting and laying, subscriber connection. Where suitable local firms are not available or cannot be spun off from the PTT, these can be developed via contractual arrangements with foreign contractors that ensure appropriate training and technology transfer.

One way of doing this would be to have one contractor design and then supervise cable installation by a different contractor, until the PTTs own design and supervision capability can be built up. Other areas where this approach could be used involve contruction and maintenance of buildings, vehicle maintenance, directory production, and data processing.

b. Separating central Government and the PTT

Many of the problems faced by PTTs derive from the nature of its relationship with central government. The thrust of most policy proposals focussing on this area is to distance the PTT from direct control by governemnt and thereby allow the PTT to be managed in line with its new character as a technology-intensive, dynamic productive enterprise.

This is essentially a political decision - albeit one with significant economic and financial implications. It requires, in most countries, a fundamental change in the perspective of the government vis-à-vis the role of telecommunications. Once this change has occurred and the decision to allow greater freedom of operation has been taken, two areas of policy will require innovative solutions. The first relates to the structure and mode of operation of the PTT - these issues are explored under the next subheading.

Second, as the PTT moves closer in character to a commercial enterprise, and as more suppliers enter the market, a completely new set of market conditions will arise, coupled with a new role for the PTT as a competitor driven, at least in part, by commercial considerations. Hence, a monitoring body has to be created which will have both a policy-making and conflict resolution function - both among private suppliers, between the PTT and other suppliers, and between the PTT and the government.

Such a body must be independent of major interest groups, technically competent, and have the power of law behind it to enforce decisions. There are many forms such a body could take depending on the particular circumstances. Whatever this may be, this monitoring body will have to take on board the following tasks:

- to regulate tariffs and financial flows among operating companies to prevent monopoly abuses;

- to ensure that equipment procurement follows local capacity development strategies discussed in the next section;

- to ensure the sector's responsiveness to broader development objectives, equity concerns and rural and regional needs;

- to exercise direct control or monitoring over the provision of international services and the interface between the domestic and international telecommunications network;

- to license and monitor the use of the radio spectrum;

- to set and monitor appropriate service standards for all user groups.

c. Restructuring, reorganizing and re-skilling the PTT

The changes proposed above have enormous implications for the PTT itself. The shift from being a direct arm of the state to a more autonomous entity much more directly responsible for its own survival involves a fundamental change in legal status. Once again there is a variety of models that could be followed with the choice depending on government objectives, existing arrangements and the competence of current staff and management - transforming a government department into an autonomus state enterprise; spinning off operating parts of the PTT into private or mixed ownership subsidiaries; reorganizing a public enterprise into a corporation under commercial law with differing degrees of state equity, etc.

Whichever form is selected, there are a number of other policy measures necessary to allow the PTT to perform competently in what will be a more rigorous and much more demanding competitive environment:

- procedures for procurement, recruitment, investment approval, etc. will need to be streamlined to allow a quick response rather than allowing the PTT to hide behind bureaucratic procedures that effectively eliminate the need for action;

- steps must be taken to allow the PTT to do whatever is necessary to attract and retain competent and dynamic technical, managerial and financial staff. This is crucial because to survive and prosper in the new environment, the PTT will require much higher levels of expertise and competence;

- the PTT staff and management must be forced to be more sensitive to issues of quality and service not only with regard to large users with political and financial clout but also in relation to small groups of less powerful users;

- innovative measures must be introduced to allow "off-budget" mechanisms for raising investment funds including the selling of bonds, the selling of shares, and perhaps even direct participation of domestic and foreign capital;

- protective mechanisms must be put into place to ensure that decisions are allowed to be taken without undue political interference - while at the same time ensuring that all major issues involving fundamental choices are openly debated and reviewed.

PTTs in developing countries often have a clear vision of the developmental role of telecommunications, and have struggled hard against very difficult conditions to build and operate a network. However, many but not all, have been very slow to realize how the new opportunities created by technological change can be harnessed for the development process. Moreover they are, like all bureaucracies, protective of their own positions and keen to resist any erosion of power diminuation of responsibility.

Consequently, they may simply oppose any change at all. As will be seen in the last chapter, they are also resisting developed country pressures for radical changes in the internationally regulatory environment as well. Perhaps the major challenge faced by the government in reforming the PTT will be to alter these traditional perceptions and positions so that the new opportunities created by technological change can be constructively exploited by the PTT both to ensure its dynamic role in the economy and to further developmental objectives.

d. Recent reform approaches

Recent surveys of developments in the sector in the Third World have shown that telecommunications policy-makers are not unaware of both the nature of the problems they face, nor of the winds of technological and regulatory change blowing across the sector worldwide (Wellenius 1987). Changes are undoubtedly being introduced - both voluntarily and as a result of a good deal of friendly "persuasion" by the international agencies providing the finance for national telecommunications projects. Most notable among the reforms attempted so far are:

- Malaysia's moves to set up an independently managed company under 100 per cent state ownership to handle operational functions;

- the spinning off of telecommunications operations in Bombay and Delhi as an independent company able to raise funds in the local capital market;

- the privatization of Chile's main telephone company;

- the reorganization of Morocco's PTT into a semi-autonomous office that now subcontracts civil work and cable network construction to private firms;

- the design, procurement and construction of outside telephone plant in Thailand by eight large firms on a turnkey basis;

- the reorganization of Jordan's and Sri Lanka's PTTs as separate companies able to operate independently of state control and able to raise investment capital from domestic and foreign sources.

These examples may well be indicative of a much greater wave of change in the telecommunications regulatory environment in developing countries. However, a crucial point to remember about these examples of shifts towards a more liberal regulatory environment is that all of the cases reported are relatively recent. We simply do not yet know what the eventual short- and long-term impacts of these changes will be on different groups and measures of performance. The net effects must be monitored very carefully before any conclusions are drawn.

5. Overall conclusions

Although the debate about reform of the PTTs and the domestic regulatory environment in favour of greater reliance on market forces frequently centres around the pros and cons of the free market versus state intervention, this focus misses the central point. The most pressing issue faced by developing countries in this area is not one of privatization versus public ownership, but one of monopolistic inefficiency and unaccountability versus competitiveness, accountability and efficiency.

Solutions to the very real problems of telecommunications regulation and PTT operation in developing countries may be found in either of the many public sector or private sector models referred to above. Which one makes the most sense depends on the circumstances involved and cannot be decided simply on the relative merits of a set of theoretical arguments about the alleged superiority of the free market or about the inherently greater wisdom of the state in pursuing developmental ideals (see the discussion in Wellenius 1987; Nulty 1987).

A second set of points that need to be drawn out relate to the issues raised above about the competitiveness of local service providers, effective user capability and the absorptive capacity of the economy. This argument suggests two things. First care should be taken in assuming the local economy will automatically gain from the market-driven provision of new services. In cases where developing country service providers and users are in competition with international suppliers, given their unequal starting positions in the competitive race and their unequal access to financial, technological and marekting resources, liberalization would almost certainly benefit international suppliers to the detriment of the infant industries in the developing countries.

Secondly, if local users are to exploit effectively access to the new services their own capacities have to be greatly strengthened - and this is unlikely to happen automatically. Hence, the designers of telecommunications policy have to liaise with informatics and industrial policy makers to identify the range of skills, support services and learning facilities that have to be made available to domestic user firms to allow them to compete effectively in the emerging electronically integrated market place.

In relation to domestic regulatory reform, developing country policy-makers are in a classic "second-best" situation because of the existence of major distortions to efficient market operation; and because explicit action needs to be taken to meet the developmental imperative of creating indigenous capacities for supply, and the rapid diffusion of services to those most in need but least able to pay. For these reasons, privatization and liberalization cannot provide blanket solutions to problems of service supply in developing countries. If they are introduced, such measures have to be applied very selectively and judiciously, in order not to counter local capacity and long-term development plans.

The structural problems of PTTs and the gross inadequacies of domestic regulatory policy in most developing countries must be dealt with. The changes already occurring demonstrate just how far technological change has already begun to affect telecommunications policy choices in developing countries. The opportunity costs are simply too high to try to respond within the old monopolistic format to the new challenges and possibilities posed by technological change and the rise of new telecommunications services. The aim of any sectoral reform initiatives on the part of the government must be to achieve complementarity between regulatory reform and developmental objectives. This will not be an easy task - but it is one that cannot be avoided.

V. NEW POSSIBILITIES FOR LOCAL EQUIPMENT SUPPLY AND LOCAL LEARNING

Technological change primarily involving digital semiconductor technology has led to massive upheaval in the international telecommunications supply market.[1/] The transition from analogue technology to microelectronic, digital systems has forced 'traditional' equipment suppliers in the US and Europe to restructure their operations in both industrialized and developing countries. All major suppliers now produce digital systems and have broadened their product ranges to include other elements of information technology (IT).[2/]

This process of technological convergence is gradually leading to industrial convergence and the blurring of historically stable market boundaries between the telecommunications, computing, office equipment and semiconductor industries. As a result, competition has intensified greatly, both among the traditional suppliers, and because of the market entry by large, vertically integrated information technology corporations from Japan, and more recently, Republic of Korea and Taiwan Province of China who are determinedly challenging the established 'electro-mechanical oligopoly' of the western firms.

In response to these dramatic changes, government policies during the 1980s in the advanced economies such as the US have focussed on ways to promote the competitive performance of indigenous equipment suppliers and facilitate the speedy development and introduction of digital transmission and switching facilities. Such policies exhibit two features. The first is massive if sometimes well-disguised programmes of government support by all leading industrialized countries for R&D and technology development in the private sector in most segments of the complex of IT industries including telecommunications.[3/]

The second, more widely discussed, feature of policy has been the promotion of much greater competition in equipment supply and service markets,

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1/ Sustained technical advance and falling real costs of equipment stimulated rapid market growth throughout the 1970s and 1980s, despite recession in the international economy. The total world telecommunications equipment market stood at an estimated $109 billion in 1986 and is forecast to reach approximately $240 billion by 1994. The telecommunications equipment sector is one of the largest international industries comparable in size with the automobile and aerospace sectors. Market size data cited in Financial Times, "Survey of the Telecommunications Sectors", London, 19 October 1987.

2/ Such as semiconductors, office and computing equipmetn and telematics and informatics systems.

3/ In the case of the US, in the late 1970s government funding for civilian R&D in communications was primarily funneled through the space and energy programmes; by 1983, when US government contracts with an R&D component for high technology products and services was running at $55 billion annually the Department of Defense had taken over as the prime source of government funding for private sector R&D.

including the breaking up of 'cosy' and sometimes collusive relationships that existed between purchasing PTTs and equipment suppliers.[1/] The assumption is that opening these markets and relaionships up to increased competition will not only reduce costs but also lead to greater investment in R&D and hence more rapid rates of innovation.

Given the importance of the telecommunications sector both as the key infrastructural element in the emerging information economy and as a major segment of the burgeoning international market in information technology, the role of state policy in helping to promote and maintain the innovativeness and competitiveness of the sector is perceived as legitimate and fundamental. This is particularly so since both domestic competence and international competitiveness in the new IT industries is viewed as a critical determinant of national economic well-being in the future.

In the current context of developed countries, government is fulfilling this role by a combination of direct support for innovative effort and the legislated unleashing of market forces. Such policies assume the prior existence of a technologically competent domestic supply industry capable of responding to incentives - however they are offered. Western pro-market analysts often forget, however, that their industry was allowed to grow to technological maturity under the extremely favourable conditions afforded by state protection of its markets precisely because of its perceived importance to the national economic interests of the industrialized countries.

There are similarities yet are more important differences between the above features and the conditions governing telecommunications equipment supply in the developing countries. As in the North, the telecommunications system is a critical element of the economic infrastructure in developing countries. Similarly, the new generation of digital technology will provide services and facilities centrally important to the future competitiveness of firms in these economies.

Within this context, the overarching policy objective of industrializing economies (like in the developed countries) should be to ensure that communications capacity develops in line with domestic economic, political and social needs. However, unlike western economies, the domestic equipment industry of most developing countries, with some important exceptions, is poorly developed and still in its technological infancy. Given this, the creation of a domestic supply capacity - in line with their market size and technological and economic capabilities - is a defensible, if contentious a priori policy objective for developing countries.

The possibilities for developing countries to go some way towards achieving these objectives have, as alluded to in section III, been enhanced, rather than retarded, by technological change - provided, of course that appropriate policy measures are taken. In light of the vast differences in the status of their supply industries, the new possibilities for creating a local supply capacity are, contrastingly, both a source of conflict between developed and developing countries as well as providing potential grounds for long-term co-operation between them. These issues are examined below.

1/ As is well known and widely reported, the US has taken the lead here but similar steps have also been taken in the UK Japan, France, Italy and Germany.

1. <u>Scale and scope of telecommunications investment in developing countries</u>

Most Third World countries are currently installing and expanding their basic telecommunications infrastructures. As argued in section II, according to measures of what would ideally be required to put the sector on a sound footing, current levels of investment are far too low. However, even the scale of investment currently underway and planned is such that developing countries face the task of managing projects of unprecedented proportions whose financial dimensions are large by any relative standard of industrial development. Together, the ten largest countries spent at least an estimated $9.5 billion on telecommunications equipment in 1987 expected to rise to $11.5 billion by 1990.

At the country level, these aggregate figures translate into a sizeable expenditure of scarce resources. China, with the ninth largest equipment market in the world, for instance, invested $1.8 billion in the telecommunications sector in 1987 out of a total of $5 billion planned by 1990. India, the 12th largest market, invested $1.5 billion in 1987 and Mexico $950 million in the same year out of a planned total of $6.5 billion by 1990, while Brazil spent more than $900 million despite severe financial difficulties.

1987 expenditures in 'second tier' countries such as Indonesia, Taiwan Province of China and Argentina averaged $700 million each and also stand at exceptionally high levels, with Venezuela registering $428 million in investment last year. Further down the scale, the national plan for Colombia calls for telecommunications investments of $300 million over the medium-term, slightly less than is expected by Thailand which is also a medium sized economy. Even large but relatively poor countries such as Pakistan ($320 million in 1987) and Bangladesh ($246 million) forecast total expenditures over the next five years of well over $1 billion each.[1/]

While such figures do not approach, in aggregate terms, developed country expenditure in the sector, they are notable within the Third World context for three reasons. First, infrastructural investments on this scale were not even conceivable in these countries as recently as 20 years ago. They undoubtedly compare on a relative basis with efforts by the advanced countries to develop the railways, power and communications sectors during their own periods of industrialization.

Second, given the present rate of investment, the bulk of the telecommunications infrastructure in developing countries, with the possible exception of Africa, will be in place 20 years from now. Telecommunications investment at the level now being undertaken will not be repeated. And once in place, the particular configuration of systems chosen will determine the telecommunications trajectory of these economies for many decades.

Third, and of greater significance, these infrastructural investments are occuring at a unique moment in technological history. Partly this is because relatively low cost, robust and flexible digital systems offer

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1/ Estimates for telecommunications spending by developing countries are from Financial Times, 19 October 1987; Telephone Engineers & Management, 3 January 1988 and private communication from Mike Hobday.

developing countries the opportunity to 'leap-frog' from less efficient, more costly, earlier vintages of technology. Because these economies are still installing their basic network, they do not face the onerous 'economics of scrapping' decision that confronts many developed countries. As was argued in section III, this ability to leap-frog from earlier technologies could provide important economic benefits to latecomer economies and is the key reason why most observers agree that even the poorest countries should invest in digital as opposed to analogue telecommunications systems (ITU 1985; Mahajan 1988).

2. Telecommunications as a "leading edge" in the accumulation of technological capacity

More importantly, though the availability of a telecommunications network has always played a key facilitating role in the development process, any indigenous technological capacities created via local participation in the design, production, installation and maintenance of previous vintages of equipment were of relatively little use outside of the telecommunications sector. This is not the case with digital technology where many of the skills derived from involvement in design and production of IT based telecommunications products and systems are generic and will be transferable across the many sectors where IT will play a major role.

The pervasive role that information technology will play in the future industrial development of all countries means any digital capacities created in the course of developing the telecommunications infrastructure will ultimately have wide applicability throughout the economy. This process is roughly analogous to the way that the machine design and build skills accumulated within the capital goods industry were so crucial to the early industrial development of the advanced economies.

By the same reasoning, the wide range of capacities required to design, manufacture, install and operate digital equipment can act as a 'leading-edge' in the accumulation of human resources and firm-specific skills on which the whole economy can subsequently draw in a future dominated by information technology.

The reason why this is possible is bound up with the nature of digital technology (Hobday 1985). Digital technology is intrinsically modular and horizontal, so that a system is comprised of a range of independent but compatible modules that form the building blocks of an expandable telecommunications network. The same logic holds in the manufacturing process where microelectronic components both constitute the building blocks of the product and increasingly resemble the final good itself.

This sharply contrasts with the vertically integrated production process in electromechnical technology that involved a large number of specialized components such as relays, screws and connectors. These analogue components were manufactured by the equipment suppliers themselves, a process which required specialized knowledge and a thorough-going and large-scale fine engineering and electromechnical interfacing capacity in virtually all stages of production, installation and maintenance.

Thus, the actual manufacture of crossbar systems is far more complex than the production of digital systems which resembles a simple assembly process whereby most of the components are standard and can be bought in from outside semiconductor manufacturers. The software-intensive design stage is crucial in digital technology, but though the skills involved are specialized, they are also generic, required in smaller numbers and are easier and less costly to build up over time. These characteristics imply a far higher degree of technological and capital "divisibility" than was the case with earlier vintages.

Divisibility in turn implies more opportunities for smaller investments in specialized product areas - even in highly complex exchange systems - and means it is possible to master the design and production process by stages, thereby gradually learning and accumulating skills to tackle more complex products and systems.

The divisibility of the technology itself as well as the design stage and production process makes for potentially much lower barriers to entry by developing countries into the less complex products such as peripherals (intelligent terminals, modern and codec equipment, key systems, mobile radio, VDUs, etc.) and some elements of transmission equipment (such as PCM and TDM equipment).

Likewise, the modular nature of modern exchange softwarr may also provide opportunities for entry by some of the more advanced developing countries into the design and production of smaller scale private exchanges - where the number of US suppliers has grown from 4 in the 1970s to over 1000 in the 1980s. Modularity means it is now possible to continuously improve and upgrade a single system. Brazil, for instance, has demonstrated that it is possible for a developing country to develop and produce not only simple digital equipment, but fairly complex small public exchange systems as well. It first developed a 1000 line exchange for rural use, built on this work to produce a 4000 line system and intends to expand into medium and large scale exchanges on the basis of these developments (Hobday 1986).

Obviously, as will be discussed below, the prospects for particular developing countries successfully entering telecommunications equipment production differ greatly depending on their market size, stage of economic and technological development, government policies, etc.

However, the key points to note here are that it is now much more feasible for developing countries to gradually 'learn' their way up the chain of technological complexity with digital telecommunications technology than it was with earlier vintages. In the course of doing this, it is also likely (and indeed has happened) that many of the problems of "inappropriateness" that plague imported digital euqipment used in developing countries (because it was designed for the very different technical conditions and operating environments found in developed countries) can be overcome.

More generally, it is much easier for these countries to accumulate widely applicable information technology-related skills through "learning-by-doing" in telecommunications than in other segments of the IT complex. And finally whereas the social and economic case for investing in telecommunications is widely accepted as valid for all developing countries (and being acted on by many on a large scale with extensive international support), this of course is not true with other IT industries where many legitimate questions have been raised about the need to establish these industries in developing countries.

It is this conjuncture of investment scale, technological evolution and infrastructural development which demonstrates powerfully that developing countries are in the midst of a period of historic importance. Thus for those countries able to justify the effort on social and economic grounds, the process of building up a digital telecommunications network could be a crucial cornerstone on which their technical progress and industrialization will depend in the decades ahead.

3. Lessons from the newly industrializing countries (NICs)

An appreciation of this dimension of the telecommunications situation confronting developing countries is critical to the development of policies to exploit it. Many countries are either not yet aware of these possibilities or so far have not yet made a major effort to exploit them. However, some governments in the smaller NICs and larger economies are indeed fully aware of the new and more dynamic role that investments in digital telecommunications can play in industrialization.

Because of their relatively stronger economies and more sophisticated cadre of policy-makers, these more advanced countries have been in a position to respond positively to the possibilities discussed above - and in the course of doing so have become major factors in the international market. The nature of their success and the strategies they have followed suggests a way forward for other countries - but also indicate potential areas of conflict and co-operation between public and private sector actors both domestically and internationally.

Among the most notable successes have been the Asian NICs such as Republic of Korea and Taiwan Province of China who, in line with their overall strategies, have pursued interventionist policies in support of local equipment supply firms that promoted their export orientation and international competitiveness. Amazingly, some of these firms are now emerging as competitors to international telecommunications suppliers in particular segments of the market.1/

1/ See Hobday 1986 for data on export performance. To lay the ground work for this, Republic of Korea, who like Taiwan Province of China embarked on export-led industrialization in the 1970s, invested $6 billion between 1982 and 1986 in the telecommunications industry within the context of protected markets for mainly public but also some private sector domestic producers. Over this period, the number of subscribers increased from 240,000 to over 5 million using an automatic switching network connecting 22 major cities; and the R&D and technological framework was laid for the introduction of domestically designed and produced optical fibre cable systems, the development of a Korean digital switching system with a capacity of 10,000 lines, the domestic development of videotex and teletex terminals; and the early introduction of ISDN. See "Fruits of Investment; South Korea", Communications International, October 1986.

Similarly, large, import-substituting countries such as China, India, Brazil and Mexico, while not yet competitive in world markets, have developed a broad indigenous technology development and supply capacity in the public and private sector that increasingly incorporates products based on digital technology. Brazil's experience in developing and locally manufacturing 1000 line 'tropicalized' exchanges is of particular relevance.

Four policy-related points should be noted about the success of these countries in developing an indigenous telecommunications industry. First, empirical studies examining how these gains were achieved document a process of gradual learning, as the countries accumulated digital design and production capacities on a step by step basis (Hobday 1988).

Second, their achievements in telecommunications parallel their considerable accomplishments in other technology intensive sectors where they have likewise developed an export base and strong domestic supply. As in telecommunications, the evidence shows clearly that these advances were due to the active involvement of local firms and research units in design and production, in turn supported by deliberate government intervention to facilitate R&D, technology transfer and the development of local input supply.[1/]

Third, as will be discussed below, the effective assimilation of imported technology and, in some cases, co-operation with foreign equipment suppliers played a significant role in the capacity accumulation efforts of these countries. Finally, there is substantial debate and disagreement in the literature over the short and long run costs and benefits of these policies both in relation to talecommunications and other sectors. Critics argue on straightforward comparative costs grounds that the equipment and technology developed under these policies could have been imported more cheaply and the benefits from its availability passed on more quickly to local users (see on the different positions Mahajan 1988; Chowdary 1986).

While this argument has some validity it is hardly universally applicable. It fails to recognize adequately both the evidence and the arguments made above about the unique entry and learning possibilities inherent in digital telecommunications technology and the long-term benefits to these economies of acquiring indigenous capacities in information technology. Given these possibilities, a judgement as to whether it is best to import on short-term comparative cost criteria or to invest in local learning and local development on long-term benefit criteria can only be taken on a case by case basis.

4. The critical role of foreign equipment suppliers and government support

It is obvious that despite the greater possibilities for local learning and local equipment supply, scale considerations and technical factors mean that the opportunities open to different countries will very much depend on

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1/ This concept and its importance is now central in mainstream thinking about industrialization. There is a voluminous literature on this subject but for a review see Dahlman et al. 1987 and Bell et al. 1984.

market size and the existing technological and economic infrastructure. For this reason most smaller countries, and indeed many of the larger economies, must accept that they will remain dependent for their equipment and technological requirements on outside suppliers to varying degrees. In all but a few cases, this technological dependence will be coupled with a requirement for financial assistance to support their investment programmes.

However, the evidence suggests that such relationships need not be either as onerous on developing countries or as unprofitable to the equipment suppliers as is the case in many other sectors. Most of the great strides forward in technological terms have occurred and are occurring within the PTTs of the advanced countries or within the R&D laboratories of the international equipment suppliers such as ITT, Siemens and Ericsson.

Consequently, access to the technology and know-how developed and accumulated by these firms is absolutely essential for the future development of telecommunications capacities in developing countries. The more advanced countries have recognized this fact and have successfully sought to establish various forms of co-operation with foreign suppliers while at the same time striking the best possible terms for the deal.

Competitive conditions in world markets are in fact currently structured in favour of developing countries. Many large suppliers have based their expansion plans and justified heavy R&D commitments, particularly in digital exchanges, on the basis of capturing a large share of telecommunications equipment markets in developing countries. These markets are of interest to the equipment suppliers for two reasons. First, they are already fairly large in specific categories in both relative and absolute terms. For example, the Latin American market for digital public switching curently accounts for 16.3 per cent of world sales, compared with 27 per cent for Europe and 28 per cent for the USA. Second, rates of growth are, in general, higher than in the advanced countries, particularly in areas like peripherals and switching technology, where an explosive annual rate of growth of 25 per cent through the first few years of the 1990s is predicted for developing countries.

The key characteristic of these markets is that in contrast to the de facto closed markets in Japan, Europe and the US, developing country markets are uncommitted and relatively open to competitive bidding. Access to and success in these markets is crucial to international equipment supply firms who by the early 1980s had collectively spent well over $6 billion to develop 16 major systems - all chasing annual uncommitted export markets of only $2-3 billion.

As a result, competition for market access has become increasingly fierce between established and new suppliers. Several large and medium-sized developing countries have recognized the existence of this "buyer market" and utilized the monopoly purchasing power of their PTTs to 'encourage' competition between suppliers not just on price but on criteria such as increased local manufacture of systems by subsidiaries of foreign firms, and in some regions, large scale technology transfer agreements and co-operation in joint ventures.[1] In addition, the suppliers' home government is frequently brought in to "sweeten" the bid with offers of financial support and other types of assistance. Some firms and governments - such as those from the US and UK have resisted these pressures - and lost contracts as a result.

The trend towards much greater competition between suppliers and the culmination of deals involving genuine technology transfer and government support is well established and widely documented. One of the many examples comes from the struggle between ten major suppliers to win a recent Indian contract for switching systems. Eventually the French system (from CIT-Alcatel) won the order - but only after CIT-Alcatel agreed to transfer exchange technology and the French government was obliged to step in and offer an 'aid for trade' cheap loan arrangement and support for a major training programme involving French scientists. This is a tactic that the French have employed vigourously to win contracts in Singapore, Chile, Argentina, Brazil and Venezuela - and are using right now to try to win a contract to establish a 300,000 line digital exchange plant in China (Mattelart/Schmuccler 1985).[2]

Similar cases could be cited involving Ericsson (of Sweden) in Brazil, Venezuela, Ecuador, and Costa Rica, Cable & Wireless (UK) in China, Siemens (FRG) in Taiwan Province of China and Indonesia - all of which feature the same elements of market access exchanged for financial support, technology transfer and local production as in the French/Indian example. A similar set of deals involving Japanese firms offering low price and favourable technology transfer terms to governments in Latin America and Asia has been proving particularly worrying to the established suppliers because it marks a further breakdown of their longstanding traditional alliances with these governments. Firms such as NEC (now the third largest supplier of telecommunications equipment to developing countries), Fujitsu and Oki have already employed these tactics to gain large shares of Third World regional markets - and will undoubtedly aggressively continue with this strategy in the future.

1/ The centralized nature of most telecommunications investment and purchasing is unique within the complex of other IT industries, where purchasing is usually carried out by a wide range of public and private sector users. Conversely, the large bulk of equipment is normally purchased by a government-owned or controlled agency. This monopoly power has, in many cases, porved critical in the bargaining between PTTs and foreign suppliers for favourable technology transfer agreements and developing country PTTs are very unlikely to relinquish it under any circumstances.

2/ Ericsson of Sweeden was particularly quick to recognize that co-operation with developing country industrialization strategies could provide them with competitive advantage over other competitiors, especially in the large market countries. In response to government requests in Brazil, Mexico, Venezuela, Ecuador and Colombia, Ericsson have transferred technology and, where appropriate, adapted their systems to suit local needs and introduced local training schemes for indigenous personnel.

5. Concluding policy observations

Over the longer term, developing countries will gain much benefit if they can constructively use the need for large scale investments in telecommunications to build up their domestic technological capacities. Such a strategy must exhibit a number of components.

First, the main regulatory and procurement authority must recognize the development of local capacity as a main priority and equally must appreciate the significant opportunities open to it to exploit both the competitive market conditions and the divisibility of the technology to achieve these objectives. On the one hand this may mean moving away from the reliance on a "cosy" relationship with a single supplier towards more open competition - with a critical criteria for selection being the commitment of the supplier to effective technology transfer.

This implies that a prime initial policy objective must be to build up within the PTT or regulatory authority the skills and expertise to devise such a multi-faceted strategy. These include, inter alia, the sophisticated technical, financial and economic analytical capacities to evaluate alternative switching and transmission design, financing and procurement proposals which have capacity building elements in them.

Second, developing countries must recognize that the process of capacity creation will, in most cases depend on fairly extensive collaboration with foreign suppliers. In line with this, developing countries should appreciate the need for suppliers to receive a minimal rate of return and other considerations if full co-operation is to be forthcoming.

At the same time, they must also take steps to ensure they have the knowledge of technology trends, the international market conditions facing suppliers and the particular strengths and weaknesses of those suppliers in order to design an effective strategy that exploits the "buyers market" that currently exists. Such knowledge of course is also necessary to make sure appropriate equipment and training is actually provided. There are already a number of examples of countries who have made digital equipment purchases only to find out later that the equipment line provided was subsequently discontinued.

The same sort of pitfall must be avoided where "technology transfer" is involved. Realistic targets must be set by the host country - and the training delivered needs to be assessed to make sure the right knowledge and skills are being supplied. This is not an easy task but has been accomplished elsewhere (Hoffman 1985b).

Third, to support the above efforts, there must be an accurate information base regarding local market conditions, the capacities and weaknesses of local suppliers and the learning possibilities inherent in the technology being sought. This will allow the design of a realistic strategy of technology acquisition coupled with support for local skill development. Of course, care must be taken to ensure the learning programme does not incur substantial opportunity costs due to overlong learning periods on the part of recalcitrant and inefficient local suppliers only interested in the financial rewards.

This suggests that an important part of policy measures in this area should be the use of competition or the threat of competition to ensure local suppliers take all the necessary steps to learn and produce efficiently. This could include requiring local suppliers-public and private-to sumbit to price, quality, technology and delivery-time targets based on international standards, with penalties, including opening up to foreign competition if the targets are not met.

Finally, since part of the justification for investing in capacity accumulation in telecommunications lies in the gains flowing from the wider diffusion of these skills throughout the economy, an important element of this capacity development strategy must be to identify the mechanisms by which this can take place. There are a number of ways this can be tackled.

Foreign suppliers can be "encouraged" to provide start-up assistance and training to new firms in areas related to telecommunications technology, for example, in software design and peripheral production. At the same time, more people than are directly necessary could also be trained during the main training phase of the investment project. Given that conditions differ greatly between countries, different domestic manufacturing strategies would be required.

- Leaving aside the NICs, if first the larger economies such as India and China are considered, their market size and broad equipment requirements suggest the need for access to foreign knowledge on a large scale, including support for training and local R&D in the design and manufacture of central exchanges, transmission and peripheral equipment.

- For smaller, "second tier" economies such as Thailand, Indonesia, etc., the needs are similar but not so extensive. These countries have to build up their software and hardware design capabilities to allow them to modify imported technology to suit local conditions. They do not need a central exchange capability - yet - but do need to negotiate contracts which give them the training, facilities and support structure to carry out a limited amount of manufacturing and technical change in peripherals and transmission equipment.

- Finally for the much larger group of smaller, poorer countries in Asia, Africa, the Caribbean and other regions, market size, local capacities and the purchasing power of their PTTs are substantially lower than in the larger economies. Thus their aims and policies will need to be less ambitious than those of the NICs and the larger economies. Nevertheless, these countries will or should eventually be making sustained investments in their telecommunications infrastructure and the learning possibilities inherent in these investments must be explored rather than simply written off from the beginning. Training in planning, installation and maintenance is necessary of course and must be an element of any contract or technical assistance agreement negotiated. Access to manufacturing know-how, however, should really only be pursued in relation to some peripherals - and perhaps some transmission equipment depending on market size. It is in relation to these countries that the prospects for regional and international collaboration need to be explored most aggressively. (These issues are discussed in section VI.)

One final area of policy action to be discussed relates not to local producers of telecommunication equipment and services but to local users in the industrial sector. As suggested earlier, simply having access to a sophisticated telecommunications network and having services available do not guarantee that local users will benefit. Much more needs to be done, though the steps that need to be taken are to be integrated with elements of education, informatics, foreign investment and industrial development policy. Here some of these elements are only briefly mentioned.

First, care must be taken to ensure the services that are made available are those that are most needed by local users, foreign and domestic. As there is likely to be considerable mismatch between the needs of local users and what is available, this suggests new product opportunities for local service providers. Identifying these and supporting their development might be an area for government support.

Second, if foreign users - as is to be expected - will take greater advantage then steps must be taken to identify the training and support services necessary to allow local firms to effectively use the new services as well. Doing this might initially require the mounting of an education and awareness campaign to show local users how on-line access to data bases, marketing information, etc. can be an effective element of competitive strategy. This has proved to be a very difficult objective to accomplish quickly even in the developed countries. Educating and convincing users on the importance of telecommunications services and indeed IT in general in developing countries is likely to involve a long-term commitment.

Third, and beyond the above, support may be needed to assist in the selection, design and installation of the necessary equipment and software as well as monitoring the learning period, providing training for managers and support staff, etc. Again there are opportunities for local suppliers that should be explored. If these are scarce, joint venture arrangements might be explored with foreign suppliers to help establish local support and training services. This would also be a good area to involve trained personnel (involved in software programming, system design, product engineering, technical education, etc.) from the universities and public sector R&D institutions in the supply of these services since it would also expose them to the realities of an industrial environment.

There are many other steps that could be taken in these areas. Ideally such policies should be designed purely with reference to telecommunications but as part of broader country-wide efforts to formulate and implement an informatics policy aimed at ensuring that the country takes the right decisions with regard to the acquisition, introduction and effective use of all aspects of Information Technology.

VI. PROSPECTS FOR REGIONAL CO-OPERATION AND THE NECESSITY FOR INTERNATIONAL COMPROMISE

Technological change and related pressures for regulatory reform in telecommunications are creating both opportunities and contentious problems for developing countries at regional and international levels. The same factors that have led to new possibilities for individual countries to exploit the "buyers market" in telecommunications to negotiate better terms and open up learning opportunities operate at the regional level as well.

Similarly because of the unique character of telecommunications as a critical part of the international infrastructure and as "global highways" for the Information Age, developing countries are facing major pressures to accommodate radical open-market oriented changes in the regulation of international flows of telecommunications-related services. The policy issues arising from these areas are explored in this last chapter.

1. New and unexploited prospects for regional collaboration: evidence from Latin America

The changes discussed earlier have created many new opportunities for regional groupings of developing countries to explore ways in which they can use their common need for telecommunications to overcome some of the problems posed by small size in relation to both procurement and local design and manufacture. It is easiest to discuss and illustrate these possibilities in relation to a specific region. The following comments on regional collaboration issues focus on Latin America where comparatively good information on investment plans and existing collaboration agreements exists (Hobday 1985).

Excluding Brazil, Mexico, Argentina and Venezuela, the four largest countries in terms of telecommunications demand, the remaining Latin American countries account for approximately 25 per cent of total sales - around $455 million in 1985. This constitutes a substantial demand overall and there are plans in individual countries to install digital technology which in turn open up some limited possibilities for local learning and manufacture. For example, in Colombia, which at sales of $105 million in 1985, has one of the largest of the smaller country markets, a shift to fully digital technology is planned during the 1990s. Imports from European and possibly Japanese suppliers were expected to make up the bulk of the investment - but in fact the Colombian PTT could use its procurement power to stimulate local involvement.

There are some examples of local development revealing a surprising degree of expertise in telecommunications technology. For example, Uruguay has developed and installed 100 line SPC automatic telegraph exchanges. However, by and large the countries are heavily dependent on imports and their small markets pose serious constraints.

Nevertheless, if one looks closer at their investment plans, possibilities for collaboration do reveal themselves. For instance, Colombia's proposed expansion of telecommunications in the Amazon region could be an opportunity for co-operation with Brazil which is also involved with communications projects in the region. Similarly, Paraguay because of its large demand for rural exchanges is supporting development work in two electronics institutes. This effort could be strengthened greatly via collaboration with Brazil which has developed rural exchanges and is willing to engage in technology sharing. Virtually the same situation exists with reference to Costa Rica and its need for rural exchanges.

In Peru, where the equipment market is expected to reach $80 million annually by 1990, there are plans to set up an R&D centre to support a shift to SPC technology and the possibility of local participation in peripheral and perhaps transmission equipment. Virtually the same scenario is forecast in Bolivia and Chile, both heavy importers, both switching to digital technology, and both looking for ways to build up local capabilities.

It appears that for any of these individual hopes for local development and local capacity creation to reach fruition, regional collaboration is essential. In this context it is noteworthy that one of the key characteristics of telecommunications is the need for regional countries to co-operate in the establishment of technical compatability in international communications.

These forms of regional co-operation do exist in Latin America (and in other regions) and could be strengthened and built upon - CONTELCA and INCATEL in Central America (including as members Costa Rica, El Salvador, Guatemala, Honduras and Nicaragua); CITEL and ASETA in the Andean subregion. In the past some joint projects in installing microwave systems and regional training have already been undertaken. Indeed in 1981, a basic scientific and technological co-operation agreement was reached in Peru involving 10 countries that could have laid the groundwork for extensive collaboration in purchasing and technology development.

Some of these projects have succeeded whereas a number have not - for instance ASETA had established plans for wider integration in the region via a major satellite programme but this appears to have been abandoned. There may be good economic, technical, even political reasons for this and other failures but the fact remains that, as of the mid-1980s, despite many possibilities, little progress has in fact been made towards regional telecommunications collaboration in Latin America.

In Latin America, and in other regions as well, there is far greater scope for technology sharing, trading agreements and specialization in manufacturing than has so far been achieved. These are costly opportunities that are being wasted - and once missed will not reappear. This suggests that aggressively exploring the possibilities for regional collaboration should be a priority item on the agenda of telecommunications investment plans in all developing countries.

2. International regulation and the search for a compromise

Within the international regulatory sphere, the principal area for discussion, debate and decision-making is the ITU (the International Telecommunications Union), a specialized agency of the UN which has traditionally been the main forum for setting regulations governing international telecommunications.[1/] The ITU has also become a major actor in support of developing country efforts to build up their telecommunications sector.[2/]

During the 1980s, the main pre-occupation of the ITU has been with how to manage the international dimension of the ongoing transition from a stable era of international exchange based on conventional telecommunications to a period featuring the rapid growth of a variety of services due to the convergence of digital telecommunications, computing technology and media braodcast technologies.

A central feature of this new context is that the same tensions which exist between regulatory and developmental concerns at the national level (as discussed in section IV), have also permeated international telecommunications relations between advanced and developing countries. These struggles have produced contentious and often acrimonious debate and discussion and so far many of the main issues have not been settled. Finding a solution will demand major concessions from both sides.

Over the past decade the impact of technological advance, new specialized uses for international networks, the rapid diffussion of new services and pressures for openness in international trade have placed great

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1/ The role of the ITU is paramount in international telecommunications matters. It is responsible for establishing interconnection standards and agreements on equipment, operating procedures, signalling and routing between the many national netowrks as well as setting charges and accounting procedures. In addition, the ITU is responsible for regulating and distributing the radio frequency for point to point telecommunications such as telephony and telegraph, as well as mass media communications; and since the 1960s it has regulated the geo-stationary satellite orbit, a crucial part of the overall communications capacity of most countries. The ITU is an extremely powerful and necessary body and it is in the interest of all countries that it work successfully.

2/ The current strength of this focus was underlined by the findings of the Maitland Commission (published as The Missing Link) that highlighted the enormous inadequacies of telecommunications systems in developing countries and the establishment in 1986 of the Centre for Telecommunications Development to respond to the many requests it receives for technical assistance from the Third World.

strain on the ITU and its operating groups.[1/] New market entrants, supplying a wide range of information services for education, commerce, banking, industry and many other areas, have emerged as autonomous service providers - outside the jurisdiction of the traditional PTT carriers and the ITU.

As a result, it is widely agreed that the existing regulations (decided upon in 1973) are now out of date and need to be fundamentally overhauled. Though the technical aspects are complex, the two main issues facing the ITU can be simply stated as (a) whether the new international telecommunications services should be regulated at all, and (b) if so, to what extent they should be regulated. The next round of ITU international conferences in late 1988 and 1989 are viewed as a major test case in its ability to provide a broad regulatory framework for the 1990s and beyond.

a. <u>The pro-regulatory stance of the ITU and the developed country opposition</u>

The ITU wants to extend its jurisdiction over new services (and their providers), and wishes to make compliance with ITU recommendations mandatory. However, there are many powerful opponents to the ITUs moves to maintain close regulatory control over international flows of telecommunications services.

The US, the UK and the large International Telecommunications Users Group (INTUG) in particular argue that the ITU should adopt a minimal regulatory approach, to be applied only to basic transmission and service provision (i.e. telephone, telegraph and telex). In short, they believe that compulsory standards and regulations would limit consumer choice, prevent competition, restrain innovation, and in effect 'strangle the new information technology revolution at birth.'

1/ Within the ITU, there are three main committees dealing directly with standards and regulations: The CCITT (the Consultative Committee for Telegraph and Telephone), the CCIR (the International Radio Consultative Committee) responsible for all radio and broadcast matters, and the IFRB (the International Frequency REgistration Board). The detailed discussions and negotiations that go on within these committees are critcal in determining the final proposals that are put to member governments for agreement.

The mechanism for achieving international agreement on telecommunication resource distribution and standardization are through the resolutions agreed to by ITU members during large international conferences such as the WARC (World Administrative Radio Conference) and the WATTC (World Administriative Telephone and Telegraph Conference), the next rounds of which are being held in 1988 and 1989.

These follow on from previous world conferences and establish the reules for telecommunications operations, sometimes for periods of up to ten years and beyond. The tensions between the desire to promote the growth of telecommunications internationally and trade in related services through de-regulation and privatization, and the need to maintain control over standards and provide for the basic requirements of the developing countries, are manifest both in the work and functioning of the committees and in the deliberations of these conferences.

The ITU's case for extending regulatory control to services and their providers rests on the need to consolidate the worldwide operation of one integrated standardized service network, and to ensure that individuals and countries have equitable access to both basic and enhanced services - a position that is largely endorsed by the developing countries.

b. Issues of transborder data flows

One specific fundamental area of conflict is in the regulation of transborder data flows (TBDFs) - which itself is part of a much larger contentious North-South debate over trade in services that will begin to be formally tackled within GATT this year. Third World countries are still highly dependent on developed countries for data processing and information services and they fear that control over TBDFs by private sector entitites - both large and small - in the developed countries could in fact limit the transfer of information to the developing countries either because access will be denied outright or because the terms of access will be too stringent and costly.

Another major concern is that TBDF can occur between TNC parent and subsidiaries without the knowledge and control of the government and could then be used to the commercial advantage of the foreign firm and result in loss of revenue to the developing country. They may for example, be able to place bids for mineral exploration rights based on knowledge not available to domestic firms or devise strategies for negotiating with the government based on insider knowledge.

Some developing countries have therefore registered strong disapproval at moves to prevent the ITU to have any say in the regulation and content of TBDFs. The stage is thus set for a contentious set of debates over the general issue of TBDF and the specific ITU proposals on this topic described earlier. At this time it is unclear what the outcome will be.[1/]

Given the very high stakes involved in the decisions to be taken at the forthcoming ITU conferences, the possibility exists that if the ITU and the developing countries do not give way on developed country demands for flexibility and minimal regulation in major areas of conflict (including also the allocation of satellite services), the latter groups will remain equally firm thus throwing the whole system of international telecommunications regulation into a state of fundamental uncertainty.[2/]

1/ For a discussion of the outcome of the most recent conference on mobile radio regulation see FCC Week, Alexandria, Virginia, 26 October 1987.

2/ It is clear from the statements of INTUG, the EEC, US and UK delegates, and other interested groups, that if the "arch-regulartory" stance of the ITU were to be adopted at the next interantional conferences, it would be rejected in practice. See Renaud, 1987 and Aronson, 1987 for a specific and a general discussion of these possibilities.

c. A compromise solution

These damaging conflicts have arisen at the international level because each side believes its position to be mutually exclusive. It could be argued, however, that there are large areas of complementarity between them but that to find these, each side has to recognize the validity of the others position.

The thrust of this argument is that a pluralist approach needs to be pursued in relation to the contentious issues now separating North and South in telecommunications. The ITU and the developing countries should recognize that the massive increases in financial resources required to meet their basic infrastructural needs can only come from international sources. These resources can best be generated and supplied within an international economy that is growing rapidly.

The rapid global diffusion of telecommunications services and resources is critical to stimulating global growth because of the expansionary effects of these services and the new technology on all areas of economic activity. Deregulation and relatively free exchange within the industrialized countries is the best way to achieve this - and thus create the conditions for resource transfer. The major concession required of the ITU and developing countries therefore is that they accept that market allocation principles could be applied to the question of new service regulation within a framework administered at the international level.

The developed countries should at the same time recognize the legitimacy of Third World fears that the single-minded pursuit of total de-regulation and an unrestrained market free-for-all, without making allowance for telecommunications resource transfers, could increase the gap between North and South at an extraordinarily rapid pace and effectively eliminate whole segments of the Third World from participating in the most dynamic sectors of the global economy in the future.

Thus, the western countries would have to accept the need for regulation of the basic international infrastructure. At the same time, they should make major commitments to support a planned expansion of telecommunications in the poorer regions and to ensure adequate access to international resources in the future. Ideally this should be done within the framework of the ITU (and the new Centre for Telecommunications Development) by making more funds available and seconding technical and training staff. Steps should also be taken to ensure the more effective participation of developing countries in the deliberations of the working committees of the ITU by contributing financial assistance and extending training and information to those involved.

These moves would allow the ITU committees to carry out their important work with regard to ISDN and other issues that are of primary interest to developed countries, while at the same time ensuring that the needs of the Third World can be met as well. In return for this, developing countries should drop their reluctance to allow the work of the committees on these issues to go ahead.

VII. GENERAL CONCLUSIONS

The developmental concerns of the Third World with regard to telecommunications are legitimate on historical, economic and technological grounds. The rapid expansion of their telecommunications network is a key determinant of economic growth - but this expansion needs to be carried out in a planned and equitable manner that also allows for the creation of indigenous technological capacities when this is feasible.

The structure and management of the telecommunications network reflects many of the problems characteristic of the conditions of underdevelopment - underinvestment, limited availability and poor service; inadequate and often myopic management; excessive regulation and state interference and the biased allocation of resources towards the high income urban groups away from subsistence income rural populations. These difficulties are compounded by the unique pressures, opportunities and dangers caused by technological change and the ongoing revolution in international telecommunications and the accompanying explosion in transnational flows of information and services.

Two broad challenges face the developing countries as a result of the above. First they need to take steps to transform telecommunications and their main service providers into dynamic, efficient engines of development at three levels - rapid expansion of the basic infrastructure giving due weight to rural requirements, via investment in the creation of human, enterprise and institutional capabilities in information technology for design, service and, where feasible, manufacture of equipment and peripherals; and by ensuring that the telecommunications needs of the commercial sector are met as efficiently as possible. This will certainly require major reform of PTTs to push them in a more efficient, competitive and innovative direction as well as a recasting of the nature of government involvement particularly in the financial area where a way needs to be found to put more resources into the sector rather than taking them out.

Second, development implies greater integration with the world economy and inevitably greater dependence on the developed economies. This is particularly the case in relation to telecommunications both for technological reasons and because the investment levels required are far beyond the capacity of most countries - external resources are essential. If developing countries wish to capture benefits from the growth of the world information economy they will have to do their part to ensure that conditions exist that will stimulate global exchange and economic growth - this means facilitating the relatively rapid and free diffusion of new services. At the same time, they need to reach a <u>mutually advantageous</u> accommodation with international firms both in terms of their domestic operations and vis-à-vis the international exchange of services.

Making progress towards both goals does not demand that developing countries privatize, break up their monopolies, allow foreign competition or cede national sovereignity and autonomy to outside entities in matters of regulation and information flow. In some cases, however, liberalization may bring benefits. The more advanced developing countries, for their part, have to realize that they may be moving into a position where they could benefit overall from relaxation of the more restrictive elements of their regulatory regime. This is particularly the case where the pursuit of exports is an objective and where steps must now be taken to ensure the international competitiveness of domestic producers and the existence of an environment attractive to foreign firms.

Nevertheless, some regions of the developing world - particularly the poorer countries - are not yet sufficiently advanced to take advantage of the powerful ability of liberalization policies to stimulate improvement in performance. This requires a minimum degree of indigeous, dynamic technological and industrial capabilities coupled with a stable institutional framework that, in effect, defines the "rules of the game" and allows the advantages of liberalization to be captured by the whole economy. Unless these minimum conditions exist, market oriented solutions could well have the effect of further reducing public accountability and transferring income to the already most favoured groups in the economy.

The challenge the developing countries face is trying to formulate policies that address both their equity concerns and the need for efficiency and innovativeness within the domestic context; while also finding the right balance between independence and interdependence in their relations with the global economy and developed countries. These are difficult accommodations to achieve. But their importance to the long-term prospects for economic advance in the Third World means these issues must be tackled with great urgency in the current period. The costs of not doing so are likely to be unacceptably high.

CHAPTER THREE

Technological and Organizational Change in the Global Textile-Clothing Industry. Implications for Industrial Policy in Developing Countries
by Kurt Hoffman*

INTRODUCTION

1. Textile and clothing industry in North-South economic relations

The textile-clothing complex has historically played a crucial role in the industrial development strategies of many Third World Countries (UNIDO 1987c). The clothing segment was the first manufacturing branch that achieved a rapid growth of exports to the industrialized countries increasing by more than 20% annually between 1968 and 1978. The accompanying expansion in clothing output (7 % annually during the 1970s), based initially on imported fabrics, in turn stimulated the development of a textile industry in a number of countries. Textile exports to the industrialized countries also expanded rapidly with the consequence that the developing countries' share of world trade in textiles and clothing more than doubled from 16.4% in 1965 to 42.1% in 1985. Despite the growth of output and exports from other industrial branches textiles and clothing have remained important to the Third World, accounting for 4.5% of total manufactured output and over 35% of manufactured exports.

As is well known, the newly industrializing countries (NICs) in Asia, particularly Hong Kong, the Republic of Korea and Taiwan Province of China were by far the largest textile-clothing exporters during the 1960s and 1970s, on average contributing more than 75% of total Third World exports over that period. There is little doubt that the NICs' early industrialization efforts benefitted substantially from the dynamic export-oriented expansion of their clothing industry.

While this is significant in itself, the "demonstration" effects of the NIC success in exporting to the industrialized countries (and in subsequently diversifying into other labour-intensive manufactures) has been much more important. Many other developing countries were persuaded by the NIC experience to pursue the establishment of export-oriented textile-clothing production in the 1970s in the hopes that they could follow the same path to export-led growth and industrial development.

This pattern of rapid export growth, first by the NICs and then by a much larger group of smaller economies was the source of considerable problems for the industrialized countries who saw their combined share of world clothing exports drop from 65% in 1965 to 40% in 1985. By 1984, developing countries' clothing exports accounted for 50% of OECD imports of $39 million, with 65% of these going to the US and Canada and 29% to Europe. The US alone imported $17.7 billion worth of clothes from the Third World in 1987, accounting for 23% of their domestic market.

Not surprisingly, the initial success of the NICs followed by a much larger group of countries in their footsteps has long been one of the key sources of tension in North-South trading relations. Developing country

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exports have been blamed by industrialists and trade unionists in the North for the precipitious contraction of employment in the industry over the last 20 years during which time total job losses have exceeded 3 million. However, Thirld World exports of textiles and clothing have by no means been entirely responsible for the loss of employment in the industry in the North. Nevertheless, starting as far back as 1962, tariff and non-tariff barriers imposed by the industrialized countries and directed at excluding textiles and clothing produced in developing countries from the domestic market have continually risen in level and scope. The distorting effects of this protectionist response have been well documented - and to this day and for the foreseeable future, OECD trade barriers will remain the single most important factor determining the scale and distribution of North-South trade in textiles and clothing.

2. The changing importance of technology and non-technology factors as determinants of international competitiveness

Trade barriers have by no means totally removed the threat of low wage imports since for most countries, particularly the US, these barriers have been "permeable" rather than absolute, controlling the rate of growth of imports rather than halting them altogether. Thus since the mid-late 1970s, a sentiment has been growing that the textile-clothing industry in the OECD can only survive and prosper by increasing its competitiveness via the development of new and substantially more efficient production techniques. Manufacturers and capital goods suppliers have become increasingly preoccupied with the search for cost reductions via technological change.

Given this perception, it is not surprising that the emergence of microelectronics technology in the late 1970s attracted a great deal of interest and attention both within the OECD clothing industry and by observers, analysts and policy makers concerned with industrial development in the Third World. This concern arose because of the evidence that emerged early in this decade that the application of microelectronics to the automation of industrial processes could lead to significant reductions in labour inputs per unit of output and a corresponding reduction in labour costs as a share of total costs.

Accordingly, it was feared that the productive gains arising from the rapid diffusion of microelectronics-based innovations in the North could undermine the low wage-based comparative advantage of developing countries across a broad range of product categories, particularly in low-technology sectors such as textiles and clothing. There was widespread concern that there would be a rapid and major degree of trade reversal or relocation involving substitution of domestically produced products in the North for those previously imported from developing countries. Given the importance of this sector, the application and diffusion of microelectronics to textile-clothing technology was consequently viewed as a major threat to trade, employment and indeed the prospects for industrial development in a large number of developing countries.

Some ten years have passed since these concerns were first raised about automation and trade reversal in the textile-clothing industry. The reality of what has actually happened over this period both on the technological front and in relation to trading patterns both confirms and contradicts these initial concerns. Technological change has affected North-South trading patterns in the sector - but primarily in textiles and in clothing, where the most important innovations have only recently begun to feature the extensive use of microelectronics and computing technology. The full automation of clothing production in the North and the threat this would imply to developing country exports could still become a reality in the near future. However, it is unclear when this future will arrive - the fears of ten years ago that this would happen virtually overnight have proved unfounded.

However, much more importantly from the point of view of industrial policy, other factors and trends have emerged which are now of equal if not more importance than technical factors in determining international competitiveness in the textile-clothing sector and the pattern of North-South trade. There have been fundamental changes in the structure and nature of the market for both intermediate products (yarn and textiles) and final products (garments).

This alteration in the character of demand has sparked off a dramatic shift in the marketing and product strategies of retailers and manufacturers, and in turn stimulated a wave a major innovations in the way production is organized within the firms and in the relationships between buyers and sellers. These non-technology induced changes have already had a significant impact on the relative competititiveness of different firms and countries in the OECD and are just now starting to affect developing country trading patterns. However, unlike the genuine although still distant threat posed by automation, the impact of these new factors on developing country export prospects now and in the future need not be negative by any means.

Both the technology and non-technology determinants of trade and competitiveness in textiles and clothing are closely interrelated. Industrial policy for the development of the textile-clothing sector must take into account all of these elements in a comprehensive manner and cannot focus on technology alone. This is the main area of concern of this chapter.

Its principle focus is on understanding and responding to the technology and non-technology determinants of international trade and competitiveness in the clothing sector. However, developments in the textile sector are of interest because it is here where we see the clearest examples of the impact of technological change on North-South trade. This is discussed in section II. The third section discusses current and future developments in clothing technology and makes the case for a careful monitoring of future trends. Section IV sets out to demonstrate the new and growing importance of firm strategies towards greater diversity, flexibility and responsiveness and the impact of these on inter and intra-firm production organization. The final section explores their wider implications for industrial development in the Third World.

II. TECHNICAL CHANGE AND INTERNATIONAL COMPETITIVENESS IN THE TEXTILE INDUSTRY

During the 1960s and 1970s, the successful diversification of a select group of Asian economies and some large Latin American countries from clothing production into textile production and the rapid expansion of textile exports from these countries to the industrialized countries indicated yet another opportunity for other developing countries to industrialize by exploiting their low wage competitive advantage at the expense of domestic textile producers in the North. Yet, in direct response to this threat, the textile industry in the industrialized countries, beginning in the late 1960s, embarked on a massive wave of investment in new technology coupled with structural change and a marked-driven industrial strategy. These developments have significantly altered their future prospects in a positive direction - while at the same time raising considerable obstacles to the continued success of developing countries as textile exporters.

The progressive automation of virtually the entire textile production process has been underway for some time, and in some segments is quite far advanced compared to other sectors. This wave of innovation has had multi-dimensional effects across three inter-linked areas of performance: the reduction of labour content in the production process: increased product quality; and much greater flexibility in production. Dramatic improvement in all these areas has taken place in all the main phases of textile manufacturing - with all of these developments having direct implications for developing countries.

1. Technological innovation in the textiles industry

The sources of productivity growth and other performance improvements have been many and varied, covering a wide range of new technologies both specific to textiles and dependent on innovations from outside the sector, particularly microelectronics and information technology in more recent years. These advances have occurred in both synthetic and natural fibre-based textiles with equally dramatic results. However, in order to simplify the presentation, the following discussion of technological changes will concentrate on the manufacture of natural fibre textiles.

In the opening rooms, automatic equipment for opening, cleaning, picking and mixing bales of fibre is now being rapidly substituted for manual systems eliminating much of the onerous labour input previously required at this stage. In turn, older, slower carding systems are being replaced by hign-speed chute feed systems which eliminate whole segments of labour-intensive activity including doffing, racking, manual transport to the card room and hanging the lap. Overall efficiency improvements of at least 200% have been recorded at this stage.

Improvements in opening room technology have had a profound impact on quality as well through allowing a better and more consistent mix of cottons leading to more uniform and stronger yarn. Likewise, technological change in carding has also had quality effects via the ability to make tighter, closer settings thus achieving a better integration of fibres and reduced weight variation. Yarn quality is also improved due to the presence of few broken threads and from the elimination of thick lap joints.

Spinning has traditionally been the labour-intensive heart of textile production, accounting for 50-70 per cent of all yarn manufacturing costs. Open-ended spinning which first emerged in the mid-1960s eliminates a large number of steps in the spinning production process such as drawing and roving thereby greatly increasing labour productivity, while making change-overs easier as well. This equipment along with spinning attachments such as automatic loaders and yarn-splicers, developed and used extensively in Europe in particular, is now four or five times as fast as conventional ring spinning, as well as allowing the processing of a far lower grade of cotton. Quality gains arise here also because of self-cleaning mechanisms which keep rollers from getting dirty, computerized fault monitoring systems, less manual (more robotic) handling of materials and other improvements which produce higher yields of first quality cloth. Moreover, jet spinning, a relatively recent Japanese innovation, spins yarn even faster than open-ended spinning and does it fine enough for high quality shirting and blouse fabrics.

In weaving, conventional shuttle looms are being replaced by high-speed shuttleless looms (using missiles, rapier, water-jet and air-jets). These looms are now three to tens times more productive than conventional equipment via their much greater speed and an ability to produce broader widths.

Better quality is visible via dramatic increases in first quality woven cut lengths, twice as long as with conventional technology. Defects are eliminated through the automated removal of bad picks in the cloth, the repair of broken threads without leaving starting marks, and through perfectly woven, closed selvedges. The high pace of change in weaving technology continues - a British firm has developed a high-speed multiple rapier machine that weaves from both ends, while a Czech firm has a machine that weaves two fabrics at once.

There have been less gains from computer technology so far in terms of flexibility in weaving but there are examples where it has been applied with great success - in one US plant, computer control and automated materials handling devices allow production of 1.2 million yards of fabric per week in 300 different styles, compared to 300,000 yards a week and 100 different styles without the computer.

Radical technological change is visible elsewhere throughout the textile sector including, of course, the extensive use of computers in all phases of production management, financial matters, marketing, communication, etc. In some segments of the knitting sector, for example, automated knitting equipment capable of producing finished garments is increasingly common, as is the use of programmable knitting machines which allow changeovers to new styles to be accomplished in a matter of minutes.

Some of the most advanced applications of computer technology in the industry are to be found in the dyeing and finishing stages where firms are exploiting the flexibility of the technology to respond to growing demands for short re-orders and variation. One European firm has jet dyeing equipment that can handle lots under 500 yards whereas the standard technolology of only a few years ago could handle only a minimum of 10,000 yards. Computer-controlled dyeing has also greatly improved quality as well as allowing precise colour matching when moving from batch to batch or producing to reorder.

Other examples of current computer applications range from the increasingly extensive use of CAD in the design stage feeding through into direct instructions for weaving machines; to computer-controlled, automated carpet-tufting machines; and finally to fully automated inventory systems where computer-directed sensors and robots operate fabric warehouses by keeping track of thousands of items and automatically filling orders for despatch as they are received.

2. Rationalization and new product strategies

Pervasive technological change has been accompanied by equally extensive rationalization measures on the part of the industry that were in many cases facilitated by major programmes of government support for this adjustment process (and which also included substantial subsidies/incentives for investment in the new equipment that was being developed). The deep involvement of the public sector in the restructuring efforts of their textile industries is a point to remember now that many OECD governments are so vigorously preaching the benefits of non-intervention to developing countries.

Apart from major investment programmes in new technology, the rationalization moves pursued by Northern textiles producers, inter alia, involved: better integration of the design, spinning, weaving and finishing stages; the closure of old plants and dismissal of workers when productive capacity outran demand; and finally a large number of bankruptcies.

Perhaps most importantly, OECD textile manufacturers also vigorously pursued a variety of new marketing and production strategies explicitly designed to improve their international competitiveness in the face of low wage competition from developing countries. These strategies all differ in specifics but mostly represent a shift away from mass production of standardized products towards the production of smaller runs of more highly styled products.

Italy, the Federal Republic of Germany and Japan all have textile industries that evolved from a mass production strategy to one based on shorter runs of more sophisticated products to serve highly defined niche markets. All are now highly successful exporters - with Italy and the Federal Republic of Germany now standing at first and second place in the value of textile-apparel exports in the world. The US textile industry has been slower to pursue a niche production strategy but has gone further than the others in exploiting computer technology to reduce unit costs in high-volume production.

The net impact of this wave of technical change and rationalization in the textile sector in industrialized countries has been impressive. Over the last two decades, textile employment in the North has been reduced from 8.9 million to 6.8 million. In turn, because of the higher capital costs of the new equipment - a shuttleless loom in 1982 cost 3.5 times a flyshuttle loom in 1950, a ring spinning mill is 5 times more capital intensive per worker - the textile industry in the developed countries is now a capital-intensive industry.

Underlying these changes have been signficant improvements in productivity. A modern spinning room is almost completely empty of people. Already by 1983, 7 out of 8 new looms installed in developed countries were shuttleless. As a result, in the US, during the fifteen-year period between 1972 and 1987, labour productivity in textiles has risen by about 90 per cent - roughly double the rate at which productivity grew in manufacturing as a whole. Consequently, and helped recently by the fall of the dollar, US unit labour costs now compare favourably with those of its European competitors and of Japan (which have themselves been declining due to labour-saving innovation), and in a number of cases US producers have begun to reach price levels approaching those in much lower cost Asian and Mediterannean economies.

3. Impact on the competitive position of developing countries

In assessing the implications of these developments for developing countries, a number of points need to be noted. Firstly, while there has not been a massive rollback of the trading gains made by developing countries in the textile sector in the 1960s and early 1970s, neither has there been the expected expansion and subsequent destruction of textiles procedures in the North by exports from the South. On the contrary, having survived the initial onslaught largely by hiding behind protectionist barriers, Northern producers are now beginning to reap the benefits of their investment in new technology - gains that in future could be extracted at the expense of the developing countries.

Moreover, recent changes in the pattern of market demand have played right into the hands of the Northern producers and their new technological base. The textile technology now in place is well suited to allow producers to respond to pervasive changes in demand which are now driving the market - more frequent style changes, greater emphasis on design and styling, shorter runs, and the use of finer yarns and more lightweight fabrics. In short, the greatly increased strength of the automating textile industry in the OECD countries has already introduced a permanent constraint on the textile export aspirations of the large majority of developing countries.

Recent work by UNIDO has shown conclusively that with the exception of relatively few countries, the success of the North in modernizing its industry and regaining comparative advantage (coupled with widespread and severe protectionist measures) has prevented most of the poorer countries from making the heretofore expected shift to textile exporters based on an integrated textile-clothing complex and mass production for undifferentiated markets (UNIDO 1987c).

Instead, because of the growing competitiveness of the North, many have remained "stuck" as clothing exporters and the process of transition to textile exporting on which so many hopes were based has run out of steam since the mid-1970s. This process of backward integration via export expansion into western markets is unlikely for most of these countries to restart in the near future if at all.

This is particularly the case in those segments where new product lines have been developed and where international competitiveness is now based on high technology and the ability to produce in small lots. In the whole of the European textile market, there now appears to be little if any competition from developing country exports in these market segments. Indeed, some countries such as the Philippines, Sri Lanka and Thailand have in recent years moved from being net exporters of textiles to net importers of OECD textiles in these categories.

In sum, because of technological change, government support, a new product mix and the niche marketing strategies pursued by Northern producers, a major component in the textile-clothing-export equation that historically had been expected to be the first step in industrialization for many countries has now been effectively eliminated.

Nevertheless the wage gap between the OECD countries, NICs and other developing countries remains substantial in the textile sector. As a result of this traditional competitive advantage and because of the growing capital costs of the new equipment, most developing countries still rely on the labour-intensive spinning and weaving technologies of the 1960s. This might make sense in narrow economic terms by allowing them to retain existing markets for "undifferentiated" commodity-type fabrics and yarns that are low cost and also low value-added products. However, it does mean that these countries are inevitably falling even faster and even further behind the world technological frontier both in this product segment, and more importantly in the fast growing segment of "differentiated", specialty-type fabrics and yarns where the North has gained the technological and marketing edge.

In addition, it needs to be borne in mind that while microelectronics has played a role in the textile innovation process over the last twenty years, this role has been comparatively limited compared to the impact it has had in some other sectors. Moreover, where the technology has been introduced, it has been used to assist the automation of specific stages of the production process via the design of custom-engineered machinery built to do a specific task - i.e. hard automation. The vast potential of the technology to facilitate systemic integration of the production process, coupled with much greater flexibility than is already possible, has not yet been fully exploited.

Accordingly, most observers expect that the innovation process has by no means slowed down but will in fact continue apace with one important difference to that which has occurred so far. In future, technological change in textiles is much more likely to be driven by the pervasive search for flexible, systemic, integrative applications of information technology than by the search for hard automation tied to the mass production of standardized products.

Three areas where this sort of change is expected are materials transfer, inspection, process and management control. Spinning frames will be much more flexible in terms of changeover; they will be served by high mobility transfer devices carrying output to different locations. Inspection will take place throughout the process using rapid response, vision and/or tactile systems as well as transducers to measure physical properties.

Product, process and output specifications will be able to be altered almost instantaneously in response to changing plant configuration and customer preferences. This will be manifest for instance in complete dye house automation allowing for rapid change and computerized integration between dyeing and finishing. CAD technology used in design and scheduling will generate the manufacturing and marketing data-base needed to drive the system and allow much greater and closer integration with apparel producers.

Such developments are expected in spinning, weaving and knitting. Their likely impacts on productivity, quality and hence on international competitiveness and the current pattern of North-South trade in textiles can only be guessed at but are likely to be signficant - perhaps as significant as those that have already occurred.

These short- and long-term factors taken together basically mean that the poorer countries, though retaining some competitive advantage in certain segments such as lower cost commodity fabrics, including unfinished fabrics, will be less and less able to expand their export production at the expense of producers in the developed countries - though tariff-induced distortions in international trading patterns mean that their textile exports should continue to grow slowly at the expense of the NICs. Any real growth will only come from expansion of their domestic and regional markets - where they will inevitably come under further Western pressure in the future to open up these markets.

The Asian NICs and large country exporters, on the other hand, while enjoying continued strength as textile exporters face other problems. They have begun to invest in modern technology but are still some ways behind the installed capacity of the Northern competitors. This investment, coupled with relatively low wages, has largely preserved their market share (won in the halycon days of the 1960s and 70s) so far. But the rapid and continuing pace of technological change in the North, the constraining effect of protection and the ever-present threat from lower wage countries, means they must pursue technological upgrading aggressively or risk falling behind and losing ground rapidly to their competitors in North and South. As the systems become more progressively integrated, this will become a more and more difficult task.

China, of course, poses problems to all other players - the developed countries, the NICs and the poorer countries. In textiles, as well as clothing, China's competitive position in the international arena is greatly bolstered by the combination of extremely low wages, a massive modernization programme, a large market and considerable political clout with the North in the quota struggles. However, there are no guarantees that China will fulfill all of its potential. Competition is fierce and it will be by no means an easy, quick or costless task for the Chinese textile industry to master modern, computer-based, integrated textile technology.

4. Some broad policy implications

Three points summarize what has been said so far.

- First, technological change has clearly already had a major impact on international competitiveness in the textile sector.

- Second, there is no way of knowing how quickly the systemic innovations that are beginning to emerge in the North will actually diffuse, nor how quickly these will further enhance developed countries' ability to compete internationally. This may occur more rapidly than in the past - or conceivably more slowly; good arguments can be mounted for both viewpoints.

- Third, there is no doubt, that further, technology-driven changes in the determinants of international competitiveness will come to the textile sector.

Faced with a slowly growing export market, defended by Northern producers now able to generate continual and substantial improvements in productivity, quality and responsiveness to market demands, all developing country producers will find that they cannot afford to stand still in technological terms but in fact will have to invest and modernize as quickly as possible simply in order to stay in the same place.

The policy implications derived from this assessment cannot be deduced in isolation. They must emerge out of a well-planned restructuring and modernization strategy that sets out its objectives in terms of scale, products, marketing strategies and arrangements, efficiency levels, technology base and industry structure. Such a strategy can only be developed on the basis of a thorough examination of the current status and future possibilities of the domestic textile industry. Among the factors to be taken account of in such an assessment would be product prices, product mix, quality, volume and output levels, relative factor costs and production cost structures compared against international standards and emerging trends.

The industry structure would also need to be assessed, again against international standards, in order to categorize firms according to their volume, product mix, technology base, productivity, quality, delivery and response capabilities, financial profitability, investment performance, rehabilitation and modernization needs and potential, and perhaps most importantly the innovativeness and competence of firm management in areas such as marketing, design, technology and production management.

A modernization strategy of necessity would incorporate a wide range of policies and programmes that go well beyond technological issues - fiscal policies, trade policies, support for restructuring and diversification, export promotion policies, input subsidies, forward and backward linkages to the raw materials and clothing industries, institutional and conceivably sector-wide initiatives for training, marketing information, design, etc.

Focussing solely on the technological components of the modernization strategy, it would need to incorporate three elements. First and foremost, the problems of "x-inefficiency" have to be addressed. There is widespread evidence that textile firms in many countries are managed poorly and have apalling productivity records. Both of these failings represent major constraints on competitiveness.

Consequently, firm technological and managerial capacities to organize and run production efficiently and to generate a continual stream of productivity improvements from existing equipment will have to be strengthened through in-house training programmes and some form of externally organized training for managers and engineers. Many of the points raised later in sections IV and V about the need to introduce new methods of production organization and management will be relevant here.

Second, a programme of sector-wide fiscal and other incentives designed to stimulate investment in efficiency improvements and in the purchase of new equipment would have to be designed. This could be accompanied by a sector-supported information unit to provide up-to-date information on available technology choices and their appropriateness for local conditions and the objectives of the sector modernization strategy. Beyond that demonstration projects/centres/firms might also be supported to increase firm awareness of the technology choices available and their impacts on performance and competitiveness.

The technology choices available on the international market are still quite wide even though there has been relatively little specific R&D aimed at developing state-of-the-art equipment specificially suited for developing countries. One possible technological factor working in favour of developing countries over the longer term is the trend towards computer-based equipment that is both more flexible and cost-effective at lower volumes of output. This possibility needs to be examined closely however for its relevance in the specific circumstances of individual countries.

Finally, because of limited resources, selectivity may have to be exercised in the provision of firm-specific financial and technical support in the area of new technology choice, purchase, installation, operation and maintenance. This strategy is not without its risks however and needs to be carefully considered in light of the structure of the industry, how well local markets operate and the economic strength and technological and managerial capacities of the firm.

Inherent in the logic of any textile restructuring programme pursued by developing countries in the current industrial climate will be the necessity to make difficult choices that when implemented are likely to have painful, and potentially politically costly implications for the economy, individual firms and workers.

Facing up to these choices and taking the actions called for cannot be avoided - even though it may mean in the end that previously ambitious assumptions about growth rates, foreign exchange earnings and employment have to be abandoned along with a sizeable segment of industry capacity and workforce. To do nothing or assume that conditions will stay as they are is tantamount to permanently relegating a country to the lowest rung of the international textile ladder with no guarantee that it will be able to maintain its hold as a viable exporter over the longer term.

III. THE UNFULFILLED PROMISE AND LONG-TERM POTENTIAL OF RADICAL TECHNICAL CHANGE IN THE CLOTHING INDUSTRY

1. The basic structure of the clothing industry

In the clothing industry there is a unique but straightforward relationship between the product, the production process, industry structure and competitiveness. This relationship not only explains the international division of labour and the pattern of North-South trade in the sector; it is also the key determinant of the short- and long-term impact of microelectronics technology on the role of developing countries as major exporters of clothes.

The clothing production process involves distinct activities that can be grouped under three headings - pre-assembly when the garments are designed, patterns are made and individual components (sleeves, pockets, front and back panels) are cut from cloth; assembly when the components are sewn together into the finished garment; and finishing when the garment is pressed, packaged and despatched.

Of these, the assembly stage is by far the most important since it accounts for 80% of value added in clothing manufacture and involves 80% of the workforce. The interaction between operator, machine and material is the critical feature. Sewing machine operators are highly dextrous and once trained can handle a wide variety of sewing tasks. The basic piece of equipment used in assembly is a standard industrial sewing machine that is low cost ($200 - $1,500), robust, simple to operate and easy to maintain and adapt to specific operations.

Through many minor innovations and small improvements, the sewing machine can now stitch two to three times faster than it did 50 years ago - just about to the limit of a human operator's abilityy to guide material under the sewing head. The combination of a flexible operator and a low cost flexible machine remains the dominant production unit in the assembly stage in clothing factories all over the world.

Clothes are made from "limp" fabrics that have unstable and highly variable handling characteristics that necessitate extensive manual positioning by the sewing machine operator. Because of this, it has historically proved extremely difficult to mechanize materials handling. The garment assumes a three dimensional character early in the assembly stage - skilled human operatives can cope with all the variations involved quite easily; machines could not.

Consequently, materials handling by the operator accounts for 80% of the production cycle, with actual sewing time (i.e. when needle and thread passes up and down through the material) accounting for only 20% of the cycle. As a result the rate of output in clothing production is essentially labour-paced. This caracteristic, along with the many styles of clothes produced by the same factory, means production is done in batches, making it difficult to achieve scale economies.

Thus in the clothing industry, where process know-how and production skills are easily mastered and equipment is cheap and widely available, neither technology nor scale economies have ever acted as a barrier to entry as they have in other sectors. Low barriers to entry have, in turn, affected directly the structure of the industry both domestically and internationally. At the national level, ease of entry means that the domestic industry is typically composed of many small firms (under 100 employees) and relatively few large firms. Under these conditions, retailers are able to foster fierce price-based competition, forcing producers to constantly seek to reduce unit costs without imparting flexibility or incurring large expenditure.

At the international level, a similar process underlies the international division of labour in the industry. Firms from both developed and developing countries enjoy equal access to the same range of techniques while also facing roughly similar materials costs. In this situation, unit labour costs become the key to competitive advantage. And because their wages are so much lower than in the North, developing country firms enjoy a substantial degree of cost advantage in many product categories despite higher productivity and other advantages enjoyed by developed countries.

These structural features (determined by the economics and technology of assembly) are characteristic of many segments of the clothing industry. They essentially explain the past and current highly successful export performance of developing countries. They also indicate that if an across-the-board, technology-induced, trade reversal is going to occur, then this will only happen if the assembly stage, with its complex materials handling aspects, can be automated.

So far, even with the computer and robotics technology available today, this has not yet happened - at least not on a sufficiently pervasive scale to affect broad trading patterns. Concerns expressed in the early 1980s about the imminent loss of the Third World's low-wage based competitive advantage have not been fulfilled. This is not to suggest conditions will not change. Indeed, as will be shown below, there are clear signs that the extensive automation of the assembly stage will almost certainly emerge at some time in the future.

However, the pace of automation in the assembly phase - and the threat this poses to developing countries - has been superceded by other developments on the technological front and by changes in the organization of production and the structure of the market. These developments have more immediate implications every bit as significant from the Third World policy perspective as those arising from the future threat of assembly automation.

In the remainder of this section the nature and impact of microelectronics-based technological change in the clothing production process will be discussed. Section IV will explore the non-technological factors of changing market demand and organizational innovation that have, somewhat surprisingly emerged as critical determinants of international competititveness in the clothing industry with wide implications for the Third World.

2. Radical advance and incremental change in clothing technology

It would be a mistake to assume on the basis of the above discussion that microelectronics technology has so far had no impact on the economics of production and international location in the clothing industry. This is not the case as the technology has found application in all stages of the production process - and in some cases these represent state-of-the-art achievements not found in other sectors. The discussion below will concentrate on technological developments in pre-assembly and assembly as these are the stages where the technology has had its greatest effect and where it will have an even greater impact in the future.

a. Systemic automation in pre-assembly

By far the most dramatic changes have occurred in the pre-assembly phase where new, electronics-based capital goods firms have introduced computer-aided design (CAD) and computer-numerical control (CNC) technology. The CAD systems are used for grading patterns (making pattern parts for various sizes) and for marking (laying out the pattern parts as a guide for cutting). By digitizing information regarding the shape and size range of the clothes to be produced, the CAD system uses stored "rules" to quickly and efficiently perform grading and marking tasks previously carried out manually by highly-skilled, well-paid operators.

The other major microelectronics-based innovation in the pre-assembly stage involves the use of CNC guided, fully automated cutting systems that replace manual cutting techniques used previously. In the computer-controlled cutter, digitized information (produced by the CAD system) is used to guide a self-sharpening, reciprocating blade across a cutting table at very high speeds (20 metres/minute) on which many plys (layers) of fabric (up to 300) are compressed and held in place by a vacuum mechanism.

The CAD grading and marking systems and the CNC cutter offer a wide range of benefits. In the case of the CAD systems, while skilled labour input is reduced, by far the most important gains are faster turnaround time in grading and marking (improved by a favor of 4-6 times) and improvements in fabric utilization (up to 15%) due to making "tighter" lays of the patterns on the cloth for cutting - very significant since fabric costs are 40-60% of total costs.

More recently, users have also begun to take more advantage of the greater flexibility offered by CAD systems via their abality to make rapid alterations to styles. Alterations and changes that used to take hours, even days done manually can now be carried out in a matter of minutes. This flexibility offers enormous advantages in a market that, as will be shown, is beginning to demand a rapid response capability from producers far beyond anything required before.

In the case of automated cutters, reductions in skilled labour usage (from 25-60%) are a much more significant benefit, along with better quality (more accurate cutting) and materials saving via closer cutting of more tightly fitting patterns. The biggest gains, however, are from greater output (200-300% improvement) due to higher cutting speeds and the ability to cut more layers of cloth at one time than was possible with manual methods.

Unlike many other industries where the integration of CAD with CNC technology (CAD/CAM) is still proceeding very slowly, clothing manufacturers have had this option open to them since the late 1970s. The CAD/CNC cutter integration in clothing technology thus represents one of the most advanced CAD/CAM applications anywhere in the manufacturing sector. And while savings arising from use of these systems on a stand-alone basis are significant, the systemic gains that arise from their integration are of a much higher order. Most importantly perhaps in the longer term, by establishing a digital data base defining the product, the use of CAD in particular is a critical first step in the automated integration of all phases of the clothing production process.[1/]

These systems are expensive, with prices ranging upwards from $100,000 for a single system to as much as $10 million for a multi-CAD/cutter installation. Nevertheless, diffusion has been relatively rapid, and now over 50% of all clothes produced in the US come from firms using CAD systems and computer-controlled cutters, while more than 65% of all UK firms surveyed in a recent comprehensive diffusion study already have CAD systems and/or cutters installed or on order (Hoffman/Rush 1988; Whitaker 1988). This degree of diffusion represents a fundamental transformation of the pre-assembly stage that is all the more remarkable since the clothing industry has traditionally been very loathe to invest heavily in new technology of any kind - let alone buying systems costing an average of $250,000 to replace equipment costing a few thousand dollars at most.

The process of change continues in pre-assembly technology. Most importantly, the unit cost of these sytems is coming down and will continue to do so as patents expire, new suppliers enter the market and manufacturers target smaller companies. Moreover, both cutters and CAD systems are being improved in a variety of ways while automation is being extended to other parts of pre-assembly - CAD systems capable of true design work depicting garments in 3-dimensional space are being developed; computer-based fabric evaluation and inspection systems are now available; automated spreading technologies are more common; and laser cutters able to continuously cut single lays of fabric look set to make a major impact.

1/ This is because once the information defining the shape, style, components, etc. of a garment are digitized for use on the CAD system, this same information can, in theory, be used to direct the operation of equipment at every subsequent stage of production.

Because of the advantages derived from the use of already existing pre-assembly automation, these systems are rapidly becoming an essential technology for firms in many segments of the clothing industry in developed countries if they wish to remain competitive in domestic markets. One measure of this is a US government estimate that more than half of the annual 3% productivity improvement registered by the country's clothing industry during the 1980s has been due to the use of automation technology in the pre-assembly stage.

b. Trade relocation rather than trade reversal

Even though they have had only limited effects on unit assembly costs, the increasingly widespread use of these techniques is beginning to have an impact on North-South trading patterns. This is occurring not via trade reversal but due to trade "relocation" from one region of the Third World to another. Growing market pressures on retailers to provide greater product variety are playing into the new competitive strengths of Northern users of pre-assembly automation.

As shall be discussed further in the next section, retailers are pushing suppliers to offer a rapid turnaround on reorders. The use of CAD systems and CNC cutters gives this responsiveness at the pre-assembly stage - reorders can be graded, marked and cut in a matter of hours. However, long assembly times and even longer transit times still pose a problem. In order to reduce turnaround times in the assembly stages, domestic producers who previously might have sent pre-cut pieces for assembly to Asia are now turning for offshore assembly to the Caribbean and Mexico in the case of the US and the low-wage countries of southern Europe, the Mediterannean and North Africa in the case of Europe.

Wages in some of these countries may be higher than in Asian locations - but the economic advantages derived from the use of pre-assembly automation are proving sufficient to tip the balance in their favour. Figures are difficult to come by but some analysts estimate that pre-assembly automation has already accounted for a 5-10% shift in the US offshore assembly trade from Asia to the Caribbean countries. No comparable estimates exist for the scale of European trade relocation but it may even be higher. At any event, this technology-induced sourcing shift denotes the growing importance of geographical proximity as a new competitive advantage for some countries.

c. Incremental progress towards assembly automation

Unlike the pre-assembly phase, the application of microelectronics technology to sewing has proceeded at a much slower, more incremental pace. the basic changes introduced have been microelectronic-based control units added onto the sewing machine - but without any major redesign of the machine or of the principle of sewing two pieces of fabric together using a needle and thread.

Two sorts of applications have been developed. The first is the use of microprocessors and CNC units on expensive ($20-40,000) high volume, special purpose machines used for such tasks as belt-loop attachment and collar stitching. The second type of application has been the development of less costly ($2,500 - 7,500) more flexible operator-programmable machines used for a variety of tasks. This application allows the operator to "teach" the machine a sequence of operations that it then repeats automatically and at high speed.

In both cases, there are significant gains in machine productivity over conventional equipment via greater speeds (up to 60% faster) and more accuracy. However, with conventional machines costing anywhere from $500 - $1,500 these applications are still only cost-effective in a limited range of tasks. Diffusion has been limited - at best in the US only the largest firms have as much as 20 per cent of their sewing machines equipped with microelectronics-based controls. The picture is a little different in Europe where generally higher wages and more progressive management has meant a greater degree of penetration in specific segments - particularly among the larger firms (Mody/Wheeler 1989).

However, it is still the case that even with these innovations, the critical one machine/one operator link has not been broken. Nor has the universal automation of materials handling both between work stations and around the machine head yet been achieved. Therefore with a few important exceptions as discussed below, the central determinant of international competitive advantage in the clothing industry remains largely unchanged.

This shows up in the results of the few available studies that have sought to establish the degree of trade reversal and plant relocation from developing to developed countries that has occurred up to now. In relation to the US, some of this has already occurred in segments such as hosiery, jeans, shoes, men's shirts and children's clothes as documented in Hoffman and Rush (1988). Mody and Wheeler (1988) likewise point out that assembly automation-induced trade reversal has occurred to a somewhat greater extent in Europe because the higher wages there (20-30% above the US) have prompted greater investment in assembly automation thus making domestic firms more competitive with low cost imports.

However, these scattered examples of trade reversal are vastly overwhelmed by the clothing exports from the developing countries that have now reached approximately $20 billion annually. This finding has important implications for developing countries. Rather than facing the rapid erosion of competitive advantage in one of their most important export sectors, assembly automation at the moment is in fact a barely visible phenomenon. At least in terms of shifting trading patterns, assembly automation is unlikely to cause developing countries any signficiant worry in the short term.

There are however some important indicators of ongoing developments that suggest Third World clothing exporters cannot afford to be complacent or assume that the situation will never change with regard to automation in the sewing room. These indicators of potential change are briefly discussed below.

3. <u>The growing possibility of radical technical change in the future</u>

There are three factors at work which sugges that the scope and pace of assembly automation may increase substantially in the future.

a. <u>Growing concentration</u>

The first of these factors is a tendency towards greater concentration among clothing manufacturers, in the US as well as Europe. Though still low, concentration levels are beginning to move upward - a trend that has led to one estimate that by the end of the century, between 75 to 100 US manufacturers could account for 75% of total output (Hoffman/Rush 1988).

This trend is significant. One of the major factors constraining the diffusion of assembly automation have been the very large numbers of small firms that dominate the industry in the OECD countries. These firms are risk averse, suffer serious capital constraints and operate at low levels of output - all factors that make them unwilling to make high investments in equipment that is still very expensive and inflexible relative to their requirements. However, as concentration increases, and large firms account for a growing share of total production in the sector, they should be more willing to invest the sizeable sums in R&D and equipment purchase that will be necessary to automate the sewing room.

b. More innovative capital goods suppliers

Suppliers of production equipment to the clothing industry have traditionally been basically mechanical engineering firms. Faced with industry demand for low cost, relatively unchanged technology, there has been little incentive for these firms to embark on major R&D programmes designed to make a breakthrough in automation technology.

However, the structure of capital goods supply is beginning to change character. New, electronics-based equipment suppliers have entered the sector. This is most notable in relation to pre-assembly where all the major suppliers of CAD and CNC technology are essentially electronics firms. The same sort of firm is beginning to take an active interest in assembly automation. At the same time, both the traditional equipment suppliers and large clothing producers have begun to target their R&D efforts on developing radical innovations in assembly technology. Together with the developments reviewed below, these forces represent an industry focus on assembly automation that has never existed before.

c. Public-sector supported initiatives in R&D

This resurgence in R&D aimed at assembly automation on the part of equipment suppliers and clothing producers is also linked to a major set of government financed R&D initiatives with the same target. These projects, taking place in the US, Japan, Sweden and the EEC are the most significant new element to be injected into the innovation process in the clothing sector for the last 50 years. All are focussing on cracking the assembly automation problem through the investment of substantial resources in R&D carried out on a collaborative basis with clothing manufacturers, equipment producers, automation specialists, etc. Below only the US and Japanese projects are reviewed in detail.

The US project is a joint initiative between the textile-clothing industry and the government known as the Textile & Clothing Technology Corporation (TC2). The objective of TC2 is to produce a system using computers and robots that could automatically load, fold and sew limp fabric into a finished garment. From 1981 to 1988 the government provided $3.5 million per year with industry and organized labour contributing another $5 million plus per year to the project currently being carried out at the Charles Stark Draper Laboratories of the Massachusetts Institute of Technology.

So far it is still far too early to judge the technical and commercial success of this initiative. On the technology side, a variety of prototype machines involving automated assembly of sleeves, coat backs and trousers and the automatic pick-up and positioning of a single fabric ply have been developed and subcontracted to equipment manufacturers for further commercial development. At the same time, the deadlines for achieving some of the more ambitious technical goals have been postponed. Nevertheless the commercial results of TC2s work are eagerly awaited by the industry.

Beyond the R&D efforts, there have been other important spinoffs from TC2. In April 1988, a multi-million dollar demonstration project, was opened in Raleigh, North Carolina. Called the National Apparel Technology Centre, it is intended to be operated as a clothing factory producing products for sale but using all available conventional and leading edge systems. The aim is to stimulate the industry to invest in new technology and have the Centre serve as a training centre and as a focus for industry seminars and the forging of new co-operative alliances. The Centre's set of activities could well be TC2s most important contribution to bringing the clothing industry into the mainstream of the information technology revolution.

The Japanese project, sponsored by MITI, was planned with a longer-term perspective, greater funding and more industry co-operation than the US initiative. Established in 1983 with a 7-10 year timetable and $100 million of government and industry support, the Japanese Automated Sewing System project (involving 3 research institutes and 28 companies) covers the whole assembly process from design through cutting to sewing, pressing and finishing and retail.

Its objective is to cut manufacturing time by at least 50% by developing elements of a flexible manufacturing system (FMS) for pre-assembly, assembly and finishing. At the core of the assembly automation projects is the plan to carry out sewing in three dimensions, using a movable sewing head that works on garments draped over a dummy. The ultimate vision driving the Japanese approach is even more revolutionary - to develop a system in which a salesman in a clothing store would take a hologram of a customer's body, and digitally controlled machines would then tailor-make an article of clothing!

The commercial aim of the project is not solely or primarily to revitalize the Japanese apparel industry - but to develop commercially viable systems that can be sold worldwide. Prototypes are expected early in 1990 with full-scale commercial production of the equipment expected to start some time in the early 1990s.

Given their past record at targeting market niches and then developing and producing products to fill those niches, it seems clear that the Japanese are striving to be the first to produce a flexible manufacturing system for use in the clothing industry. On the basis of past performance in other sectors, one has to rate their chances of success as excellent - with dramatic consequences for the clothing industry as a whole.

At the same time, however, there are still major technical, structrual and attitudinal obstacles to be overcome by all of the private and public sector automation initiatives currently underway in the industrialized countries. These should not be underestimated for they have so far stymied assembly automation efforts. Thus there is a great deal of uncertainty still surrounding the question of when and with what effect the automation of the assembly room will arrive and what will be its implications in developing countries.

Nevertheless, a recent effort to construct an econometric model to show the likely effects on North-South competitive advantage of the widespread diffusion of fully automated assembly technology generated results that are worth mentioning briefly (Mody/Wheeler 1989). The model calculated full costs of production and shipping for a range of garments to the US (with and without tariffs) for one low-wage Asian country (China), one high-wage Asian country (Rep. of Korea), the US and one low-wage regional exporter (Jamaica) as well as for different production partnerships (cutting in a high wage country and assembly in the low wage partner) involving these countries. Different levels of technology were assumed ranging from fully automated assembly (future best-practice), semi-automation (current best practice) and manual.

For standard garments in all cases, China or joint US-Chinese production is least cost. When full automation is introduced, US production is at near parity with Chinese costs in most cases, with US-Jamaica producting coming a close second in costs but uncompetitive in terms of time with US full automation. NIC production is not competitive in most of the cases - losing out to either low wage competition from China, low wage/quick response competition from US/Jamaica or automated production from the US.

These results are provocative suggesting declining NIC competitiveness, the growing strength of China at the expense of other low-wage countries and renewed competitiveness for the US. Whether they will be borne out or not depends on many factors. Careful observation of the trends in technological change that might underpin these developments in the longer term is clearly called for. However, there are other forces at work in the indusry which deserve much more immediate attention and which have major implications for policy in the short run. They are dealt with in the next section.

IV. MARKET-DRIVEN RESTRUCTURING AND FLEXIBLE RESPONSE: THE NEW COMPETITIVE CONTEXT IN THE CLOTHING INDUSTRY

Though fully automated clothing production still lies some time in the future, the structure of the clothing industry in the OECD countries and its sourcing, manufacturing and retail strategies are moving in a direction that is fundamentally different from before. The essence of these changes is a shift from the mass production of standardized products, using narrowly skilled workers and dedicated, high volume technology, towards a mode of production that involves the manufacture of specialized products using a broadly skilled workforce and universal, multi-purpose machines.

Information technology is playing a part in this transformation but so are other factors. The most important of these is that shifts in the pattern of consumer demand are driving fundamental changes in the philosophy of manufacturing and supplier relations embraced by clothing retailers, clothing producers and extending through to textile firms.

Any strategy for clothing production in developoing countries must take these closely interconnected changes in markets, technology, structure and strategy as the starting point for policy formulation. More generally, valuable lessons can be drawn from the changes now underway in the OECD clothing industry that are of immediate relevance for the whole of manufacturing industry in developing countries. To grasp the essential character of these developments, it is best to start with a brief review of changes in the market place and in the pattern of demand that gave initial impetus to the ongoing transformation of the clothing industry.

1. <u>Changing market conditions</u>

As consumer markets developed and expanded in the industrialized countries in the post war period, clothing manufacturers seeking to capitalize on the rapid growth in demand, gradually adopted the methods of mass production. A number of factors hindered these efforts such as the technical characteristics and economics of assembly (discussed above) and the natural segmentation that occurred in the market as a result of the varying clothing requirements of groups of final consumers separated by differences in age, sex, occupation and income level.

Although these constraints meant the clothing industry was not able to achieve scale economies commensurate with other assembly-intensive industries, a number of segments - e.g. menswear and workwear, hosiery and household linen - did lend themselves naturally to long runs of standardized products. And even in those segments where fashion played a bigger role and required shorter runs, there were nevertheless substantial pressures placed by retailers on manufacturers to strive for the longest runs possible of relatively standardized products in order to provide the lowest unit prices.

These large multi-store retailers - Marks and Spencer in the UK, C&A in Europe, Sears and K-Mart in the US - were able to do this because they dominated the distribution networks and retail outlets and were thus able, to an extent, to divide the market into stable segments for which they could set the pace and direction of fashion change and in turn dictate their requirements to suppliers.

This "market-induced" concentration on price competition based on high-volume production of slowly changing products left domestic clothing producers in OECD countries vulnerable on two fronts. First, they became highly dependent on the sourcing decisions of the large retailers. Unfortunately for the clothing manufacturer, these volume retailers were primarily interested in securing supplies at lowest cost and they were quite willing to quickly go elsewhere if domestic firms could not meet their price.

Second, the competitiveness of the domestic manufacturers was wide open to attack from low-wage suppliers in developing countries, who during the 1970s were able to master the skills and technology associated with producing long runs of standard products. It was therefore almost inevitable that the ceaseless search by retailers for lowest cost sources would create opportunities whereby developing country exporters were able to make the sort of massive inroads into market share of OECD procedures that was documented in chapter I.

In the early 1980s, a new set of market conditions have decisively changed the determinants of competition in the OECD clothing industry. It has now emerged that there has been a basic transition in the demographic structure of the population of the advanced countries towards one that encompasses a larger proportion of higher income, and therefore more discerning consumers. This change has been accompanied by a major and rapid shift in consumer taste towards a preference for individual choice, constant variation and higher style content in clothing purchases.

Collectively these changes have fragmented the mass market, forcing retailers to target precisely specified segments of the market by offering a wider variety of more highly styled and more rapidly changing products. Firms operating in the upper-middle segments of ladies clothing such as NEXT in the UK, Benneton from Italy (but now all over the OECD) and the Gap in the US have been in the forefront of a new breed of retailers who have perfected this new marketing strategy. And because of their enormous success, the large, multiple retailers are being forced to move away from their previous commitment to the mass supply of slowly changing product lines towards marketing strategies that incorporate tactics similar to those of the smaller retailers.

2. Changing buyer-supplier relations

These market-driven changes in retailer marketing strategies are having profound implications for buyer-seller relationships throughout the whole of the textile-garment chain. Industry leaders are beginning to realize that the responsiveness and competitiveness of the textile-clothing complex can be strengthened significantly by closer links within the industry between the major actors. The implications of this realization are becoming apparent in the actions of the industry in a variety of ways - almost all of which have relevance for developing countries. Firstly, the design relationship has altered substantially. Whereas before, individual items of clothing were designed either by the retailer or the manufacturer in isolation from each other, there is now a growing trend for a much greater degree of consultation between these groups during the design phase. First, design teams from the retailers and from the suppliers will work together on fabric, colour and pattern selection and on the progressive development of the range of clothes to be offered. Thus in an increasing number of market/product segments, a new co-operative relationship in the design phase is emerging between retailers, clothing manufacturers and textile firms in the OECD countries that never before existed.

Second, a new element of stability and trust is being introduced into the contractual relationships between buyers and sellers. Previously, when price was the main determinant of sourcing, an antagonistic arms-length relationship existed at all levels - retailers forced prices down by playing off one manufacturer against another and by offering only short-term contracts; clothing firms in turn adopted the same strategy towards textile firms; with textile firms doing the same thing to fibre suppliers. Little trust and great uncertainty characterized these relationships.

Now the different types of firms involved are beginning to search for ways to remove the sources of this instability and mistrust. This is translating into a situation where buyers are willing to deal with fewer suppliers over a longer term; they are willing to exchange technical advice and assistance; financial commitments are being informally and sometimes formally extended to cover cloth purchases and clothing orders; contracts are beginning to be awarded based on quality, ability to change at short notice and reliability of delivery rather than on price grounds alone. Price is still important but there is now an assumption that by creating a degree of contractual stability between producers and users, producers will be able to better improve efficiency and thereby reduce costs that can in turn be passed on to the retailer.[1]

A third, and perhaps the most important feature of the new relationships is that in return for contractual stability and co-operation, the buyers - particularly the retailers - expect their suppliers to be willing to offer a greater variety of product lines, and most significantly, they must be able to switch production between styles rapidly in response to short-term trends. As a result, lead times for the supply of products right across the board in clothing industry have become much shorter than was ever thought possible before - from an average of 15 to 22 weeks in the US and Europe to between 2 and 8 weeks respectively.

Retailers will now only finalize a portion of their order (30-70% on average now) at the beginning of the season and place additional orders as sales data indicate which lines are selling the best;increasingly, retailers will "book" production time with manufacturers and allocate it among styles as the season progresses. Within this there is an additional trend towards more and shorter fashion seasons increasing in number from two or three to 6 to 10 per year.

Finally, the increase in product variety and in the number of seasons and the reduction in lead times have inevitably meant that production runs have become much shorter. Whereas before orders would only need to be produced in the thousands of dozens, now the order can be for as few as 50 to 100 dozen, with specialist retailers averaging only between 1,000 to 3,000 units per style.

While it is difficult to judge just how far those new relationships between buyers and suppliers have spread in the OECD clothing industry, there is no doubt that industry leaders are aggressively pursuing these strategies. In the UK for example, NEXT, Marks and Spencer, Woolworths, C&A and Richard Shops have, to various degrees, introduced these changes into all of their supplier relationships. In the US, big retailers such as Wal-Marts and K-Mart, manufacturers such as Levi Strauss, Kellwood and Lee and textile firms such as Greenwood and Milliken have adopted a similar tactic. Given the leadership being shown by these large and very visible firms, experience

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1/ As in so many other industries these days, the system devised by Japanese textile firms stands out as the best example of this approach. The keritsu system which throughout the manufacturing sector in Japan binds different segments of the industry together is very much in evidence in the textile-garments sector. Here the chain extends from the spinner who provides the yarn, to the cloth wholesaler or apparel manufacturer who buys the fabric, produces finished goods and sends them on to the retailer. In the early 1980s, only 20 per cent of Japan's cotton and cotton blend cloth was made by weavers who were free to buy yarn on the open market; at the other end, 75 per cent of small firms sell their fabric to a single purchaser; while most garment firms make 70 per cent of their fabric purchases from no more than three suppliers. The advantage is security - selling yarn cloth and garments on the open market might bring a slightly higher price but the keritsu ties ensure that the firm sells all that it can make.

suggests that in time, these new buyer-supplier relationships will be a general feature of industry structure in OECD countries.

3. Changes in production organization and in the technology of organization

From the producers' perspective, these changes in market demand and in buyer-supplier relations, have begun to erode substantially the economic advantages of long-run garment (and textile) manufacture by shifting the focus of competition from price as the prime determinant of competitiveness to variety, style, flexibility and rapid response. Not surprisingly, the new conditions therefore have had major implications for the way manufacturers organize their production and for the technology they use to control and monitor the production process.

Since the option of full assembly automation is not available, clothing manufacturers in particular have begun to discover that a critical source of enhanced flexibility of production could lie in the redeployment and retraining of their assembly workforce, and in a basic reorganization of their production line. Previous approaches to work organization in clothing (as in all assembly-based industries) emphasized task subdivision and worker specialization to produce large lots at lowest cost. However, as runs have become shorter and style changes more frequent, clothing manufactures have begun to adopt a completely different philosophy.

Machinists are being initially trained (and then continuously upgraded) to be proficient in a wide variety of tasks including not only different types of sewing activity but also maintenance and repair, workplace "housekeeping" and quality control. In addition, lot sizes are being progressively reduced via elimination of the "bundle" system (which required an operator to perform the same task on a large number of workpieces contained in the bundle). The aim here is to strive for reduced in-plant inventories and allowing work to be produced and delivered on a "just-in-time" basis.

Machinery location, the pattern of workflow and the organization of workers is being recast according to unit flow, "group" technology and "quality circle" principles. This means small lots of garments are assembled from start to finish by small groups of workers who also have responsibility for quality control, for making suggestions to improve efficiency and for planning their work schedule.

Payment and incentive structures are being altered as well. Whereas before uniform piece rates were the norm, now the pay scales for individual workers go up as they acquire additional skills through in-house training. At the same time, the basis for calculating payment is shifting from the piece-work performance of the individual to the completed product performance of the group.

Finally, some companies have sought to completely overhaul their management-workforce relations on the assumption that many problems arise because of management mistakes rather than because the labour force is not working hard enough.[1/] This is the most difficult of all problems to tackle

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1/ For the best discussion of the problems that management faces when introducing the new practices, see Walton 1987.

because it requires a degree of openness and honesty and willingness to admit mistakes on the part of people that is not normally found in the workplace. Yet in one US firm where this approach was adopted, quality improved by an order of magnitude, savings related to efficiency improvements were between five and ten per cent of sales, and absenteeism and employee turnover virtually disappeared as a problem. Admittedly, the large majority of OECD clothing firms have not yet begun to alter their approach to production organization nearly as far as the above suggests. There is little doubt, however, that these changes in work practices and production organization in OECD clothing firms are occurring and that the rate and scope of change will increase and expand in the future. And as will be discussed below, and in the next section, the implications for developing countries of the organizational transformation of the OECD clothing industry could be much more important than any technological developments that have occurred so far or are likely to happen in the near future.

4. Technological change in support of organizational change

Organizational change is not the only way that manufacturers are enhancing flexibility. Information technology is playing a major role as well at three levels within clothing manufacturing. The first has already been mentioned - the use of CAD and CNC systems in the pre-assembly stage increases flexibility signficantly because of the ability of these systems to very quickly accommodate changes in design parameters.

Second, within the assembly stage, a reorganization of the production line from batch to flow principles is emerging. Linked computer-based materials transport systems known generically as unit production systems (UPS) have begun to attract a great deal of attention. Work flow and component movement between work stations can be optimized and directed centrally while garments are moved automatically from station to station by means of a computer-directed overhead delivery system linked to workstations linked to terminals that can also monitor operator performance.

The advantages offered by such a system are much greater flexibility, reduced inventories, less handling time and greater control. There are regular reports in the industry press that the institution of UPS has among other benefits allowed firms to cut production times for individual garments from weeks to days and slashed 40-70 % off work-in-progress inventory figures.

UPS systems do have problems, however, in terms of having enough flexibility to meet the needs of the, particularly small, manufacturer while they are still quite expensive on a workstation basis ($3,900 - $4,500). This will restrict their use to large firms - but they could nevertheless spread rapidly among these in the future as the technical problems are overcome and as unit costs come down.[1/]

1/ One Japanese firm using UPS has already begun to produce individual garments on a made to order basis - and has plans to take individual orders specifying style, fabric and size by computer while at the same time issuing the customer with a guarantee that the garment will be delivered a few days later. See Roberts 1986.

Finally, electronic communication within the firm, particularly in the assembly stage, and between firms is rapidly emerging as the technological heart of the clothing manufacturer's new rapid response capacity. Increasingly sophisticated, yet lower cost computer-based management information systems are beginning to diffuse rapidly through the clothing industry in developed countries.

For larger firms either using CAD systems in pre-assembly or already having central computer facilities, these can now be used to estimate costing as well as do cut-order planning and production scheduling. At the smaller scale end and where most firms operate, cheap micro-computers are being equipped with software and peripherals that carry out many tasks previously done manually such as the preparation of work dockets, stock control and fabric sourcing sheets.

Perhaps the most far reaching innovations are occurring in the area of computer-based production control systems (such as MRP II or its variants) that allow "real-time" monitoring of work-in-progress on a continuous basis and assist in production planning, line balancing and work measurement. One of the largest UK producers, Courtaulds, have introduced these techniques into 24 out of 40 companies and in one division producing nightware, sales have risen by 50%, "seconds" have been cut to 1% and raw materials stocks have been reduced by 30%.

These systems have begun to come down in price substantially and along the way have started to accumulate a positive "track record" in terms of cost-effective results. This trend is bringing these systems more within the reach of small firms. Provided their initial reluctance can be overcome, small firms, constrained by limited managerial resources, should find that these sytems will prove a great help in reducing unit costs, improving flexibility and shortening lead time.

The same technology also allows electronic communication between firms thereby facilitating much greater buyer-supplier responsiveness. The American textile firm, Greenwood is hooked up by computer to its fibre suppliers, so that it knows when the truck leaves the plant, what it contains and where it is headed. As a result, its fibre inventories have been cut from three weeks to 2 days; the firm has done the same with its customers for denim fabric thereby cutting their inventories from 4 weeks to 3 days in one case and in the case of another large customer allowing warehouses to be done away with entirely.

When linked up to electronic point of sale systems (EPOS) at the retail end, in-house computer links with manufacturers allow instant communication of production, product and delivery requirements. The now classic and oft-cited example of this is the way the Italian clothing firm, Benneton operates. Each of its 3,200 shops worldwide is linked with EPOS terminals into a central computer which transmits detailed sales information to headquarters allowing rapid analysis of sales trends. Production scheduling from its own factories and 200 subcontractors is therefore tied directly to actual orders from the shops with deliveries facilitated in Italy and the US by a fully automated warehousing system. The success of this approach has virtually compelled other firms to pursue the same strategy.

The end results of these moves by the OECD industry to link new forms of inter-firm technological and contractural relations with intra-firm organizational and technological change are impressive, especially when considered from the perspective of the textile-garment-retail complex as a whole. Numerous documented examples can now be cited that show substantial increases in sales, greatly improved reliability of supply and significant cost savings from inventory reductions and efficiency gains right down the whole chain of sale and production (Kurt Salmon Associates 1986; Cotton 1986).

Where these gains are coming from is just as important as the size of the benefits being derived. Up to 83% of a garment's life cycle, from raw material order to final sale, is spent in inventory rather than in production. Thus, a large share of the final price is accounted for by inventory "carrying" costs. It is precisely in this area, where these changes are having an impact. Industry estimates are that anywhere between 15-40% of the retail price for domestically produced garments could be eliminated by the widespread adoption of these new organizational and technological innovations.

Price reductions of this kind could bring OECD producers into a much stronger competitive position vis-à-vis developing country exports in a wide range of products where they simply are not competitive now. Of course, there are many structural, economic and psychological obstacles to change in this industry - witness the slow diffusion of even low cost, incremental sewing machine innovations through the industry.

But at the same time it needs to be remembered that the techniques being discussed above - apart from the sophisticated computer-based materials handling and communication system - are much less costly and risky to introduce than say a CAD system or a CNC cutter. Yet the potential gains to the successful adopter are potentially as great if not greater than those arising from the use of pre-assembly automation and existing assembly automation technology.

5. Industry level gains from organizational and technological innovation

The preceeding discussion suggests that these organizational and communications technology innovations may well diffuse very rapidly once a "threshold of awareness" about the net gains from their adoption is reached within the industry. There are some observers who claim that this is already beginning to happen in the UK clothing industry which next to the US had the highest overall rate of import penetration from developing country products of some 35% by 1981.

Individual examples abound - for example, Claremont, a large supplier to Marks and Spencers, has seen a regeneration in its fortunes and profitability due to a combination of the introduction of the new production methods and pre-assembly automation. It is now able to finish a garment in eight hours compared to four weeks, it has the highest margins of all Marks and Spencers suppliers, and it has boosted its return on capital employed to over 50 per cent.

This sort of improvement at the level of individual firms has translated into a much improved trade performance. Import penetration has been reduced slightly and stabilized at 31.2% overall; while there has been a pronounced shift in the composition of imports away from developing countries towards Western Europe - the share of developing countries in UK imports fell from 45.7% in 1980 to 38.9% in 1985 while that of the EEC and Western Europe rose from 26.6% to 36.2%, with the imports concentrating at the upper end of the market where quality and design count for more than price alone.

These changes have not been confined to the UK. Countries such as Switzerland and Austria have also registered similar shifts in the composition of imports away from low-cost garments towards higher priced, higher style products. Italy, as is well known, has been at the forefront of OECD countries who have benefitted from these changes in market preference.

The Italian clothing industry is characterized by products with a high design content, extreme flexibility (Italian firms can deliver garments in under two weeks even at the busiest time of a season) and a unique industry structure that features both close links between retailers and small producers and an extensive degree of regional co-operation between small producers in areas such as fashion forecasting, market research and technological information.

The advantages offered by these structural features have catapulted Italy in the space of 10 years into the position of the world leader in textile and clothing exports. In 1987, the Italian industry registered a trade surplus of $10.2 billion, a remarkable feat considering that wage costs per direct employee (including social costs) are nearly twice those in the UK, four times those in Hong Kong and twenty times those in countries such as Sri Lanka.

6. <u>The potential significance for developing countries of organizational innovation in the clothing industry</u>

It would be tempting at this point to draw the conclusion that the diffusion of these new inter and intra-firm organizational practices will have a major, and possibly negative, impact on North-South trade in clothing. These changes undoubtedly represent a fundamental shift in the market conditions confronting developing countries. The move away from long runs of standardized products to small runs of a wide variety of frequently changing products would appear to work against the traditional competitive advantage of most developing country exporters (Mody/Wheeler 1989). The same is true of the trend towards greater design intensity and the retailers' growing demands for more rapid turnaround times and a high degree of flexibility in ordering.

Such an assumption would, however, be static in character and potentially misleading since it does not allow for the possibility of a competitive response by developing country exporters. Indeed, from our perspective, the true significance of these developments derives not from the potentially negative trade implications (of their adoption by OECD firms) but rather from the real possibility that developing country firms may be equally if not more able to benefit from the introduction of the new organizational practices than their competitors in the North - particularly the US.

To understand this perhaps surprisingly optimistic argument, a little background information is necessary. The clothing industry is by no means unique in terms of experiencing fundamental change in the way production is organized. The same inter- and intra-firm organizational innovations now being slowly introduced in the clothing industry in the North are, in fact, spreading rapidly throughout many other sectors in the OECD countries, having first been developed and cultivated in Japan during the 1960s and 1970s.[1/] Indeed it is now widely accepted that much of Japan's early international competitive success in sectors such as automobiles, motorcycles, consumer electronics, etc., can be attributed to the gains in quality, productivity and responsiveness that Japanese firms derived from the assiduous application of these new approaches to production, organization and management.[2/]

After an initial period of reluctance in the early 1980s (similar to the present situation in clothing), many firms in the US and Europe have nc embarked on a "frenzy of adaptation" in order to introduce these organizational innovations. A recent review of what is now a large and rapidly expanding literature has identified examples of their introduction in well over 40 sectors in the US and Europe, ranging from automobiles and engineering products, through to consumer electroncis and other light assembly products to continuous process industries such as steel and petrochemicals. One respected industry analyst has recently claimed that as many as 75% of the Fortune 500 firms are currently introducing major programmes of organizational change both within their own plants and in relation to their supplier networks.[3/]

The reason for this rapid uptake of the new approaches is simply that the gains from their adoption considerably exceed the costs incurred. Indeed so significant are the advantages deriving from the successful introduction of the new practices that many OECD firms have begun to feel that their competitive success in the future will depend just as much on their ability to

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1/ In the clothing industry literature, these techniques are commonly referred to as "Quick Response" technologies, while in the wider industrial policy, innovation and business school literature they are collectively grouped under headings such as Total Quality Control, Just-in-Time Inventory Control, Total Preventive Maintenance or more generally as Japanese production methods because many were originally developed and perfected in Japan.

2/ For a thorough discussion of the automobile case where the Japanese organizational competitive advantages were first documented see Altshuler 1984. For other mainstream publications where these issues are discussed and the evidence reviewed see S. Cohen and J. Zysman 1987; M. Piore and C. Sabel 1984; Schonberger 1987 and Garvin 1988.

3/ For an extensive review of the literature and discussion of the whole area of organizational innovation and its relevance to developing countries see Hoffman 1989.

introduce organizational change as on their ability to apply automation technologies.[1/]

These new developments raise a very important issue for developing countries. If, as appears to be the case, the new modes of production, organization and inter-firm relations are widely applicable across sectors and countries in the North, might they not also be applicable in developing countries as well, not only in clothing industries but across the manufacturing sector? If so, the positive advantages accruing to successful adoption in the South would be considerable. This is the question addressed in the final section, along with a consideration of the policy implications of the current and future patterns of technological and market change in the clothing industry.

V. CONCLUSIONS AND POLICY IMPLICATIONS

The changes in technology, markets and industry organization that are taking place in the OECD countries indicate that developing countries are now confronted by a profoundly different competitive context in the textile-clothing market from what existed in earlier periods. In the 1960s and 1970s, these countries sought to establish and nurture export-oriented fabric and clothing production so that they could take advantage of their inherent low-wage competitive advantages in an industry where entry into production was low cost and markets were relatively open.

In the 1970s, because of rapid Third World export growth, the developed coutries were forced first into a defensive, protectionist position and subsequently had to resort to draconian restructuring measures to survive. Since then they have been striving to re-establish their competitiveness through technological innovation and demand-driven marketing and sourcing strategies.

In textiles this competitive response has been very successful - in many industrialized countries, highly efficient, versatile and very capital-intensive producers are now in a position to resist any further major inroads on their market share from low-wage suppliers. As a result, developing country producers - both estbalished and new entrants - have no choice but to undertake major modernization and technological upgrading efforts in the textile sector simply to retain their current position in the world market and prevent loss of market share.

1/ This is a view increasingly shared by policymakers in the industrialized countries as demonstrated by this quote from an influential study recently prepared by the US National Research Council. "The changes in people and organizations will be a difficult aspect of the revolution in manufacturing. They require a dramatic operative sharing of responsibilities. Many enterprises need changes not only in broad organizational areas and management philosophy but also in employee behaviour, union policies and customer-supplier relations. Every stakeholder - managers, employers, owners, suppliers and customers - must recognize the challenge. The demands placed on manufacturers to be effective in an increasingly competitive marketplace can be expected to relentlessly push managers and workers in this direction". US National Academy of Sciences 1986 (pp. 51-52)

In the clothing industry, the competitive response of the North to low-wage competition from developing countries is just now beginning to reshape the determinants of international success in their favour. This somewhat delayed recasting of the OECD clothing industry and market provides developing countries with an opportunity to mount a competitive response of their own - something they were largely unable to do in the case of textiles. However, the rate at which restructuring is taking place internationally does not permit any complacency on the part of developing countries. Rather it makes it imperative that they, in turn, develop strategies to counter the new forms of high-wage competition that are now emanating from the clothing industry in the North.

Clearly, in this altered international context, conventional strategies for developing and expanding an export-oriented clothing industry will grow less relevant over time. Production of clothing is no longer the logical first step in export-oriented industrialization. The simple fact is that throughout the global clothing sector, demand has contracted, market access is much more difficult and the rates of return are now much lower for inexpensive, simply styled garments produced in long runs by unskilled workers - precisely the type of clothing products where most of new entrant Third World clothing manufacturers have been successful in the past.

What is required now are government policies and firm strategies that take full account of the new context and the emerging determinants of competitiveness so that their existing positions can be strengthened and lost advantages can be reclaimed. These strategies will undoubtedly differ according to the current status and capabilities of the clothing export sector in different countries, particularly with regard to the growing importance of geographical proximity as a determinant of advantage in the marketplace.

Moreover, the new conditions are being shaped not just by the technology element but by a range of non-technology factors most of which were not even considered important components of the international competetive equation in clothing 5 years ago. Any strategies and responses therefore have to take as much if not more account of these other factors in the short run as they do of the potential problems posed by automation technology - even though, as argued in section III, the technology factor could become a much more important variable in the trade equation towards the end of the next decade.

Because the primary focus of this paper is on technology issues, this concluding section first discusses the policy implications of the technological developments reviewed earlier. It then goes on to discuss the wider range of policy issues arising from the discussion in section IV.

1. Monitoring and managing the technological window of opportunity

By far the most important policy implication of the trends reported in this paper is that there does not appear to be any imminent danger of a technology-induced shift in competitive advantage and North-South trade reversal in the clothing industry. This means that the industry and policy makers in developing countries can largely concentrate their efforts on responding to the many other changes in the competitive context that are in fact taking place in the international clothing industry.

Clearly, however, developments relating to the pace and scope of technological change must be monitored closely. In the area of assembly technology, the various assembly automation R&D projects now underway in Japan, the US, the EEC and elsewhere must be kept under closer observation. The economic and technical characteristics and eventual pattern of diffusion of any system commercialized as a result of these projects must be studied and documented. It is simply too early to speculate on the competitive efforts and policy implications of these developments - the best strategy at this point is to remain well-informed and in touch with what is going on.

In relation to the diffusion and impacts of currently available stand-alone applications of CAD and CNC technology in the pre-assembly stage and the use of dedicated and programmable automated sewing machines, monitoring must also be a central element of any strategy. It has been shown above that there is evidence of a slight technology-induced pattern of either trade reversal or trade relocation due to the diffusion of these technologies.

Product segments in which this is or might be occurring need to be identified since it is conceivable that the trends could develop into a larger scale phenomenon in some important segments characterized by long runs and standard products - e.g. men's shirts and workwear. Countries whose exports are being or could be injured by this movement need to assess what, if any, responses are called for in order to overcome these trends - improving efficiency, upgrading quality, greater incentives or perhaps switching productive resources into another clothing product segment where their advantages remain intact.

In the case of the NICs who appear to be losing ground to low-wage countries both because of quotas and because of technology, these trade shifts raise the question of these countries pulling out of the sector altogether - something which they have so far been reticent to do; or suggests at the very least the need for a willingness to subcontract a far greater share of their production (than they do now) to lower cost countries, thereby benefitting all parties involved.

Those countries who are benefitting from the shifts - (for example the Caribbean and North African countries) need to take steps to consolidate their position and further increase their attractiveness as off-shore sourcing locations - by enhancing the incentives offered, by also improving efficiency and quality, as well as upgrading communications and transport facilities, ensuring raw materials supplies, etc.

However, in a slowly growing market characterized by oversupply of standard products, fierce competition between low-wage producers within different regions of the Third World is likely to increasingly characterize trade in clothing, with the main beneficiaries being the retailers in the developed countries. This appears to be an unavoidable dimension of the emerging situation.

The question of the use of microelectronics-based clothing innovations by developing countries as part of these strategies is also a relevant policy concern. Perhaps the most important point to be made here derives from the discussion in Chapter IV. All countries are likely to gain far greater competitive benefits by first sytematically exploring ways to improve efficiency and quality on the basis of established productive capacities and already available conventional technologies rather than seeking any solutions in automation.

With some exceptions related to the NICs, there is no technological imperative at work in the clothing industry dictating developing countries must use computer technology to remain competitive. The economics of low unit-wage costs will clearly not work out in favour of expensive automation in most cases. More importantly, it has become clear now that unless major changes are made in the way production is organized at the firm level, firms are unlikely to be effective users of automation technology. This is going to be even more true in developing countries than it is in developed countries (Hoffman 1989).

Obviously there will be cases where circumstances make the use of more automation justifiable - some of the larger NIC producers are finding it economical to use more automated sewing machines for some products. Equally, there are grounds for arguing developing country producers should explore the use of CAD systems both because of the gains in terms of fabric saving, as well as the greater flexibility offered by this technology. Again some of the Asian NICs do appear to be increasing their use of this technology - with government support.

Having a CAD capability compatible with their Northern customers may be one way that countries in a geographically favourable position can further enhance their competitiveness. Moreover, as CAD will play such an important role in future, more automated, clothing systems, there are many "learning" benefits that could be derived by manufacturers if they had regular access to a CAD system but did not have to bear the costs and risks of purchasing an individual system. This could be organized through the establishment of a sectoral support institution - a policy initiative discussed in more detail below.

Overall, the NICs are undoubtedly faced with the hardest choices on the technology front since they are pressured on the one side by the OECD producers benefitting from advancing automation and still able to hide behind protective tariffs, and on the other by least-cost producers. As a result, if they wish to remain strong clothing producers, the NICs, particularly those with small domestic markets, need to move up the technology ladder in the same incremental fashion that the North is now doing.

This challenge already seems to have been recognized in countries such as the Republic of Korea, where the government is taking a very active role in bringing about the modernization of the clothing industry through a battery of fiscal measures encouraging investment in new technology and through the joint support with industry of sector-specific institutions that act as focal point for policy implementation, information collection, new product development, training and the provision of technical services (UNIDo 1987c).

For other countries, the need as well as the justification for investing in the latest in technology is much less. Of course, government policy must ensure that domestic clothing producers are aware of and have incentives to invest in the level and type of technology that is "appropriate" to prevailing factor costs and their own absorptive capacitities. Almost certainly, many producers in these countries will be using technology well below industry standard - this is as true in the developed countries as it is in the Third World.

The low wage advantage enjoyed by developing countries still provides them with a position at the "starting line" in the competitive pursuit for export markets, particularly in the OECD countries. But under the new conditions of competition, it is clear that low wages will no longer guarantee who is going to win the race. Winners and losers are now increasingly much more likely to be determined by their relative success in mastering the non-wage and non-technology determinants of competitiveness discussed in section IV.

The changes in market preference in all categories of clothing towards higher style, more variety and more seasons, combined with the restructuring and strategic responses of the Northern clothing producers towards greater flexibility, closer buyer-supplier relationships and intra-firm organizational innovation suggest three related areas where new policy initiatives are likely to be required. These are discussed in turn below.

2. New approaches to industry strategy and industry surveys

The first set of measures - the need to carry out a comprehensive industry survey and to draw up an industry strategy - is perhaps a fairly obvious starting point about which, however, some less obvious points can be made. Regular industry surveys which collect standard economic data on firm size, output, employment, investment, productivity, profitability, etc., are, or should be, an essential precondition for effective policy making.

In the past, however, in many countries, such surveys were carried out perfunctorily, on an ad-hoc basis and with only partial coverage. Government policies for the sector were often equally superficial, with the government's main policy concern usually being to secure the maximum degree of trade concessions from the importing countries and then to allocate these among local producers. Competitiveness on the part of the local industry was automatically assumed.

As has been argued above, this assumption is no longer valid and the change in perspective this implies needs to be reflected in a government's approach to sectoral development and support. This is necessary in all countries but is particularly critical in the many poorer economies where the sector is a major employer and where clothing exports account for a large share of current and planned manufacturing sector foreign exchange earnings. Strategic planning in relation to the short- and long-term development of this sector is now a necessity. OECD governments and clothing firms are investing considerable resources in information generation activities to support their strategic planning efforts precisely because conditions are changing rapidly and new perspectives are called for. Developing countries need to do the same if they want to stay in the game.

a. Instilling an international perspective

The process of change in approach needs to begin with the content and objective of industry surveys. The first step is to ensure that policy makers possess a clear understanding of current and future trends in all relevant areas. This means that a first priority must be a review of relevant international trends in demand, fashion, purchasing, protection, technology, quality, delivery times, buyer-supplier relations etc.

This information needs to be collected at the level of specific product categories as conditions and determinants of competitiveness differ markedly between categories. Most importantly the coverage of this must include existing OECD and potential regional markets. The need to focus on regional markets is obvious for countries with an in-built geographical advantage. They are now in a better position than ever before to exploit their proximity in time and space.

For those countries more distant from the traditional markets of the US and Northern Europe, the focus of international survey efforts must incorporate the relevant rapidly growing regional developing country markets - the high income Asian or Latin American countries, countries in the Middle East, as well as low income Europe and other niche market countries such as relatively high income island economies such as Cyprus, Greece, the Seychelles, etc. Market diversification will be critical in years to come - to assume that traditional markets will always be accessible or allow manufacturers to operate under that assumption is the same as condemning the industry to gradual disintegration.

b. Assessing the domestic industry

The knowledge generated by international surveys can then be used to guide the collection of information on the national industry. An important component of this national survey will be a review of domestic market conditions both in terms of pattern of demand as well as the degree of openness and competition faced by local manufacturers.

Typically domestic markets are largely closed to foreign competition in developing countries. Yet some movement towards greater openness will almost certainly benefit both the consumer and domestic manufacturers. Attention to expanding local market share in the face of competition is one of the best ways, manufacturers can hone the skills needed for export success. Moreover, a local "style" may also be a source of inspiration for designers to develop a national "look" that could be successfully marketed internationally.

Beyond this focus on the local market, a national survey of manufacturers will, in addition to the usual economic data categories mentioned above, need to give particular attention to collecting data and gaining knowledge in the following areas so that the response capacities of firms to the new conditions can be judged:

- firm product and marketing strategies;
- firm sources of knowledge and information;
- distribution of firms (by size) across product categories;
- nature of customers and their previous purchasing patterns;
- raw material availability and fabric finishing capabilities;
- firm performance in lot size, delivery and lead times;
- factory layouts, stock levels and work-in-progress inventories;
- management structure, capabilities and perspectives;
- numbers, quality and pattern of deployment of designers;
- educational and skill level of managers, technicians and workers;
- transport and communication availability and requirements;
- sector wide availability of specialist sources of know-how.

c) Stragegy formulation and firm involvement

With these two bodies of knowleoge available, a sectoral strategy can be generated. The components and objectives of this will vary - but critically it needs to be formulated in light of relevant international trends and a comparative assessment of national industry performance against international standards. Some general points on these issues are made below.

First, our review suggests two elements will need to be present in most country strategies. The first is the upgrading of the design intensity and demand responsiveness of the product mix and marketing strategies of individual firms and of the sector as a whole. The second is the continual improvement of efficiency, reliability and flexibility so that long-term relationships can be built up with foreign retailers and suppliers to replace the unstable, short-term, price-dependent links that now dominate.

The relative weight given to each will vary between countries and product segments. Ultimately, however, both elements must converge - demonstrable productive efficiency and flexibility are necessary for unknown manufacturers to break into new markets and consolidate their position in established markets while improved design content and greater market responsiveness are necessary to allow expansion once the foothold is secured. Points of policy relevance following form each of these elements are explored below.

Second, as should be obvious, the policy making process cannot be carried out in isolation either from the reality of international trends or from the reality of domestic constraints operating on local industry and on the government's ability to deliver the policy measures called for. One dimension of this awareness is the need to recognize that the days of pervasive government involvement in all aspects of industrial development seem to be coming to an end. This is as true in clothing as is in any other sector.

Hence the success of any strategy for strengthening the clothing industry is going to depend partly on the government's ability to bring sector specific expertise to bear on the problem, as well as on the willingness of the producers themselves to support the policy proposals put forward by the state. The best way to achieve the latter aim is to ensure that the industry is fully involved in all policy stages - initial data collection and analysis, strategy formulation and, if possible, implementation as well.

This is likely to be quite a new departure for most governments, and one difficult to manage since it implies a diminuation of control and responsibility for middle-level policy makers. However, a way forward must be found through the protective bureauctratic malaise characteristic of many government departments (in developed as well as developing countries). The experience of other countries suggests that a good mechanism for enhancing the effectiveness of the type of sector-specific government/industry initiatives called for by the new conditions is to channel these through some form of institutional framework for the provision of collective services. This is the next area of policy concern to be discussed.

3. Collective provision of services

As indicated above, one element of industry strategy must be to upgrade the design intensity and demand responsiveness of the product mix and marketing effort of export-oriented producers. To do this, detailed information is needed on current and prospective fashion trends, design forecasts and good research on the characteristics of different markets. Generating this information is an expensive and time consuming proposition far beyond the capacities of the many small firms making up the clothing industry in developing countries. Yet to actually acquire and interpret this knowledge requires sector specific expertise generally not available within governments.

This sort of problem illustrates why the fragmented nature of the clothing industry in most developing countries, and the small average size of firms is typically seen as an obstacle to progress. Yet one of the features of the new competitive conditions is the fact that a fragmented industry composed of small firms now appears to possess competitive advantage because of its inherently greater flexibility and responsiveness. This is a key characteristic of the highly successful Italian and Japanese clothing industries.

However, small firms do need organizational and technical support. Institutions to provide both of these have been fostered by the national and local government in Italy and Japan and this pattern of joint public-private co-operation suggests an innovative way forward for government policy in the clothing sector in developing countries.

In Italy, regional co-operatives composed of, some large but mainly, small firms (less than 50 employees) provide their members with a comprehensive range of professional services. These co-operatives were started up with regional and local government support but are now almost entirely self-financing on the basis of a small annual subscription fee ($600 average) paid for by each member.

The services provided by these co-operatives (with a staff size of 6-8 people) range from information services in the areas of design intelligence, market research and fabric sourcing to technical assistance in the area of (new and old) technology choice and adaptation as well as management training. They also act as a focum for organizing joint production and order distribution initiatives. In one instance, a regional co-operative was instrumental in setting up a computer network that was used to divide up incoming orders among the members which otherwise would have had to be turned down (Office of Technology Assessment 1989).

Almost precisely the same form of industry/state supported co-operatives funcioning primarily to advance the fortunes of small firms exist in Japan and as yet on a much smaller scale in the US and UK. Another aspect is that, again, in both Italy and Japan, large manufacturers (such as Benetton and Asahi Toray) perform very similar functions for their network of subcontractors.

There would appear to be considerable opportunities for governments to take the initiative in setting up similar clothing industry co-operatives in developing countries. Seed money for the start up could come from government and/or international agencies. But the service agencies would operate on a permanent basis only if the industry was prepared to provide both financial support and to be deeply involved in their actual day-to-day management and functioning.

The scope of tasks undertaken by these co-operatives could be quite wide ranging from provision of the knowledge-intensive, market-oriented services described above to a variety of other specialist activities derived from the specific need of developing country firms to respond to the new competitive conditions now facing them. Some of these activities could include:

- the carrying out of joint export marketing for local firms;
- the operation of a CAD bureau to service local firms and provide training on, and exposure to, this critical technology;
- the compilation of a register of local and international designers willing to work with domestic firms and/or to act as the focal point and conduit for the development of local design capabilities;
- the provision of advice and information on technology availability, costs and benefits and support for its introduction;
- the enforcement of agreed industry standards on quality, reliability and delivery;
- the focus for other industry initiatives in areas such as raw material acquisition and fabric finishing or the setting up of just-in-time supply relations between buyers and suppliers;
- the provision of centralized and/or in-house training facilities for management, technicians, supervisors and production workers;
- the provision of consultancy services for factory layout, design of incentive systems, organization of the delivery network, reoganization of the workforce into groups, etc.

Under each of these headings, specific policy initiatives would be called for some of which might be quite different frm the conventional approach because the thrust would be on providing services suitable for the new competitive conditions. An example might be the training offered. At one level, more training of all skill categories will certainly be necessary since the clothing industry is notoriously poor at providing sufficient training. However, it is the substance as well as the quantity of training that needs to be different. Managers have to be introduced to the new practices and operatives need to be equipped with broader skills.

Specifying the nature of the different policy initiatives and programmes called for would require care but would not be a difficult task. If necessary, a competent specialist advisor, knowledgeable in current internatonal trends, working with a national expert familiar with local conditions and equipped with a data base on the domestic industry organized along the lines described above could carry out the task of policy design according to the new parameters defining firm and industry strategies.

The problems, however, lie less with policy design than with effective implementation. Responsibility for different segments of industrial policy is usually shared among different government departments each with multi-sector and multi-task responsibility such as vocational training, export promotion and the provision of technical advice. Typically, none of these departments really have the resources or expertise to cope adequately, effectively and efficiently with specific industry needs - a particularly costly constraint at a time when firms need to respond to rapid and fundamental change.

The logic underlying collective service provision is that industry as well as government is centrally involved on a co-operative basis in the funding, design and operation of the proposed collective service institution thereby substantially increasing both the resources and the expertise that can be made available well beyond what is usually offered.

Indeed, it is possible also to envisage an industry-wide association that in fact takes on the responsibility for administering other government policies in the clothing sector including the design of an overall strategy, administering quotas, modernization of grants and tax-related incentive schemes, assessing new investment plans and generally presenting the industry case within government. While this may seem an ambitious objective, the Republic of Korea has established just such an institution to oversee the modernization of its textile industries (UNIDO 1987c).

Such an integrative insitution could eliminate the costly and frequently counterproductive duplication of responsibilities for clothing industry development referred to above. The economies of specialization inherent in collective service provision means that a much larger number of firms would have access to services designed to improve their competitiveness than with conventional initiatives. Member firms would therefore be direct beneficiaries of (and have an explicit interest in) its efficient and effective operation rather than being suspicious of a wholly-government financed agency staffed by non-experts. By bringing industry into the process, a much more coherent industrial structure can be created - one that is responsive to market conditions rather than dependent upon government fiat.

4. Pursuing new routes to productivity improvement and greater competitiveness

It was emphasized above that developing country clothing firms have to find a way of consistently improving their levels of efficiency if they wish to win and retain long-term relations with Northern retailers and manufactures. There is nothing new about such a recommendation. Indeed, it is virtually axiomatic that reports like this one place the need to improve firm level efficiency at or near the top of their policy recommendations. This emphasis on the paramount importance of improving productivity is entirely justified in relation to the clothing sector (as in many other industries) since there is often a gap of anywhere from 25-50% between productivity levels in the North and those in the South, even when the technology levels are roughly equivalent.

Typically, the measures called for relate both to the need to inrease the quantity and quality of training made available for managers, technicians and direct production workers; and the need to ensure that firms are managed according to best practice standards in the industry. Identifying what training measures are required and specifying ways to improve firm management is straightforward enough under normal conditions.

However, the discussion in section IV has argued that in fact a new best-practice approach to production organization and the training of workers is beginning to surface in the clothing industry in the OECD some time after it started to sweep through other industrial sectors. Production lines are being reorganized along flow rather than batch principles; inventories and lot sizes are being reduced while varieties are increased; workers require new and broader skills to respond to the new demands of varied output and more flexible work organization; and incentive systems are having to be recast to take account of their higher skill levels and greater responsibility.

It has been shown that firm-level gains arising from the adoption of these new approaches are substantial and indeed their introduction is viewed as increasingly critical to the competitive success of Northern firms since they eliminate many of the advantages currently enjoyed by low-wage countries. This is true not only in clothing but in many sectors.

If management and production organization practices based on mass production methods are being abandoned by firms in the industrialized countries, what are the implications of this for industrial policy in the Third World - again, not just in clothing but across sectors? Can developing countries respond to these developments? Or are they trapped in the same sort of capital, scale and capability constraint that severly limits their prospects for effectively absorbing automation technology? These are among some of the most critical industrial policy questions that developing countries have had to face in the last decade - yet they revolve around issues and concepts which are still unfamiliar to most policy makers and industrialists in the Third World.

Can the new organizational practices be transferred to developing countries? There are many reasons to argue that it will be extremely difficult to introduce the new practices in developing countries. Clearly there will be major obstacles. All of the financial, economic and market-related problems that currently constrain efforts to raise productivity and improve quality in the Third World will work against the introduction of new practices.

The most critical of these are likely to be skill constraints. The new practices are particularly demanding of managerial and engineering skills of which there are severe shortages in developing countries. Another is the distorting effect of poorly forthcoming and highly protected markets on incentives for firms to undertake any innovative efforts at all. This problem will be particularly pronounced where there is excessive state intervention in production. Many other constraints on adoption could be listed.

However, at the same time, the available evidence on the diffusion and impact of these practices suggests, a priori that the preconditions for their introduction might be much more favourable to developing countries than it might appear at first glance. There are a number of reasons for taking this position. First, there is no doubt that the techniques, concepts and principles of the new practices are transferable across countries. They have diffused from Japan to the very different production environments in the US and Europe suggesting that most of the new approaches are not culturally-specific to Japan as was feared initially.

Second and much more important, the wide sectoral range of successful adopters in the North indicate strongly that many of the new practices are neither scale nor sector nor product specific. The specific management and organizational techniques developed to facilitate quick change over, broader worker training, lot and inventory reduction, production line reorganization, etc., can be introduced into any type of firm regardless of its product or output level.

And, while it is true that the new practices have been developed under conditions of assembly complexity and large volume (as in the auto industry), it is widely acknowledged that many of the approaches are in fact much better suited to light assembly and smaller volumes of output - precisely the sort of conditions that exist in much of Third World industry.

Third, the knowledge required to understand what the techniques are and how they operate in practice is neither patented, restricted nor highly priced. This knowledge in fact is "codifiable" and highly accessible at low cost since by now many of the leading practitioners have written practical, "how-to-do-it" books that are intelligible to anyone with experience-based knowledge of industrial practice.

Fourth, the techniques do not require new investment in embodied technology (i.e. new plant and equipment) and in fact are best introduced in the context of standard small volume machinery typically found on the factory floor of most Third World firms. In fact, as mentioned in section IV, it could be argued that unless some of these practices are introduced firms will not be able to reap the full benefits of new technology. Thus organizational change can be seen as a key precondition to successful technological change.

Fifth, and related, the costs of introducing the practices are likely to be very low since no new capital investment is called for and the techniques themselves can be introduced on a modular basis. Indeed, there is evidence to suggest the new techniques are capital saving since existing machinery is typically used far more efficiently and over a longer period than conventionally. This greatly reduces the overall risk element associated with their introduction - whereas the risks and costs of investing in new technology are likely to be relatively high.

Finally, we are not totally in the realm of speculation when arguing the new practices can be introduced into developing countries. There is in fact a limited amount of, as yet anecdotal, evidence that suggests these practices are already being successfully introduced in some developing countries. According to (unpublished) information, the furthest advanced appear to be NIC subsidiaries of Japanese firms operating in the electronics sector, followed by the Mexican and Brazilian subsidiaries of TNC automobile and component firms based in the US and Europe.

Most surprisingly, some of the best examples of successful introduction in developing countries are to be found in the textile-clothing sector. One case involves a large (20,000 employees/20 factories) clothing producer in Brazil. Senior management in this firm, drawing on its knowledge of Japanese management techniques and group technology ideas has reorganized production in each of its plants precisely along the lines suggested by the new practices.

After the new system was introduced, work-in-progress inventory was eliminated completely after having previously accounted for 30-40% of product costs; the cycle time was reduced from weeks to hours; and productivity was increased by between 200-400% for different tasks.

In another case involving a textile firm in Venezuela, previously notorious for its low productivity and apalling labour relations, the firm introduced group technology practices and management adopted a more co-operative approach towards its workers offering higher pay for those willing to learn more skills. Productivity increased by 300% and the firm is now hailed as a model of mangement-worker co-operation.

Taken together, these points appear to constitute a powerful a priori argument that the new practices could be successfuliy introduced in developing countries not only in the clothing industry but across sectors. Indeed, it can even be argued that they could be introduced across a far wider range of countries and sectors than is the case for the new computer-based technologies which are suitable only for the most advanced developing countries. The new practices could well be applicable even in the poorer, smaller economies who are rendering ineffective most lines of conventional policy advice regarding the regeneration of industry.

CHAPTER FOUR

Technological Change in the Machine Tool Industry. Implications for Industrial Policy in Developing Countries.

by Staffan Jacobsson*

I. INTRODUCTION

This chapter deals with one of the main industrial branches on which microelectronic innovations have had a significant impact. Indeed, numerically controlled machine tools (NCMTs) have come to be considered as the most typical example of how microelectronic technology has revolutionized industrial production.

In section II a general characterization of the machine tool industry is provided before the main features of the new technology embodied in NCMTs are briefly analysed. Further, an overview is given of the current diffusion of NCMTs both in terms of the main industrial branches using these new machine tools and in terms of their international diffusion in developed and developing countries.

Section III first reviews the patterns of production and trade of NCMTs at the international level. It then analyses the structural composition of the NCMT producing industry in developed countries with special emphasis on the main types of corporate strategies and the related market entry barriers.

In section IV the impact of NCMTs on user industries is briefly assessed and the main determinants of the choice between NCMTs and conventional machine tools are discussed.

Section V provides an assessment of the industrial policy implications for developing countries of the availability and increasing utilization of NCMTs. First, policies conducive to an enhanced diffusion of NCMTs are discussed before the issue of building up a domestic supply capability is looked into.

II. NUMERICALLY-CONTROLLED MACHINE TOOLS: THE TECHNOLOGY AND ITS DIFFUSION

1. Some general features of the machine tool industry

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

First, the machine tool industry is therefore a very heterogeneous industry in which "almost 100 strategically different business segments have

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been identified in metal cutting and metal forming, many of which have numerous subsegments" (Boston Consulting Group 1985:21). This implies, inter alia, that an analysis of the impact of new technology on the machine tool industry can not be undertaken at the level of the entire industry. Some broader features and trends can, however, be identified at this level.

Second, the machine tool industry is very small in national terms. According to Jones (1983:1), it accounts for between one and three per cent of manufacturing employment in the developed countries, generally speaking. In a dynamic perspective, however, the machine tool industry has certainly had a proportionally greater impact on industrial development as it has been an important transmission mechanism whereby the latest machining technology has been diffused throughout the economies. As MTTA (1983:2) puts it: "No modern product exists without machine tools, if not directly involved then certainly only one remove away".

A third characteristic hence is the centrality of the machine tool in modern industry as well as its perceived role as a generator and transmitter of new technology which have led to the belief that the industry is of strategic importance.

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

2. The advent of numerically-controlled machine tools (NCMTs)

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

During the recent decades only in the case of a very limited number of products, e.g. engine blocks, production volumes have been high enough to justify investment in rigid, special purpose and automatic production systems. The bulk of engineering products, however, are produced in small and medium batches. Indeed, one source suggests that in Japan, this type of production accounts for 70-80 per cent of the overall production value. Accordingly, the workshops catering for a very diversified demand, e.g. 1,500 different types of pumps, must have a very flexible production apparatus. This need for flexibility meant, until recently, that multipurpose and hand-operated machine tools had to be used. It was thus not possible to benefit from automation in the bulk of the engineering industry.

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

Nowadays the production of an advanced machine tool (itself made by using other machine tools) draws not only on the traditional (yet ever more sophisticated) disciplines of metallurgy and mechanics but increasingly on electrical science and above all electronics. Indeed, there are indications that the electrical-electronic component in machine tool manufacturing costs now is in the region of 30 per cent. This shift in the nature of the product is, within the main OECD countries, altering the character of the industry and the activities of the firms within it. Leading firms now engage in substantial buying-in of components, especially electronic control systems, must use large teams of design engineers including computer software specialists to solve problems for their clients (packaged solutions), make sizeable R&D expenditures, and produce a wide range of items (coverage of product series seems to be a key factor in market success).

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

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

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

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

3. The diffusion and industrial distribution of NCMTs

a. General trends

These technical and economic developments have greatly contributed to a fast diffusion of NCMTs since the mid-1970s. Table 1 shows that the share of NCMTs in the total production of metal cutting machine tools rose in the leading OECD machine tool producing countries from 25 per cent to 67 per cent between 1976 and 1986. It is worth noting that this fast diffusion process has led to a stagnation in the demand for conventional machine tools even in nominal dollars.

Table 1. Share of NCMTs in the total production of metal cutting machine tools in the major OECD machine tool producing countries[a], 1976-1986

		Production of metal cutting machine tools		
		NCMTs	Conventional	Total
1976	mn $	1,201	3,694	4,895
	per cent	25	75	100
1982	mn $	4,173	6,065	10,238
	per cent	41	59	100
1984	mn $	4,511	3,575	8,086
	per cent	56	44	100
1986	mn $	7,405	3,732	11,137
	per cent	67	33	100

a/ USA, Japan, FRG, France, Italy and UK.

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

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

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

Table 2. The substitution of CNC lathes for conventional lathes in the major OECD machine tool producing countries[a/]

	Production of conventional lathes		Production of CNC lathes	
Year	Million $	Per cent	Million $	Per cent
1975	1,147	72	445	28
1976	1,057	62	498	32
1977	1,132	74	626	36
1978	n.a.	n.a.	983	n.a.
1979	1,515	54	1,310	46
1980	1,625	46	1,906	54
1981	1,554	49	1,639	51
1982	885	38	1,416	62
1983	634	33	1,280	67
1984	558	27	1,510	73
1985	542	24	1,714	76
1986	623	22	2,146	78

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

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

The same trend applies to machining centres (Table 3) as substitutes for conventional milling machines. CNC milling machines do also exist as a substitute for conventional milling machines, but as is evident from the table, it is machining centres which have come to dominate as a source of milling technology. While in 1976, machining centres accounted for only 38 per cent of the production of machines performing the milling function, the share rose to 65 per cent in 1986. The share of CNC milling machines seems to have stagnated at about 25 per cent whereas that of conventional milling machines shows a continuous decline from 48 per cent in 1976 to 9 per cent in 1986. Again, the value of production of conventional machines declined also in nominal terms.

Table 3. The substitution of machining centres and CNC milling machines for conventional milling machines in the major OECD machine tool producing countries[a/]

Year	Machining centres		CNC milling		Conventional milling	
	Million $	Per cent	Million $	Per cent	Million $	Per cent
1976	395	38	145	14	493	48
1982	1,232	51	633	26	557	23
1984	1,433	61	597	25	332	14
1986	2,398	65	937	26	340	9

a/ USA, Japan, FRG, France, Italy and UK.

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

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

b. The diffusion of NCMTs by industrial users

When discussing the industrial policy implications of technological change in the machine tool industries, the distinction between producers and users of machine tools is crucial. As will be shown in subsequent chapters of this report, it is only relatively few developing countries which actually produce modern machine tools and even for those countries the share of machine tool production in overall manufacturing value added is marginal. It is on the industrial user side, however, where machine tools are of great importance in a wide range of branches and countries.

Data on the distribution of NCMTs across industrial branches are given in Table 5 which looks at the situation in the USA and Japan. Not surprisingly it is the general machinery sector (broadly ISIC 382) which accounts for approximately half of the installation. The transport equipment sector is the second largest user of NCMTs followed by electrical machinery in the case of Japan and metal products in the case of the USA.

Table 4. The substitution of CNC grinding and polishing machines for conventional machines in the major OECD machine tool producing countries[a]

Year	Production of CNC grinding machines		Production of conventional grinding machines	
	Million $	Per cent	Million $	Per cent
1976	10	1	480	99
1982	115	8	1,330	92
1984[b]	126	11	998	89
1987	710	36	1,989	64

[a] Japan, FRG, France, Italy, UK and the USA.
[b] Excluding UK and Italy.

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

Table 5. Distribution of the stock of NCMTs by industrial branches in Japan (1981) and the USA (1983) (in percentage of total stock)

Industrial branch	Japan[a]	USA[a]
General machinery	43	51
Electrical machinery	16	10
Transport equipment	23	15
Precision machinery	7	5
Metal products	5	14[b]
Casting/forging products	2	3[c]
Miscellaneous	4	2

[a] The Japanese inventory covers plants with 100 employees and more. The USA inventory covers all sizes.

[b] Fabricated metal products.

[c] Primary metals.

Sources: Edquist and Jacobsson 1988:28.

c. The diffusion of systems

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

Data on the diffusion of systems is notoriously difficult to find, partly because of definitional problems. The larger systems (FMS) have been most studied so far and ECE (1986) suggests that there were 350 FMS in the world around 1984/85. All in all, 309 of these were studied and were found to contain 2,139 machine tools. This would mean that less than one per cent of all NCMTs worldwide were incorporated into FMSs. Latest trends indicate a more rapid diffusion of systems in the most advanced industrial countries taking place mainly in the form of FMMs and FMCs.

4. The international diffusion of NCMTs by countries

NCMTs are clearly being diffused in both the developed countries and in the Newly Industralizing Countries (NICs). In Table 6, the estimated stock (column 1) of NCMTs is given for some NICs and some developed countries. Among the NICs, the Republic of Korea is the largest single user of NCMTs, with a stock of 2,680 units in 1985, followed by Brazil and India. Among the developed countries, Japan is the largest user with 118,000 units installed by 1984. In terms of density (column 2) in the use of NCMTs, the NICs are still far behind the developed countries. The leading developing country in terms of using NCMTs, the Republic of Korea, had a density of only about half the value for the UK. Taken jointly, the five NICs (excluding Argentina) had an average density of 1,665. The developed countries had an average density of 14,230 which is 8.5 times higher than in the case of the NICs.

The NICs are also behind in terms of the flow of NCMTs, measured as the share of NCMTs in total machine tool investment. This is evident from Table 7 showing that this share amounted to between 7 and 23 per cent for some NICs whilst it ranged from 40 to 62 per cent in some OECD countries.

Table 6. The stock of NCMTs and the density in their use in selected NICs and developed countries

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

a/ The stock data range from 1983 to 1985 whilst the data for the number of employees in the engineering industry are from 1979 or 1980.

b/ Number of NCMTs divided by million employees in the engineering sector.

Source: Edquist and Jacobsson 1988: Table 12.1.

Table 7. Estimated annual investment in NCMTs in relation to total investment in machine tools in selected NICs and developed countries

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

Sources: Edquist and Jacobsson 1988: Tables 3.2 and 9.2; Korea Machine Tool Manufacturers Association (1987): 488-191 for Taiwan Province of China.

III. PRODUCTION, TRADE AND STRUCTURAL COMPOSITION OF THE INTERNATIONAL MACHINE TOOL INDUSTRY

1. Global patterns of production and trade

Table 8 gives an overview of the largest producers of machine tools in the world in 1985. Exports and imports are also shown. The largest producers are by far Japan, FRG, Soviet Union, United States and Italy. Jointly, they accounted for more than 70 per cent of the global production of machine tools in 1985. Among the developing countries, China ranks highest as number 10, while Taiwan Province of China is number 13, Brazil number 14 and the Republic of Korea and India follow with number 18 and 20, respectively. Jointly, the developing countries accounted for not more than six per cent of the output of all countries listed in Table 8. In 1972, the developing countries, listed in a similar table, accounted for only 2.6 per cent (UNIDO 1975).

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

The principal trade flows in machine tools are shown in Table 9. Japanese and EEC exports to the USA are very large as are EEC exports to the developing countries and to the Comecon countries. The table particularly shows the weak position of the USA. The import share of apparent consumption of the USA rose dramatically in the past decade, from 21 per cent in 1978 to 49 per cent in 1986. For numerically-controlled machine tools, the import share rose from 23 to 61 per cent. (NMTBA 1987/88:126). The deteriorating position of the US industry is a main feature of a changing global trade pattern in machine tools in the recent decade. Another, although minor, feature is the growing strength of the developing countries, in particular Taiwan Province of China, which already is the third largest exporter to the USA. In total, in 1986, the developing countries exported machine tools to a value of US $258 million to the OECD countries.

Where do the developing countries stand in trade? For the key countries listed the findings reveal a very mixed set of situations. On the export to production and net trade to gross trade indicators, Taiwan Province of China is distinct from the rest. It exports $7 in every $10 produced and, notwithstanding an import/consumption ratio that is not small, has a positive balance that compares very favourably with the leading OECD exporters. All other countries have negative balances: Brazil has an overall participation in trade that is low compared with any other country listed but the rest have large negative accounts. For India and Republic of Korea their industrialization thus makes relatively heavy use of imported MT despite the stress laid by both countries, albeit in different ways, on strengthening domestic production capabilities. These data suggest that the trade picture raises rather separate questions for the developing countries and the OECD. In the former case the problem is how to use imports to reinforce local capabilities whereas in the latter the current emphasis is towards not only developing an export industry but also ensuring domestic output will meet the demands posed by a total reorganization of manufacturing.

Table 8. World machine tool production and trade, 1985
(million of US dollars)

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

a/ Rought estimate from fragmentary data.
b/ Year ended June 30.

Source: NMTBA 1987/88:166.

Table 9. Principai trade flows in machine tools in 1985
(million US $)

Importers	Exporters			
	USA	Japan	W. Europe	Developing countries
USA	-	840	644[b]	159[c]
Japan	20	-	130[b]	23[d]
W. Europe	63	339	-	76[e]
Comecon	1	127	552[b]	n.a.
Developing countries	145	489[a]	884[b]	-

a/ Mexico, China, Indonesia, Republic of Korea, Malaysia, Singapore and Taiwan Province of China.

b/ EEC.

c/ Brazil, China, Singapore, Republic of Korea, Taiwan Province of China. The data are for 1986.

d/ Brazil, Hong Kong, Republic of Korea, Taiwan Province of China and Singapore. The data are for 1986.

e/ Mexico, Nicaragua, Columbia, Brazil, Argentina, 'Other Near East', India, Singapore, China, Republic of Korea and Taiwan Province of China. The data are for 1986.

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

A central feature of the international NCMT industry is the rise of Japan to a leading, indeed dominant position.[1] The Japanese dominance in the output of CNC lathes and machining centres is reflected in its strong position in the US and European markets. Of the Japanese production of 10,882 machining centres in 1986, 5,893 are exported (54 per cent). The equivalent figures for CNC lathes were 15,988 and 8,773 (55 per cent). More than half of the export went to the US where Japanese producers have captured the bulk of the market.

1/ The share of the US industry in the global production of CNC lathes fell from 36 per cent in 1975 to just 5 per cent in 1986. Similarly, its share in the global production of machining centres fell from 42 per cent in 1978 to 6 per cent in 1986.

The Japanese dominant position overseas has led to the imposition of trade restrictions by both the USA and the EEC countries in the form of 'voluntary' export restraints by Japanese producers. The collapse of the US industry has even led to 'voluntary' export restraints by Taiwanese producers. From 1987 onwards these are allowed to export only 202 NC lathes and 220 machining centres to the USA.

2. Structural composition of the NCMT industry in developed countries

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

a. Cost leadership strategy

In the mid-1970s, some Japanese firms started to apply a business strategy which could be labelled an overall cost leadership strategy (Porter 1980). The firms had as their basic objectives to penetrate very large parts of the engineering industry. The key factor involved in the definition of their strategy was the design of lower performance, smaller and lower cost CNC lathes and machining centres than hitherto had been available to the customers. These machines were primarily, but not exclusively, aimed at the smaller and medium sized firms. So the Japanese firms deliberately tried, and succeeded in, opening up a new market for this technology. The success in doing so allowed them to grow in size and to capture, hitherto only potential, significant economies of scale. As a consequence, the size of the leading firms grew in a phenomenal way and accordingly, concentration ratios have drastically increased.1/

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

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1/ The five largest Japanese firms in 1987 accounted for 71 and 54 per cent respectively of the country's total production of CNC lathes and machining centres.

backward integration into the numerical control unit production for technological reasons. Rather, for reasons of cost efficiency, backward integration may be interesting although it should be noted that Mori Seiki, the largest producer in the world, still buys its units from Fanuc.

As regards the main entry barriers into this group of producers three factors can be mentioned.

- Economies of scale and economies of scope

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

- Access to a large marketing network

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

- Design skills

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

b. Differentiation strategy

It is of course possible to pursue other strategies than the overall cost leadership strategy. Some firms focus on the demand from a range of customers across the engineering industry who need higher performance machines and who are prepared to pay a price premium for this performance. Frequently, these firms demand smaller systems too, in particular FMMs and FMCs. It appears that, so far, firms pursuing this differentiation strategy (Porter 1980) frequently specialize in the production of either CNC lathes (e.g. Index and Traub in the FRG) or in machining centres (e.g. Mandelli in Italy). In the case of the FRG, none of the largest producers of CNC lathes produces machining centres nor do the largest producers of machining centres produce

CNC lathes. Occasionally, however, some firms produce both types of machine tools (e.g. Matrix-Churchill in the UK). An open question is if firms in this strategic group will not have to broaden their product range to include both CNC lathes and machining centres in the future.

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

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

- Design skills

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

- Brand image

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

- Economies of scale

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

IV. THE MICRO IMPACT OF NCMTs ON USERS

1. Organizational changes versus hardware changes

The impact of new technology on the productivity on the shop floor is not only a function of new hardware being introduced in a production process. Rather, the ability to organize the proper use and interaction of labour, machinery and materials is an equally fundamental factor determining shop floor productivity. Organizational ability has many aspects to it. An important one, which this section focusses on, is the formal organization of the flow of materials and the set-up of the machines.

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

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

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

JIT is not a question of only the relationship between an assembler and the suppliers of raw materials and components, but refers equally, as is clear from the quotation, to organizational changes within a company and workshop. GT refers to the case where families of products are identified, for example components for pumps of different sizes, and a production line is organized in which all or many of the production processes that are required to complete the component are present. Such an organization is distinct from the traditional functional layout where machines of a specific type, e.g. milling machines, are grouped together.

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

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

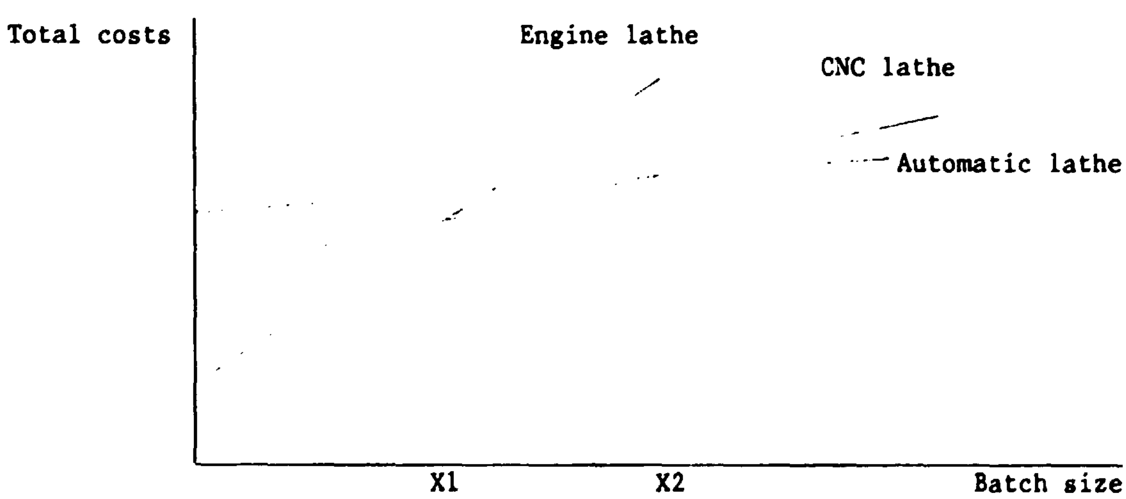
2. Choice between NCMTs and conventional machine tools

Unlike in some other new technology areas, in the case of machine tools there is - and for quite some time will continue to be - a choice between new NC machine tools and more conventional types of machine tools. Machine tools of different levels of sophistication are available in the market and they can all be put to economical use depending on the particular circumstances in which they are placed. It is only in very limited cases of manufacturing high precision products that in order to meet demanding specifications NCMT are indispensable. In most cases, however, technology choice is a real option. At the same time it is a complex issue. Given that a real opportunity exists to choose between NCMTs and conventional machine tools, two main determinants of that choice can be identified:

- fixed cost of preparing the machine tool (e.g. setting and programming);
- variable cost of cutting or forming the metal, i.e. the cost of the actual machining. This variable cost is a function of three factors:
  - the cycle time, which is the time it takes for the workpiece to be machined;
  - the cost of capital per unit of time, i.e. both the cost of the machine and the interest rate;
  - the cost of labour for operating the machine tool per unit of time.

Using these main factors, the choice of a machine tool is essentially interpreted as a function of the fixed cost of preparation and the variable cost of actual machining. (Figure 1).

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



In figure 1, the choice of CNC lathes is compared with engine lathes and automatic lathes. The engine lathe is a simple lathe which is manually operated. It is very cheap in comparison with other lathes but the cycle time is long which implies high variable costs, especially when labour costs are high. The fixed costs, however, are very low. The CNC lathe has a shorter cycle time which may mean that the variable costs are lower than for engine lathes, especially again when labour costs are high. The fixed costs have traditionally been higher than for engine lathes due to the need to prepare tapes or computer programmes, but the programme costs have been reduced substantially in the past. In addition, once a computer programme has been made, the fixed costs of preparing another batch of the same part is close to nil. This means that the more often the production of a particular part is repeated, the lower are the fixed unit cost of using a NCMT in relation to other types of lathes. The fixed costs may, in some instances, even be lower than for engine lathes. The automatic lathe is characterized by very short cycle time and the use of very little labour, implying low variable costs. The fixed costs are however very high.

The characteristics of the different types of lathes in our example mean that engine lathes would normally be used for batch sizes smaller than X1 in Figure 1, CNC lathes would be used for batch sizes in between X1 and X2 whereas automatic lathes would be used for batch sizes larger than X2. CNC lathes are thus more flexible than automatic lathes but normally less flexible than engine lathes. In some situations, characterized by frequent, repetitive production of an identical part, CNC lathes could, however, have lower variable and fixed costs that engine lathes.

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

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

Thus, the three key factors determining the choice of techniques in this model are:

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

Other factors do, of course, influence the choice of technique. If we disregard such factors as the perceived status derieved from introducing latest technology, one important aspect is the ability to maintain a high degree of capacity utilization. This in turn can be a function of the availability of the precise skills not only to use NCMTs (both to plan the use and to operate) but also to repair and maintain the NCMTs. The availability of these skills would tend to vary between the various technologies.

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

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

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

V. IMPLICATIONS FOR INDUSTRIAL POLICY IN DEVELOPING COUNTRIES

1. The overall impact of NCMTs on competitiveness

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

Furthermore, the structure of costs in a modern engineering company is heavily skewed away from production proper, e.g. machining. A stylized cost breakdown of a modern engineering firm would have the following structure:

- Research and development	7 per cent
- Externally sourced components and materials	40 per cent
- Machining	15 per cent
- Assembly	8 per cent
- Marketing	30 per cent

NCMTs constitute only part of the costs of machining which may account for approximately 15 per cent of total costs. Accordingly, any cost savings resulting from the introduction of NCMTs will be diluted when aggregated up to the firm level.

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

What appears more important than pure cost considerations is the fact that the use of NCMTs has become an industrial standard in some areas, due to either high precision requirements in certain products groups or the need to ascertain flexibility in meeting varying product specifications within relatively small batch production. Where this is the case, the choice also for developing country firms is either to introduce NCMTs in production or to loose out in the global competition.

2. Policies towards the domestic diffusion of NCMTs

The present level and rate of diffusion of NCMTs is substantially lower in the NICs (and by assumption in the rest of the developing countries) than in the developed countries. One partial reason for this lower rate of diffusion appears to be the branch composition of industrial production (Boon 1985:40) which provides less potential for applying NCMTs than in the industrially advanced countries. However, there are also factors suggesting that the present level and rate of diffusion is substantially below its actual potential. There is quite a lot of evidence (Edquist and Jacobsson 1988: Chs 9 and 12) pointing towards a lack of information about NCMTs and a lack of knowledge of how to use, repair and maintain them, especially in the small and medium sized firms. In addition, in many NICs, the price of NCMTs is very high in relation to both the price of labour and the price of conventional machine tools. This reduces the scope for profitable application of NCMTs.

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

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

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

Prices of NCMTs and access to a wide range of models etc., are important aspects of the decision about how (and if) a domestic supply capability should be supported. This will be discussed in the next chapter.

Although there is reason to believe that the present level of diffusion of NCMTs in the NICs is sub-optimal, the potential level of diffusion is most probably lower than in the developed countries, simply on account of different relative factor prices. The reduction in the supply capacity for conventional machine tools in the OECD countries might therefore be looked upon as problematic for future industrial users of conventional machine tools. However, the supply of such machine tools in the NICs has remained very great indeed. In the Republic of Korea and Taiwan Province of China, only 20 per cent of the production of machine tools was in the form of NCMTs in 1986. Large production capacity in conventional machine tools also exists in China, India and Brazil. Accordingly, access to conventional machine tools will probably not be a problem, not even in the long term.

3. Policies towards building up a domestic supply capability of NCMTs

As was shown already above, there is a considerable production of NCMTs in some more advanced developing countries, including China. The largest producers are Taiwan Province of China with a production of 1,917 units in 1986 (Korea Machine Tool Manufacturers' Association 1987:491); the Republic of Korea with a production of 1,124 (Korea Machine Tool Manufacturers' Association 1988:123) and Brazil with a production of 710 units in 1986 (Fleury 1988). India produced 193 units in 1987 (CECIMO 1988). Most, if not all of these countries foster their machine tool industry, often due to an alleged strategic importance of this industry. In this final chapter of the paper, the question of government policy vis-à-vis the domestic machine tool industry will be briefly addressed. Detailed policy prescriptions are not made but the discussion seeks to identify the proper role for the local machine tool industry which, in turn has a bearing on government policy.

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

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

To the extent that the development strategy aims at an integration with the world economy, the government policy for the machine tool sector should therefore aim at fostering internationally competitive firms which eventually will end up as full scale participants in one of the strategic groups outlined in Chapter III.2. At the same time, the instruments of intervention should be chosen so as not to reduce the scope for choice for the local metalworking industry as regards different variants of machine tools.

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

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

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

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

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

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

CHAPTER FIVE

Industrial Applications of Biotechnology. Implications for Industrial Policy in Developing Countries.

by Martin Fransman*

I. INTRODUCTION

It is worth at the outset summarising the major themes that are presented in this chapter. These are the following:

- Biotechnology is best thought of as a set of old and new technologies which together are having pervasive effects in and on both developed and developing countries. These effects are likely to accelerate as new biotechnologies and their applications are perfected.

- It is a mistake, however, to draw too close an analogy between biotechnology and information technology since there are significant differences between them with consequent important implications for policy-makers in developing countries. In section VI these differences are analysed.

- Although the potential of biotechnology has been considerably enhanced by the development of the so-called new biotechnologies, it is likely to take a long time before biotechnology makes a substantial impact.

- At the present time, entry barriers into biotechnology production are relatively low. Many developing countries are able, with relative ease, to acquire the necessary 'upstream' scientific biocapabilities. However, the bottleneck in most developing countries lies in the 'downstream' bioprocessing side, including weaknesses in the infrastructure necessary for effective biotechnology production. Distribution and marketing networks constitute a further constraint. It is to these areas, therefore, that policy-makers in developing countries will have to pay significant attention. This is one of the more important current differences with information technology where the entry barriers are significantly greater and where, with the important exception of software engineering, most developing countries have not managed to make a successful entry.

- In the future, however, as the product and related technology cycle advances, it is likely, at least in a significant number of application areas, that economies of scale, and other advantages of size, will increase and that barriers to entry will accordingly be more significant. Nevertheless, at the present time, for reasons that are considered in more detail in this paper, economies of scale are not yet very important in many areas of biotechnology. Evidence for this proposition comes from the large number of start-up or venture capital new biotechnology firms to be found in the United States and several European countries.

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- One of the great potentials of biotechnology lies in the ability to exploit substantial economies of scope. In other words, by acquiring a set of biocapabilities (including capabilities in the areas of recombinant DNA, cell fusion, cell culture, protein engineering, and bioprocessing) a developing country is able to apply these capabilities to a significant number of industries and products and processes within these industries. The successful reaping of economies of scope may substantially increase the returns derived from investment in these biocapabilities. This point will be illustrated later in connection with the case study on Cuba.

- However, while the biotechnology revolution will provide new opportunities for developing countries, it will at the same time produce new constraints as developed country corporations, governments, and universities advance biotechnologies in ways which at times will have negative, even if sometimes unintended, effects for developing countries.

II. THE TECHNOLOGIES, THEIR GENERATION AND DIFFUSION

In U.S. Congress, Office of Technology Assessment (1984) a more detailed account is given of the main technologies involved in biotechnology. Here a brief summary is provided setting the scene for the subsequent discussion on the generation and industrial diffusion of biotechnologies.

1. Biotechnology, old and new

Biotechnology, defined as the use of biological organisms or their constituents such as cells and DNA for the transformation of inputs into commercial outputs, is as old as human society as is evident from activities such as the fermentation of wine or soya and the brewing of beer. Bioprocessing, therefore, has a very long history. Similarly, before the advent of so-called new biotechnology, sophisticated methods had been developed for the manipulation of biological organisms in order to serve human purposes. Examples include screening and cross-breeding in order to enhance desired characteristics in biological organisms. The Green Revolution and the new plant varieties that it introduced, it is worth recalling, were made on the basis of 'old' biotechnology.

From around the mid-1970s, however, the potential of biotechnology was considerably enhanced by the introduction of a number of new powerful tools. These included the breakthroughs of Boyer and Cohen in 1973 in recombinant DNA and Milstein and Kohler in 1975 in cell fusion. These techniques enabled new combinations of genes to be created in order to produce and subsequently separate and purify proteins that were otherwise difficult or expensive to obtain, or to modify the functions of biological organisms. At the same time, the sophistication of bioprocessing was increasing greatly as a result of improvements in automation and control facilitated in part by the application of information technology. Technologies such as these, referred to generically as 'new' biotechnology, greatly increased the potential power of biotechnology.

2. Capabilities and assets required for efficient industrial application of biotechnology

In order to take economic advantage of biotechnologies, it is necessary that a firm or country develop a stock of necessary and complementary biotechnology capabilities and assets. This stock includes the following:

- Core scientific capabilities;
- Complementary capabilities 1 (at the company level);
- Complementary capabilities 2 (at the national level);
- Complementary assets.

The contents and interaction of these capabilities and assets are elaborated upon below.

a. Core scientific capabilities

Biotechnology, and new biotechnology in particular, is science-based in the sense that it draws closely on a number of scientific disciplines. For example, in setting up its International Centre for Genetic Engineering and Biotechnology, UNIDO (1986 a,b) identified a number of basic scientific capabilities that underlie the research programme to be undertaken in this Centre. These include molecular biology, chemistry, biochemical engineering, microbiology, cell biology, and informatics (information processing).

Expertise in these areas may be referred to as the core scientific capabilities which underlie biotechnology. These capabilities are drawn upon in the research and development of biotechnology-related products and processes. The source of these scientific capabilities is to be found in the universities. In building up these capabilities a developing country may draw on universities in developed countries, on universities in other developing countries, as well as on local universities. One of the difficulties that most developing countries face in developing core scientific capabilities is the weakness of local universities in some of the scientific disciplines needed in biotechnology. For example, in searching for a developing country base for its International Centre For Genetic Engineering and Biotechnology, UNIDO carried out detailed investigations in the countries that were considered potential locations for this Centre. In a report on these investigations it was concluded that unlike "say applied microbiology or applied botany which are parts of biotechnology for which the basic sciences exist in many developing countries, the basic science underlying genetic engineering is essentially absent". (UNIDO 1986a, p. 27) It was concluded that "In general, the genetic engineering and biotechnology research base, particularly in molecular genetics, at institutes and universities in each developing country visited by the Selected Committee [of UNIDO], was observed to be weak. In effect none of these countries presented substantial evidence of genetic engineering and biotechnology research being conducted at a competitive international level". (UNIDO 1986a, p. 15)

b. Complementary capabilities 1 (company level)

However, even if a developing country has solved the problems involved in building the necessary core scientific capabilities, whether through the use of local or foreign universities, this will not be sufficient to begin efficient industrial application of and appropriating economic rent from biotechnology. It will be necessary for the country also to develop other complementary capabilities which will enable it to apply the core scientific capabilities in producing new or modified products and processes. For example, it will be necessary to scale-up the production of products and processes and ensure efficient bioprocessing if the enterprise is to become commercially viable. The additional capabilities that are required within the firm to transform the fruits of the core scientific work into commercially viable output may be referred to generically as complementary capabilities 1. In general, these latter capabilities will be developed within firms rather than in the universities.

c. Complementary capabilities 2 (national level)

However, it is still insufficient for the country to possess the necessary core scientific capabilities and complementary capabilities 1. It is also necessary for the country to be able to provide a conducive "environment" surrounding the activities of the firm which will facilitate its transformation of core scientific capabilities and complementary capabilities 1 into commercially viable output. These 'environmental' conditions may be referred to as complementary capabilities 2. They refer to the overall industrial infrastructure including elements such as transportation facilities, electrical power supplies, repair facilities, availability of laboratory technicians, foreign exchange in order to import necessary inputs unavailable locally, etc.

A concrete example will make this clearer. As noted in UNIDO (1986a),

> "Most enzyme and related materials are unstable at ordinary temperatures and are generally shipped in dry ice. The standard size cartons cannot take more than a few kilograms of dry ice that normally lasts for 24-48 hours. However, the journey time to many cities in Asia and Latin America is usually more than 48 hours. Increasing the quantity of dry ice makes air transportation charges prohibitively expensive. Further, there are usually no facilities for cold storage at the receiving airports in developing countries. Therefore, goods collection by the customer has to be extremely efficient, which is not always the case." (p. 52/3)

This gives an idea of some of the problems that scientists and biotechnologists in developing countries will have to grapple with, problems that their rich country colleagues can simply assume away. The importance of complementary capabilities 2 is dramatically indicated by the fact that Japanese companies, despite massive direct foreign investment in East and South-East Asia, so far have refused to locate fermentation-based biotechnology activities in these countries. The reason is not the absence of core scientific capabilities, complementary capabilities 1, and complementary assets (to be discussed in the following section) since the Japanese companies already possesses these capabilities and assets and would bring them as part of their direct foreign investment package. Rather, it is the absence of complementary assets 2, the necessary infrastructure for the production and distribution of fermentation-based products, in these countries which has inhibited Japanese investment in these areas.

d. Complementary assets

In order to reap value from biotechnological capabilities there are a number of further conditions that must be met. These include access to distribution and financial 'assets'. It is insufficient to be able to efficiently produce biotechnology-related products and processes; these products and processes must also be distributed. Furthermore, access is often required to external sources of finance. The truth of this assertion is vividly demonstrated by the experience of the so-called new biotechnology firms, or start-up or venture capital firms in the developed countries. These firms, which often begin as spin-offs from university research, usually have excellence in the area of core scientific capabilities. Often, however, they are much weaker in the areas of complementary capabilities 1 and complementary assets. Accordingly, the large majority of new biotechnology firms have had to establish alliances of one form or another with large companies that possess the necessary 'downstream' processing capabilities (complementary capabilities 1), the distribution networks, and perhaps the financial capabilities. Alternatively, finance has been obtained from financial institutions or venture capital markets.

3. The biotechnology-creating system

The present discussion of the stock of necessary capabilities and assets has a number of extremely important implications for the policy-oriented analysis of the generation and diffusion of biotechnology in developing countries. The main point here is that the capabilities and assets frequently exist in different organisations. This point has already been made in connection with the discussion of new biotechnology firms. To take this discussion further, the necessary core scientific capabilities usually exist in universities (it was stressed earlier that biotechnology is science-based) and sometimes in relatively small new biotechnology firms. Complementary capabilities 1, however, often exist in different firms with expertise and experience in 'downstream' processing. Complementary capabilities 2, on the other hand, exist in and are influenced by a large number of other organisations, such as the transportation and the electrical power authorities etc. Complementary assets, such as distribution and financial assets, are frequently available in still other organisations such as banks, whether in the private or public sector, and enterprises specialising in distribution.

Since it is necessary to bring these necessary capabilities and assets together in order to reap economic rent from biotechnology, it is appropriate to conceive of a biotechnology-creating system of interdependent organisations and insitutions which together influence the generation, application and diffusion of biotechnology. It is the functioning of this system which should be the focus of attention for policy-makers interested in deriving economic benefits from biotechnology. This concept will be further developed and applied in the rest of this paper.

4. The industrial diffusion of biotechnology-related products and their associated processes: some examples

A further implication of the present discussion is that it is necessary to take care in defining 'diffusion'. To begin with, diffusion may be defined in the conventional way to refer to the adoption of biotechnology-related products and their associated processes. Examples which will be analysed in more detail shortly include the diffusion of immobilised enzyme technology and microbial technology in order to produce sugar substituting sweetners, the diffusion of tissue culture technologies to produce productivity-enhancing oil palm clones which lower the costs of producing vegetable oils, the diffusion of genetic engineering technology to produce bovine growth hormones which significantly increase milk productivity, and the diffusion of tissue culture techniques to produce more economically in developed countries economically useful plant varieties previously grown in developing countries. All of these examples of diffusion have had significant consequences in developing and developed countries.

However, in analysing the diffusion of biotechnology it is also valid to be concerned with broader aspects. To the extent that our concern is with the diffusion of the ability to put biotechnological knowledge to economic use, then, as the concept of a biotechnology-creating system emphasises, it is necessary to examine the diffusion of a complexly related set of capabilities and assets. This makes the analysis of diffusion more complex than is usually acknowledged. This point will be further elaborated upon in this paper.

In a number of cases biotechnology-based products have already begun to penetrate markets with important consequences for both developing and developed countries. The following serve as examples.

a. Sugar-substituting sweetners

More than 50 million people are employed in the sugar industry in developing countries. Their income from this source is currently undergoing singificant change as a result of the introduction of sugar-substituting sweetners. For example, high-fructose corn syrup (HFCS) which substitutes for sugar has been produced with the use of immobilised enzymes, a technique that has been developed in the biotechnology industry. Similarly, aspartame, a microbially produced sweetner, has also been substituted for sugar.

A substantial rise in the consumption of non-sugar sweetners relative to sugar in the main industrialised countries has resulted in a major decrease in the world price of sugar. Since 1982 this price has been below the cost of production. The decrease in the price of sugar has had a major negative impact in Third World sugar exporting countries. For example, in the Philippines revenues from sugar exports decreased from $624 million in 1980 to $246 million in 1984, and resulted in the relocation of som 500,000 field labourers. (Fransman 1986; Ruivenkamp 1986; Bijman et al. 1986; and Joffe and Greeley 1987)

b. Increasing the productivity of vegetable oil sources

The two most important sources of vegetable oils and fats are soya and oil palm. The productivity of the latter has been increased by 30 per cent (oil yield per tree) as a result of the cloning of oil palm plants. The greater profitability of oil palm production relative to rubber production in Malaysia has meant that plantations previously producing rubber have switched to oil palm. Since rubber production is more labour-intensive, the jobs of Malaysian and migrant Indonesian workers on rubber plantations are threatened. Furthermore, in the future the greater productivity of oil palms could lead to a reduction in the world market price of vegetable oil generally which would reduce the incomes of other producers of vegetable oils such as coconut farmers, many of whom are small and lack the resources to switch to oil palm production. In addition, less efficient oil palm producers, such as a number of African countries, may see their share of world markets dwindle. (Fransman 1986; Bijman 1986)

c. Producing new productivity-increasing inputs - the case of bovine growth hormones (bGH)

Milk productivity (output of milk per cow) has been rising since the 1960s as a result of traditional techniques. These include improved management and feeding practices together with conventional methods of improving the quality of herds such as selection. These techniques have in the United States resulted in "an average annual compounded increase in milk production of more than 1 per cent per cow since the 1960s". (Kalter et al. 1985, Fransman 1986)

Biotechnology, however, promises to substantially raise the rate of increase of productivity by providing a method based on genetic engineering of producing in a cost-effective way bovine growth hormone (bGH). The "daily injection of bGH beginning about the 90th day of lactation has been found to increase output by up to 40 per cent. That level corresponds to a 25 per cent increase over the entire lactation cycle... While the capacity...to stimulate milk production was recognized in the 1930s, it has been only since the advent of biotechnology that the compound (that is, the bGH) could be produced at a level and cost making it economical for farm use." (Kalter et al. 1985, p. 71)

In the study by Kalter et al. a calculation of the cost and benefit of adopting bGH was made. The cost of adoption included the price of bGH, the administration costs associated with the use of bGH, and the cost of the additional consumption of feed by cows receiving the hormone. On the other hand, the benefit to the farmer was calculated taking account of the productivity increasing effect of the bGH together with assumptions about milk prices. The increase in the farmer's rate of return as a result of adopting the bGH was then computed. The resulting information was then given to farmers in the form of a questionnaire survey in order to calculate diffusion rates. "Farmers expressed an acute awareness of the potential of increased milk output to further depress milk prices. Some...farmers questioned the desirability of bGH being made available given market conditions (that is, the low price of milk), one farmer writing, 'it should be outlawed'. Others noted that if other farmers used bGH they would, practically, have no option but to adopt as well." (ibid, p. 81).

Kalter et al. therefore concluded that bGH will be widely adopted when introduced (with the diffusion path following the usual sigmoid pattern but with a high rate of early adoption); that adoption will lead to a significant increase in milk output in the United States; that in the absence of government price support, the price of milk will fall; and that this will lead to a substantial reduction in both the number of dairy farms and dairy cattle (the precise numbers depending on the various assumptions made).

d. Producing in developed countries plants that were produced in developing countries

One area of application of biotechnology involves the production in developed countries of plants that were grown in developing countries, thus undermining the natural comparative advantage of the latter. One example is the plant shikonin which has medicinal properties and sells for about $4,500 per kilo. This plant, which takes a long time and is extremely difficult to grow, was produced mainly in China and the Republic of Korea. It is now being produced in bulk with the use of tissue culture techniques in Japan by Mitsui Petrochemical.

Other examples include the growth in developed countries by means of tissue culture of other plants with pharmaceutical uses such as pyrethin, codeine, and quinine. Since tissue culture involves the use of industrial processes, land, soil quality, and climate are no longer necessary conditions for the growth of plants. The comparative economics of industry-based and land-based production, however, is the major determinant of which production method will be chosen. Accordingly, it is high value industrially produced in developed countries.

However, genetic engineering is also being used to develop new plant varieties that are more suited to the temperate climates of the developed countries. One well-known example is the development of so-called ice-minus organisms. These organisms in their natural state populate tomatoes and produce crystals in cold weather which spoil the tomatoes. By altering the genetic structure of these organisms, however, it is possible to circumvent the production of crystals thus possibly facilitating the production of tomatoes in temperate climates. To the extent that plants hitherto grown in developing countries can viably be grown in developed countries as a result of developments such as these, and to the extent that developed countries enjoy circumstances which give them a comparative advantage vis-à-vis developing countries (such as superior distribution systems, lower costs as a result of proximity to large markets, etc.) the competitiveness of developing countries will tend to be undermined.

Furthermore, it is difficult for developing countries to derive significant benefit from one of their main sources of comparative advantage, namely their possession of varieties of germplasm which contain genes that can be used to improve the yield performance of other plants. For example, the germplasm from a wild Turkish wheat plant has been used to significantly improve the yield of a commercial variety of wheat by giving it resistance to particular diseases. Germplasm from developing countries is important because most of the world's major crops had their origin in these areas. However, despite the additional value added to commercial seeds and crops as a result of the use of germplasm from developing countries it is difficult for developing countries to ensure that they receive a share of this extra value. Ideally developing countries would be able to control the supply of germplasm and by so doing ensure that, as with any commodity in inelastic supply, they earn an economic rent from its sale. The price paid for germplasm by seed companies and other buyers would then reflect the added value that these purchasers expect to receive from the sale of the final improved varieties. In practice, however, it has been difficult for developing countries to control the supply of germplasm. One reason is that once bought a plant from a developing country can be infinitely reproduced through the use of tissue culture. This undermines the ability of developing countries to control the supply of germplasm in order to earn an economic rent.

III. CONSTRAINTS ON THE DIFFUSION OF BIOTECHNOLOGY

As the examples in the previous section make clear, biotechnology both old and new, has begun to diffuse and have effects on both developed and developing countries. However, as pointed out in section II 3., if we are concerned with the diffusion of the ability to put biotechnological knowledge to economic use, then it is necessary to examine the diffusion of the complexly related set of capabilities and assets contained in the biotechnology-creating system. This issue will be analysed in the present section, paying particular attention to the diffusion of the biotechnology-creating system in developing countries.

1. Constraints at the company level

a. Firm size

At the present time economies of scale in production tend not to create substantial barriers to the entry of firms into biotechnology. The main reason is that the scaling-up of bioprocesses does not always guarantee scale-related cost advantages as a result of the complex interactions of the biological systems existing in bioreactors. Further indirect evidence in support of the contention that economies of scale tend not at the moment to be important constraints comes from the large number of small new biotechnology firms that have emerged particularly in the United States and Europe.

Supporting this point Kenney and Buttel (1985) note that "biotechnology is more knowledge-intensive than it is capital-intensive. For example, Nelson Schneider...a vice-president of E. F. Hutton, has estimated that the critical mass of scientists needed to start a biotechnology firm would be at least 25 PhDs and approximately 10-20 million dollars would be needed in initial investment capital." (pp. 77/8) However, downstream processing, involving scale-up, is more expensive. Nevertheless, "even Eli Lilly's recombinant DNA insulin plants cost only $40 million each" and a "monoclonal antibody research endeavour would probably cost from $3.5 million dollars to $4 million over three years. If the objective was eventually to produce usable monoclonal antibody based products, the total cost would be from $20 to 40 million over three years." (p. 78) Kenney and Buttel note that "these costs, of course, may seem large, yet when compared to the outlays and subsidies committed to the building of luxury car assembly plants...the costs...are not unreasonable." (p. 78)

Accordingly, they conclude that "biotechnology still provides a sufficiently open and fluid structure such that successful entry need not be limited to a mere handful of multinational corporations." (pp. 79/80) This stands in strong contrast to the microelectronics and information technology field where few Third World countries, apart from the largest and industrially sophisticated, are able to produce products like semiconductors, computers and digital telecommunications switches, although more are able to provide simpler peripheral equipment and still more are able to use these technologies imaginatively.

However, although economies of scale in production may not be particularly important as a barrier to entry at the present time, there are a number of other advantages of size. In this connection particular mention may be made of economies of scale in marketing and distribution. Marketing and distribution were included earlier in the complementary assets that are a necessary part of the package of capabilities and assets necessary to translate biotechnological knowledge into industrial value-added. Having produced biotechnology-related products, it is necessary to sell them and in so doing it is possible that there are advantages of scale. It is for this reason that new biotechnology firms frequently enter into agreements with larger companies for the marketing and distribution of their biotechnology-based products. To the extent that economies of scale in marketing and distribution exist, this will tend to be a barrier from the point of view of the ability of an entrant to reap value from biotechnological knowledge.

b. Technological and skill capabilities

It was seen above that according to one estimate a minimum of 25 PhDs are necessary to create a new biotechnology firm. Insofar as core scientific capabilities are concerned, there are no significant barriers to the acquisition of these capabilities. In general it is relatively easy for developing countries, if their own universities do not provide the necessary training in the required disciplines, to send trainees to developed countries for further study. In this way, for example, China has managed in a very short space of time to catch up rapidly in terms of core scientific capabilities in the biotechnology area. The same is true for Cuba, as will be seen in the case study below, despite the severe political constraints that have limited its biotechnologists from studying in several Western countries, particularly the United States.

However, the constraints imposed by the necessity for complementary capabilities 1 are far more serious. The main reason is that it is more difficult to acquire the knowledge needed for the effective implementation of bioreactor and bioprocessing technologies. In the case of core scientific capabilities access to the public knowledge available in universities is relatively easy and the cost is not particularly high. However, bioreactor and bioprocessing technologies are usually developed in private companies. On the one hand these companies frequently tend for commercial reasons to keep this knowledge private; on the other hand there is often a significant degree of tacitness inherent in this knowledge with the result that it cannot readily and at reasonable cost be made explicit and conveyed to outsiders. Accordingly, the acquisition of complementary capabilities 1 may constitute an important barrier to the entry of developing country enterprises into the biotechnology area.

c. Financial requirements

Start-up biotechnology enterprises will require access to external sources of finance. This is usually particularly important in the early stages after start-up until the enterprise begins generating sufficient revenue to cover its costs. Government has a potentially important role to play in the provision of finance. The reason is that market-based transactions might face inherent difficulties which prevent the enterprise from receiving sufficient finance. These difficulties are likely to be particularly severe in developing countries where the absence or newness of venture capital companies imply the lack of experience in dealing with new technology ventures.

The difficulties result partly from what Williamson (1985) refers to as "information impactedness" and the potential under these conditions for opportunism. More specifically, the new biotechnology enterprise might have more information about the biotechnologies that it will use, and about the market prospects for the products that it will be selling than the provider of capial. In this sense information is 'impacted' or unequally distributed between the parties to the transaction. Under these conditions it is possible that the enterprise might behave opportunistically, in this case, for example, exaggerate the potential returns that might be earned from its activities. Without the necessary information, private venture capital companies might be unable to assess the likely rates of return. While in developed countries venture capital companies have built up their own expertise in order to make assessments of returns, for example by employing their own technical and marketing personnel or by using outside consultants, such possibilities may be more constrained in developing countries. Under such conditions the costs of making a market transaction, in this case concluding a contract for the supply of capital and reaching agreement for the associated terms, might be high. It is therefore possible that the market might 'fail' to allocate sufficient capital to such new biotechnology enterprises.

Under these circumstances, the government in developing countries might have an important role to play. To begin with, the government may (but not necessarily) be in a better position to reduce the degree of information impactedness by drawing on government expertise, for example, the scientific and technical expertise in government laboratories and universities. More importantly, however, since government has the power to tax to finance its operations, and since industrial development including the development of new technology enterprises is usually one of the objectives of government activities, it is likely that government will be in a better position to ensure adequate access to complementary financial assets than profit-motivated venture capital companies.

2. Constraints at the national level

a. Regulation

The aim of official regulation is the control of action. The regime of regulation is therefore an important constraint on the activities not only of biotechnology enterprises but also of biotechnology research laboratories, whether in universities or government laboratories.

The issue of regulation is probably more important in the area of biotechnology than in most other industrial areas. The reason is that biological organisms, which lie at the heart of biotechnology, interact in complex ways with the biological ecosystems of which they form part. Accordingly, care must be taken to ensure that biotechnology-related activities do not have negative external effects. This is an important consideration when, for example, there is a risk that genetically-engineered organisms might accidentally be released into the wider environment or when there is deliberate release of such organisms. As a result of such dangers a complex web of regulations has evolved in developed countries, both domestically and through the activities of international organisations such as the OECD and the European Commission. In order to avoid the impact of negative externalities nationally and internationally it is extremely important that developing countries take the issue of regulation seriously and interface effectively with the ongoing attempts to co-ordinate internationally the regulation of biotechnology. This also raises the issue of risk assessment which must be undertaken in developing countries in order to make the decision regarding the boundary line between activities that are acceptable and those which are not. For a useful introduction to the issues involved in risk assessment, see Alexander (1985).

It is worth pointing out, however, that since regulation imposes important constraints, as it is intended to do, and since sectional interests are differentially affected by such constraints, there is usually significant conflict of interest surrounding the issues for the form that regulation should take. Typically, therefore, private enterprises argue that they are being unnecessarily over-regulated and that this will have negative effects on the economic benefits generated by biotechnology enterprises including their competitiveness (although there are sometimes exceptions). A similar stance is sometimes taken by researchers seeking minimal externally-imposed constraints on their activities. At the other end of the argument are to be found environmentalists and others who have a different view of the risks involved and a different weighting of the importance of the likely effects. This issue is exceedingly complex particularly since government, which is not above the political process but rather part of it, is unable to take a neutral or impartial stand on the regulation question. For this reason it is important that a wide section of interests be involved in the development of regulations for biotechnology.

b. Intellectual property rights

Intellectual property rights also provide a constraint on the activities of biotechnology enterprises in developing countries. A particularly important issue here is the extension of patentability through measures such as the Plant Variety Protection Act 1970 in the United States, to newly-created plants and other biological organisms. (See Fransman 1986 for a more detailed discussion and analysis.)

On the one hand, the extension of patentability in this way is intended to secure intellectual property rights and in so doing increase the appropriability of returns from investment in the creation of such organisms, therefore increasing the total amount of investment in this kind of innovation. It is not yet clear, however, whether the legislation is having this desired effect. After hearings on amendments to the Plant Variety Protection Act (PVPA) in 1980 the Agriculture Committee of the US Senate requested the US Department of Agriculture to analyse the economic impacts of the PVPA. In the study that was done, Butler and Marion (1985) concluded that there "is no evidence that PVPA has triggered massive investments in R&D". (pp. 1-3) However, they also concluded that "there is little evidence of substantial public costs from PVPA. Increases in prices, market concentration and advertising, and declines in information exchange and public plant breeding - the feared costs of PVPA - have either been nil or modest in nature". Accordingly, they concluded that "at the present time" the Act "has resulted in modest private and public benefits at modest public and private costs." (pp. 1-3)

While this conclusion regarding the state of affairs in the United States is encouraging, it is by no means clear that it summarises accurately the situation confronting developing countries. Frequently lacking the range of alternatives of their counterparts in the developed countries, it is possible that developing country users of new and improved seeds and other biological organisms may have to pay the cost, which could be substantial, of creating incentives for innovation in this area. To the extent that patents over seeds and biological organisms limits competition, and this is the inherent aim of patent legislation, and to the extent that developing countries lack viable alternatives, they and their enterprises may be significantly constrained by this extension of property rights.

c. Complementary capabilities 2

As was noted earlier, the lack of complementary capabilities 2 can significantly constrain the ability of enterprises to develop biotechnology-related skills and to apply them effectively. The interdependencies of the transportation system, refrigeration facilities, and the delivery of enzymes such as the important restriction enzymes used in recombinant DNA were noted as one example. This serves to emphasise again the importance of conceiving of a socio-technical system which extends far beyond the boundaries of the individual enterprise and which has a significant bearing on the ability of the enterprise to benefit from the diffusion of biotechnology and its ability to transform biotechnology knowledge into value.

IV. THE IMPACT OF BIOTECHNOLOGY AT THE COMPANY LEVEL

Having examined the constraints on the diffusion of biotechnology to enterprises, attention will now be focussed on the impact of biotechnology on enterprises. Since biotechnology will also have significant effects on the agricultural sector, for present purposes both farms and firms will be treated as enterprises.

1. Inputs and outputs

The application of biotechnology might in some cases affect both the inputs and outputs of enterprises. Here it is worth distinguishing (a) new ways of producing existing products with the use of new inputs from (b) new ways of producing new products. Examples of the former include the production of gasoline from ethanol which in turn is produced from sugar, the production of insulin using recombinant DNA technology, the production of the heptatitis B vaccine using recombinant DNA technology, and the extraction of copper using mineral leaching bacteria. The alternative inputs are oil for gasoline, porcine pancreases for insulin, human blood (with some risk of AIDS infection) for the Hepatitis vaccine, and conventional mining techniques for copper. Examples of the latter include possible medicinal substances which are produced in minute quantity in the human body and which cannot be synthesised such as insulin, interleukin, or tissue plasmonigen activator (TPA).

In the former case the biotechnology-based inputs may be analysed as competing with the other alternative techniques and as in the case of any choice of technique it is ultimately the economics of the different options that will determine the optimal choice. It is by no means clear that the biotechnology-based option will always or usually be preferable. For example, although the oil crises of 1973/4 and 1979/80 induced a good deal of interest in biotechnology-based methods, the subsequent drop in the price of oil meant oil-based alternatives often continued to be preferable.

In the latter case it is the demand for the new product that will be the decisive factor in determining the derived demand and use of the biotechnology-based inputs. In this connection it is significant that public expectation about the future demand for biotechnology-based products, as reflected for example in the price of the shares of major biotechnology companies, often diverges significantly from realised demand. When Genentech shares were first sold on Wall Street in 1980 they set the record for the fastest price increase, rising from 35 to 89 dollars in 20 minutes. In 1988, however, Genentech was beginning to benefit from its first major biotechnology product, namely tissue plasmonigen activator (TPA), used for the dissolving of blood clots. Even then sales, although substantial and rapidly rising, were below forecast as a result of the high selling price of TPA.

2. Economies of scope

In some cases biotechnology has increased the possibilities of deriving benefits from economies of scope. Examples are the move by agrochemical companies into the area of seeds, or the move of fermentation-based companies in areas such as food and alcoholic beverages into new biotechnology-based products such as pharmaceuticals. The possibility of producing new plant varieties that are herbicide-resistant creates new commercial possibilities for herbicide-seed packages. In an attempt to reap the returns from this new potential, large agrochemical companies have been involved in acquiring or setting up seed companies, previously a vertically disintegrated activity. Similarly, the possibility of developing pest-resistant plants has significant implications for the development of pesticides thus providing another rationale for the merging of agrochemical and seed research, production, and sales activities.

These economies of scope increase the returns to investment in the underlying capabilities and assets. At the same time, industry boundaries, when looked at from the point of view of the activities of the companies involved in the industry or the technologies which underlie the industry, are being re-defined. From this point of view, for example, the food, alcoholic beverages, and pharmaceutical industries, previously largely comprising distinct companies and technologies, are merging. In Japan, for instance companies from these three industries, such as Ajinomoto from the food industry, Suntory and Kyowa Hakko from the alcoholic beverages industry, and Takeda from the pharmaceutical industry have all developed capabilities in new biotechnology and begun developing and producing pharmaceutical products.

In turn this raises the issue of appropriate industrial classification. In contrast to the conventional ISIC categorisation, to the extent that the objective is to trace the effects of emerging and merging technologies on companies and industrial structure, it may be more appropriate to re-classify industries according to the underlying technologies.

3. Research and development

As a result of the advent and widespread applicability of new biotechnology, many companies have made the strategic decision to enter this area. In general, the new entrants are of two types. The first are companies whose product markets are likely to be affected by new biotechnology. The second type are companies whose existing technologies are closely related to new biotechnology. An example of the second type are companies which already have a basis in fermentation technology and wish to extend their bioprocessing capabilities into the area of new biotechnology. Some companies fall simulatenously into both categories.

The decision to enter new biotechnology has meant that new research capabilities have had to be developed. A number of different modes of acquiring these research capabilities have been used. First, new researchers with the necessary core scientific capabilities have been recruited. Second, existing researchers have been sent for training. Third, some of the larger companies have resorted to take-over or merger in order to acquire the necessary capabilities in the company. Fourth, some companies have entered into joint venture agreements, with complementary companies, competing companies, universities, or other research institutions.

V. AN ILLUSTRATIVE CASE STUDY: CUBA'S ENTRY INTO NEW BIOTECHNOLOGY

The Cuban case illustrates dramatically what can be achieved when a firm commitment is made to the development of biotechnology capabilities and their application to a wide range of areas in accordance with the country's economic priorities. In this section the Cuban case is examined in greater detail, paying particular attention to the way in which this country entered the field of new biotechnology, the areas in which new biotechnology has been applied, and the institutional changes that have been brought about in order to facilitate the development of biotechnology. Finally, based on this case study, conclusions will be drawn regarding the lessons for other developing countries.

1. The general approach

In terms of Cuba's scientific and technological development the crucial watershed occurred after the Cuban Revolution in 1959. Until this time Cuba depended primarily on its agricultural activities, which excluded sophisticated processing and research and development, and on tourism. In this way the foreign exchange was earned which financed imports of manufactured products, largely from the United States. In the period following the Cuban Revolution a new set of priorities was established. Most important from the point of view of the development of the biological sciences in general, and biotechnology in particular, was the emphasis that was given to the role of science and to the development of the national health service. Frequent reference is made by Cuban scientists to the conviction prevailing at that time that the future development of Cuba was inextricably bound up with the future development of science in the country. It was this conviction that inspired a rapid growth in the school and higher education system. At the same time, an important result of the revolution was the expansion and extended delivery of medical services to all sections of the population. This meant that within a short period of time Cuba was able to develop a relatively sophisticated medical system which included training and research facilities in universities and other national institutions. It was this medical system which was later responsible for Cuba's rapid and successful entry into new biotechnology.

However, new areas of science and research do not emerge automatically; their emergence depends on new groups of scientists and researchers, committed to the new fields of study and devoted to the institutional changes that are required to realise the new scientific research. From this point of view it is significant to observe that the new institutions which evolved in Cuba to develop the biological sciences and biotechnology emerged in a pluralistic rather than a linear way.

At the apex of Cuba's scientific planning establishment is the Cuban Academy of Sciences which was originally established in 1861 but which was substantially restructured after the revolution. The Academy contains the Superior Scientific Council which consists of about 77 distinguished scientists elected from the Academy's various institutes, from the Ministry of Higher Education, and from industry. The Academy also contains a number of other smaller but influential advisory groups. However, it is significant that the Academy does not totally dominate or control the scientific establishment. For example, only about 10 per cent of the total number of Cuban scientists and engineers work in Academy institutes.

The Ministry of Higher Education, with some degree of autonomy from the Academy, has also played an important role in the establishment of scientific institutions. From the point of view of the development of Cuban biotechnology, an important example is the establishment of the National Centre for Scientific Research (CENIC) which was the major biomedical and chemical research centre and was set up in 1965 in order to stimulate research in new areas. CENIC has a staff of approximately 1,000 and is divided into four main divisions: biomedicine, chemistry, bioengineering, and electronics. CENIC has played a significant role in research and in training scientists who subsequently have become involved in other spin-off institutes.

An important example is the Centre for Biological Research (CIB) which was established in January 1982. The establishment of CIB is of particular interest as a result of its innovative and unbureaucratic origins. In 1981 a 'Biological Front' was established essentially outside the existing bureaucratic framework. The Front consists of scientists and policy makers with an interest in extending and developing biological research in various directions. It served to co-ordinate and articulate the interests of those in the different ministries and institutes who wished to strengthen Cuban involvement in biotechnology. While the leaders of the existing scientific establishment were closely involved with the activities of the Biological Front, the Front was set up as a high-level policy-making body with relative autonomy from the Academy and the various Ministries involved in the biological sciences and their areas of application. From this position the Front supervised the establishment of CIB and later the Centre for Genetic Engineering and Biotechnology, CIGB. By helping to give birth to CIB and CIGB the Biological Front served to increase pluralism in the Cuban scientific system. While biotechnology could be developed in existing institutions, such as those under the control of the Academy of Sciences and in CENIC, this new set of technologies could also be advanced through new institutions such as CIB and CIGB.

CIB began with a staff of six researchers in a small laboratory. Its major initial mission was the production of interferon for use as an anti-viral agent. In part the interest in interferon resulted from the outbreak in late 1980 of dengue hemorrhagic fever which affected approximately 300,000 people and resulted in 158 deaths. However, in addition to this pragmatic goal, CIB also aimed to use interferon as a 'model' for the development of the wider range of capabilities and assets analysed in chapter II.2 above. In other words, interferon would be used as a springboard for the development of a Biotechnology-Creating System with expertise in the areas of genetic engineering and bioprocessing. CIB grew rapidly and by 1986 was divided into four laboratories: genetic engineering, immunology, chemistry, and fermentation. In addition to the production of interferon, CIB produces its own restriction enzymes and its research also involves the synthesis of oligunucleotides, the cloning and expression of a number of other genes, and the production of monoclonal antibodies for diagnostic purposes. Although recombinant DNA research was also done in a number of other institutes, notably CENIC and to a lesser extent the Cuban Institute for Research on Sugarcane Derivatives (ICIDCA) which was established in 1963, CIB became in the early 1980s the major location in Cuba for the development of capabilities in new biotechnology.

When CIB opened in January 1982 it began to produce human leukocyte alpha interferon using a method (which did not involve genetic engineering) developed by Kari Cantell of the Central Public Health Laboratory in Helsinki. Cantell gave assistance by transferring his method to CIB and was surprised at the speed with which the Cubans mastered the method. Having mastered this conventional method for producing interferon, CIB embarked on recombinant DNA-based techniques for producing various kinds of interferon. In this latter task a central role was played by scientists such as Dr. Luis Herrera who was Vice-Director of CIB. Herrera's background is particularly interesting because it illustrates personally the way in which Cuba was able to enter the field of new biotechnology. In 1969 Herrera studied molecular genetics (working on yeast) at Orsy University in Paris. The following year he took up a post as researcher at CENIC where he started a laboratory dealing with the genetics of yeast. Yeast was of interest in Cuba because it was used in order to convert sugarcane derivatives into single cell proteins which were used as animal feed, thus substituting for imported soya feeds, the Cuban climate not being suitable for the growing of soya. Research on yeast was partly aimed at improving yeast strains in order to increase the nutritional value of the single cell proteins by eliminating some of the undesirable nucleic acids. Under the auspices of ICIDCA there were in total 10 plants each producing 12,000 tons per annum of single cell protein for animal consumption. In developing their work researchers in this laboratory became interested in new biotechnology. In 1979 Herrera returned to France to study molecular biology and genetic engineering. With the formation of the Biological Front and the establishment of CIB in 1982 he joined this institute as its Vice-Director. In 1983 he once again went to France where he spent time at the Pasteur Institute. Representing a new breed of young, post-revolution scientists who were quickly able to master the latest international research techniques, he has since established an international reputation for his research in new biotechnology. Although in the case of Dr. Herrera entry into new biotechnology involved access to European institutes, Cuban biotechnology and CIB in particular have also benefitted from Soviet science. A notable example is the group of chemists working in CIB and mostly trained in the USSR. With a strong background in organic chemistry some of these scientists moved on to the synthesis on oligonucleotides and the synthesis of DNA. Other groups in CIB are involved in immunology, including immunochemistry and protein purification, and fermentation.

There is widespread agreement that the Cuban mastery of new biotechnology has been impressive. One example is the conclusion arrived at by a team of UNIDO experts appointed to find a Third World location for the new International Centre for Genetic Engineering and Biotechnology. This team visited the major Third World countries involved in biotechnology and concluded that the Cuban biotechnology programme was one of the best they had seen. Another example are the assessments made by distinguished foreign visitors to Cuba. While acknowledging that the Cubans are not attempting to do world frontier basic research, many of these visitors have been impressed with the level of achievement of Cuban biotechnologists.

2. Interferon as a 'Model'

Some further comments are in order on the use by the CIB of interferon as a 'model' for the development of new biotechnology capabilities.

The first point to be made is that the development of core scientific capabilities in the area of new biotechnology in CIB drew on the already well-developed science base that existed in Cuba by the time the CIB was set up in 1982. Mention was made in the last section, for example, of the earlier research done in CENIC on the molecular genetics of yeast. In entering new biotechnology, therefore, Cuba was not starting ab initio. In this way, Cuban entry into new biotechnology was facilitated by a pre-existing stock of substantial scientific capabilities. Clearly, many developing countries are not in as fortunate a position.

The second point is that interferon was an appropriate choice for Cuba largely as a result of the country's well-developed health sector. This meant that the development of interferon with the use of genetic engineering techniques was not simply a 'pure' research activity, but was an example of scientific work being closely linked to the production of useful output, namely the delivery of medical services, a high priority in post-revolutionary Cuba. This link established a unity between 'science push' and 'demand pull' determinants of technical change, which in turn ensured that this part of the science system was not 'alienated' from the needs of the rest of the socioeconomy. Interestingly, interferon has also been used as a 'model' by many Japanese companies entering the field of new biotechnology. In their case, however, the need determined from the corporation's point of view was for a way of acquiring new biotechnology capabilities at the same time as producing a commercialisable product. Interferon, it was believed, provided an example of one of the first new biotechnology-based commercial products. For other developing countries, however, a more appropriate 'road' for the development of new biotechnology may exist, depending on the circumstances and priorities of the country. For Brazil, for example, the ethanol from sugar project may have provided an appropriate road. In other Latin American countries the development of mineral-leaching bacteria for the purposes of mineral extraction may provide an appropriate way of entering new biotechnology.

Thirdly, the possibility of using interferon as a 'model' for the development of other applications and products illustrates the pervasiveness of new biotechnology. This point is further supported in the Cuban case by the history of the Centre for Genetic Engineering and Biotechnology (CIGB).

3. Realising economics of scope: The CIGB and the pervasive applicability of new biotechnology

Encouraged by the success of CIB in developing new biotechnology capabilities and impressed with the potential of this set of technologies, the Biological Front recommended the establishment of a new and larger institute which would carry on and extend the work of CIB. Accordingly, on June 1, 1986 the Centre for Genetic Engineering and Biotechnology (CIGB) was established on a new site near CIB.

CIGB was structured in terms of the following five groups, each dealing with a specific problem area:

- Proteins and hormones. The aim of this group is the production of proteins using recombinant DNA techniques for applications in the areas of human medicine and veterinary science. This group continues the work done in CIB on the chemical synthesis of oligonucleotides and DNA.

- Vaccines and medical diagnosis. The aim of this group is to develop vaccines against diseases prevalent in Cuba and other tropical and subtropical areas through the cloning of the surface proteins of viruses, parasites, or bacteria. The group also works on developing monoclonal and polyclonal antibodies and DNA probes for the purpose of detecting and diagnosing various illnesses.

- Energy and biomass. The research of this group involves the transformation of various kinds of biomass via the use of chemical methods and enzymes. For example, research is done on yeasts and fungi which transform the sugar by-products molasses and bagasse into proteins for animal consumption. A new strain of the yeast candida has been developed which increases the production of an amino acid important for both human and animal nutrition. In this way CIGB will extend research in this area done in ICIDCA and CENIC.

- Plantbreeding and engineering. This group does research on improved plant varieties using genetic engineering and other biotechnologies such as cell culture. Nitrogen fixation is one area singled out for study.

- The genetics of mammalian eukaryotic cells. This group uses the cells of higher organisms for the cloning of genes and the production of proteins.

Thus by using interferon as a 'model' first CIB and then CIGB have been able to develop core scientific capabilities in the area of new biotechnology and apply them to a wide range of areas consistent with Cuban development priorities. However, the research of CIGB has also been defined to include an emphasis on complementary capabilities 1, namely downstream bioprocessing. This has been done by making provision for a pilot bioprocessing plant in CIGB.

4. The importance of downstream bioprocessing

As noted earlier in this paper, the development of an effective biotechnology-creating system involves more than the mastery of the core scientific capabilities. One feature of such a system is the possession of the necessary downstream bioprocessing capabilities. In order to develop the latter kinds of capabilities CIGB has established a pilot plant. Two groups work with this plant, the one specialising in the fermentation process and doing research on the optimisation of productivity and the other working on questions of purification. Both of these groups are involved with the difficulties that are confronted in scaling-up the bioprocessing with the use of larger bioreactors. A major problem confronted by both groups is that there is little experience in Cuba regarding bioprocessing and scale-up. Furthermore, unlike in the case of many of the core scientific capabilities where research is done in universities and where the results are usually made public, a good deal of research on bioprocessing is done in private companies with the findings kept commercially secret. Bioprocessing, requiring sophisticated engineering skills and specialised inputs, frequently constitutes more of a constraint in developing countries than the mastery of the core scientific capabilities. The same point was made to the present author by senior officials involved in the planning of biotechnology in the People's Republic of China during a visit in 1987. In the Chinese case, in strong contrast to the Cuban example, the core scientific capabilities were rapidly acquired largely as a result of scientific interchanges with the United States. However, major constraints exist in China on the downstream bioprocessing side which depends on the capabilities of Chinese industrial and engineering enterprises.

VI. INTERNATIONAL DIMENSIONS

1. Is biotechnology as pervasive in its effects as information and communication technology?

A number of points may be made in answering this complex and controversial question.

There is no doubt that biotechnology, as an interrelated set of technologies, is having, and will continue to have, pervasive effects on a large number of industrial sectors. It is perhaps best to analyse biotechnology as a set of process technologies with application to a large number of product areas. The process technologies include classical methods of selection, recombinant DNA techniques, cell fusion, tissue culture, protein engineering, and bioprocessing. Combinations of these technologies may be applied to the research and development of a large number of products. Examples referred to in the present paper include pharmaceuticals (such as insulin, interferon, and vaccines), industrial chemicals (such as enzymes and other proteins, ethanol etc.) and new plant varieties.

One implication of the pervasive effects of biotechnology is that important economies of scope may be reaped. In other words, investment in the capabilities and assets that are necessary for the creation of an effective biotechnology-creating system may be rewarded with high rates of return as a result of the widespread applicability of biotechnology. This possibility emerged clearly from the Cuban case study where the capabilities and assets built up in CIB and later CIGB were being applied across a wide range of areas, all of which contributed directly to Cuban development goals and priorities.

For the reason mentioned in the last paragraph, there would appear to be ample justification for establishing biotechnology programmes in developing countries. Care, however, will have to be paid to the particular circumstances of each country in order to understand the limitations and constraints confronting any such programme, a point that is examined in more detail in section VII.

Nothwithstanding this general pervasiveness of biotechnology, there are a number of important differences between biotechnology (BT) and information and communication technology (ICT). For example, the link between process technology, product technology, and product characteristics is much closer in the case of ICT than in the case of BT. Furthermore, there are much stronger integrative tendencies in the case of ICT. For instance, the convergence of computing and communication technologies as a result of the digital 'common currency' has meant that ICT products tend relatively easily to become part of broader integrated systems. An example is the integration of personal computers, minicomputers, mainframes, robots, computer controlled machinery, and local and even national communication systems into a broader technological system. The same integrative tendencies are not apparent in the case of BT.

At the same time there is an important process of convergence between BT and ICT. On the one hand CIT is having a significant impact on the development of biotechnology process and product technologies. Examples are the use of microprocessors and computers in automated controls for bioreactors and DNA synthesisers, and in other areas such as sequencing. On the other hand, BT is beginning to have an effect on ICT although this effect is not yet as great as the other way round. For instance, one area of application for protein engineering is in the field of biosensors and biochips where integrated circuit technology is fused with protein engineering technology.

It is worth stressing that the entry barriers into BT are at the present time signficantly lower than those into ICT, a point that has been stressed earlier in the present paper. Very few developing countries will be able to become significant producers of ICT products such as semiconductors, smaller computers, and communication-related products such as optical fibre or PBXs, although these kinds of products are being produced by countries such as the Republic of Korea, India and Brazil. Most developing countries will be users rather than producers of ICTs. However, many more developing countries will be able to make a successful entry into the field of biotechnology. The qualifications surrounding the possibility for successful entry are examined in more detail in chapter VII below. From a policy point of view, therefore, little significance attaches to whether the pervasiveness of ICT is greater than that of BT. The policy question ultimately boils down to an analysis of the social returns that may be derived from investing in generating a biotechnology-creating system, given the circumstances and constraints of the country concerned.

2. Industrial applications of biotechnology in a global perspective: Effects on production, trade and investment

Unlike in the field of microelectronics and information technology where tangible impacts on international trade and investment patterns have already occurred and been extensively studied, the situation in biotechnologies is less clear-cut. The various technologies being very much in their incipient stages it is far from obvious what their implications for the international division of labour are going to be. Two major points can be made, however. The first is that biotechnology is already having an important impact on global production, trade and investment in some specific areas. One example, that was discussed earlier in this report is the production of sugar-substituting sweetners. These sweetners have had an important impact on the price of sugar and therefore have had significant implications for those developing countries involved in investment, production, and international trade in sugar. Similarly, biotechnology is influencing the productivity of oil palm and other developing country agricultural exports.

However, the second point to be made is that up to the present time discussions of the impact of biotechnology on economic variables such as output, incomes, production, trade, and investment have remained anecdotal and partial, relying on the documentation of particular instances of the effects of biotechnology. Attempts have sometimes then been made to 'add up' these effects in order to arrive at more general conclusions regarding the impact of biotechnology. These attempts are inherently unsatisfactory because they ignore the interdependencies that exist in the global socioeconomic systems in which biotechnology evolves and has its effects.

In order to illustrate this important point the case of oil palm is taken which was discussed earlier in this paper. As a result of advances made in the cloning of oil palm plants, the productivity of oil palm trees (oil yield per tree) has increased by some 30 per cent. In the shorter run, with the world price of oil palm, a major source of vegetable oil, holding up, this has increased the profitability of oil palm production and has therefore tended to increase investment in such production. This has happened in the case of Malaysia, for example, where many plantations which have produced rubber have switched investment to oil palm thereby decreasing their investment in rubber trees. In turn, this has had important effects on employment and incomes since rubber production is more labour-intensive than oil palm production with the rubber tapped from the tree being collected by hand. The result is that the jobs and incomes of Malaysian and migrant Indonesian rubber workers have been threatened.

However, this account of the effect of biotechnology (in this case the cloning of oil palm plants) on investment, production, trade, employment, and incomes has not dealt sufficiently with many of the further interdependencies involved. For example, there are 'Keynesian effects' that should be considered. As a result of the increase in profitability of oil palm production, it is possible that total investment increases. This in turn results in a multiplied increase in incomes as those whose incomes rise as a result of the increase in investment spend these incomes. This may mean that expenditure on consumption goods increases which consequently leads to an increase in the production of consumption goods and therefore to increased employment in the consumption goods industries. In this way the employment of former rubber workers may be increased. These Keynesian effects deal with the consequences of changes in investment on changes in expenditure and the 'knock-on' effects on other economic variables. But account should also be taken of 'Leontief effects', namely the intersectoral input-output effects. For example, as the output of oil palm increases, so the demand for inputs into the oil palm industry increases, such as the demand for agricultural implements, fertilizers, etc. In turn, as the demand for these items increases, so the demand for the inputs which they require will increase. This will have implications for production, investment, employment, and incomes in these industries. This analysis of 'Keynesian' and 'Leontief' effects still ignores the 'general equilibrium effects' on prices and the consequence of changing relative prices. For example, as the output of oil palm increases as a result of the biotechnology innovation, there may be a fall in the price of oil palm depending on the demand and supply curves for this commodity. In turn, a reduction in the price of oil palm might reduce the profitability of oil palm production with further consequences for the inter-sectoral distribution of investment, etc.

However, the 'general equilibrium' price effects discussed so far are not nearly general enough. In a truly general approach account must also be taken of other biotechnology-induced effects occurring elsewhere in the global socioeconomic system. For example, soya together with oil palm are the two most important sources of vegetable oils and fats. The productivity of soya production and the conditions under which soya beans can be produced are also being influenced by biotechnology with important implications for the substitutability of soya and oil palm in vegetable oil and fat production. Account must therefore also be taken of the soya market in a general equilibrium approach.

Although broadening the analysis, the approaches considered above still suffer from an important limitation. They treat technical change as an exogenously determined phenomenon that then has effects on the economic system. However, a more satisfactory general approach that goes beyond a concern with the interdependence of markets based on price effects would take account of the determinants which share the evolution of biotechnologies themselves. In other words, rather than taking biotechnologies and their implications as given and proceeding to examine the effects, it is important to understand how these technologies themselves are shaped. From this point of view, technical change is an inherent part of the socioeconomic system and not something external to it and 'given'. An understanding of the interrelationship between the socioeconomic system and the process of biotechnological change would enable us to appreciate more clearly the priorities and resources that are influencing the evolution of biotechnologies and their applications.

Furthermore, a general approach should also take account of the environmental effects and feedbacks. For example, while the development of high-productivity plants through the use of tissue culture may raise productivity in the short run, it also may increase the vulnerability of the plants to particular diseases and pests. The greater degree of genetic diversity in a 'conventional' set of plants might serve naturally to limit such vulnerability. Environmental effects such as these should also be included in any attempt to model the general effects of biotechnology.

To conclude, the main aim of the present discussion is to draw attention to the inherent complexity in any attempt to rigorously examine the effects of biotechnology. This difficulty follows from the complex nature of the system, both social and natural, in which biotechnology develops and has effects. However, despite the complexity it is essential that rigorous attempts be made to understand the system as a whole since such an understancing is needed to inform policy-making in important areas such as international investment, production, trade, and structural adjustment.

VII. POLICY ISSUES

1. The importance of country differences

In view of the enormous diversity both between developing countries at different income and industrialization levels (that is, high-, middle- and low-income countries) and between the countries in each category, it is necessary to be cautious in attempting to derive policy implications from an analysis of biotechnology and its potential effects. In order to structure the present discussion, reference will be made to the stock of four necessary capabilities and assets analysed in section II.2. above.

The first point to make is that one crucial determinant of a developing country's ability to enter the field of biotechnology and benefit from its potential applications is the strength of its existing science system, particularly in those disciplinary areas that are most closely related to biotechnology. The Cuban case study clearly illustrated the importance of the strength of the science system in entering and applying biotechnology. In many other developing countries, for any number of reasons, the science system does not have the same strength. This does not, however, mean that the constraint on entering biotechnology is absolute. The Japanese case, for example, illustrates very well how foreign university systems can be used as a viable mode of entry and in this respect the Chinese case is similar. An important country difference, therefore, lies in the existing strength of their respective science systems.

However, although the science system does constitute a constraint on the ability to enter and apply biotechnology, the development of the necessary core scientific capabilities, as argued earlier, does not usually pose the major difficulties. More important is the strengh of complementary capabilities 1 and 2, namely the downstrean processing capabilities within the enterprises on the one hand, and the 'environmental' capabilities on the other such as effective power generating and transportation systems. Underdevelopment is practically synonymous with weaknesses in areas such as these which, as has been shown, are crucial to the ability of the biotechnology-creating systems to operate effectively. While it is a relatively easy matter to train a bright group of science graduates in the areas relating to biotechnology, both within the national educational system and abroad, it is far more difficult to ensure the necessary quality in the areas of complementary capabilities 1 and 2. A crucial country difference, therefore, in terms of the ability of different countries to enter and apply biotechnology relates to the strength of their complementary capabilities.

The discussion so far has dealt primarily with the 'supply side' of the question. Equally important is the 'demand side'. A number of points are important here. The first is that the size of the domestic market will have obvious implications for the extent and kind of production activities that can viably be undertaken. The Cuban example illustrates that a relatively small domestic market does not need to be a significant constraint on biotechnology activities. Far larger countries, with much bigger markets, will have additional options resulting from the ability to establish biotechnology-related production on a larger scale. There are important impliations here too for the question of an appropriate foreign trade regime. For example, under what circumstances will it be advisable for a developing country to protect the domestic market through policies which restrict foreign trade in order to create an incentive for enterprises to enter the biotechnology area and produce biotechnology-related products? Here the issues are similar to the well-rehearsed arguments relating to the advantages and disadvantages of domestic-market oriented and export-oriented production. (See, for example, Fransman 1986 for a more detailed discussion.)

The question of the 'demand side' also raises the issue of complementary assets, also considered earlier. Here it should be recalled that one of the conditions necessary for transforming biotechnology knowledge into commercial output is the possession of distribution and marketing 'assets'. Once again countries will differ in terms of the quality of their distribution and marketing capabilities.

2. Modes of technology acquisition

A further set of policy questions relates to the most efficient modes of acquiring biotechnology capabilities. For example, what weight should be given to indigenous development of these capabilities, and how much emphasis should be given to other alternatives such as licensing and other technology agreements and direct foreign investment? The latter also raises the question of the advantages and disadvantages of involvement by transnational corporations. Since, however, these policy questions are essentially the same for biotechnology as they are for the case of other technologies, they will not be pursued further here and the reader is referred to the wider literature in this area. (For a survey of much of this literature and for further references, see Fransman 1986.)

3. Reassessing industrial strategies in developing countries in the light of advances in biotechnology

The advent of biotechnology requires that in a number of areas industrial strategies should be reassessed. The main reason is that since biotechnology is applicable over a wide range of industrial and product areas, a redrawing of industrial boundaries and interdependencies is implied. For example, in Japan, companies from a wide range of industries have entered the field of new biotechnology. These include the chemical, pharmaceutical, food, and alcoholic beverages sectors. A large number of these companies have begun to develop and market biotechnology-related pharmaceutical products since this is the first area in which biotechnology is beginning to have a significant commercial impact. This has important implications for issues such as industrial structure, competition and competition policy, and technology policy.

In developing countries a similar redefining of industrial boundaries and interdependencies will require the development of new industrial strategies. For example, in the area of agro-industry account will have to be taken in formulating industrial strategy not only of the agricultural enterprises that produce the inputs for industrial processing, but also of the biotechnology-related enterprises and research institutes that may impact on agro-industrial activities at various points in the food and related industrial chain.

4. Co-operation among developing countries

The industrial application of biotechnologies represents a challenge and offers opportunities for many developing countries across a wide range of industrial branches. While the responses need to be country-specific there are a number of general issues and some areas lending themselves to joint action. Below some of the issues that might form the basis for co-operation among developing countries are briefly analyzed.

Co-operation in the development of products particularly suited to developing country conditions. One example is the development of vaccines and diagnostics for ailments that are particularly prevalent in developing countries. These kinds of products, sometimes of great importance to developing countries, tend to be neglected by developed countries and their corporations where significant markets are perceived not to exist.

Co-operation in training for biotechnology. Since biotechnology is science-based, it is necessary for training to be provided in the associated scientific disciplines. Expertise in these disciplines takes time and resources to develop. In some cases it may be that regional international co-operation will allow for a process of specialisation among developing countries in particular disciplines with an exchange of students providing the means of acquiring the necessary core scientific capabilities.

Co-operation in the acquisition of complementary capabilities and complementary assets. It has been stressed in this paper that the acquisition of these capabilities and assets usually constitutes the most significant constraint confronting the attempt of developing countries to develop efficient biotechnology-creating systems. As in other technology areas, developing countries will be required to make incremental innovations, modifying and adapting imported technologies and introducing new innovations in order to increase the efficiency of the biotechnology-creating system. These incremental innovations will have a significant effect on the system's overall efficiency. Accordingly, one area for potentially fruitful developing country co-operation will involve sharing information on the ways in which particular problems have been dealt with and perhaps establishing working groups to devise solutions to others withing the context of developing country conditions. (For a more general analysis of the importance of incremental innovation in developing countries, see Fransman 1986.)

International co-operation regarding the regulation of biotechnology. As mentioned earlier, the need to regulate biotechnology is particularly important in view of the potential ecological risks. On the other hand, co-operation with other international efforts to establish and enforce codes of practice is essential. On the other hand, there are developing country-specific issues involved here which could profitably form the basis of inter-developing country co-operation. For example, in view of an often weaker supporting infrastructure for biotechnology in developing countries, a new dimension is sometimes added to questions of safety. Discussion is also needed on ways of enforcing codes of practice among developing country scientists involved in biotechnology. Developed countries have established committees which supervise events such as the deliberate release of genetically-engineered organisms into the environment. In view of these developing country-specific conditions and issues, there are strong grounds for developing country co-operation in this area.

Co-operation over the question of intellectual property rights. Developing countries are being affected by legislation in the developed countries which allows for the patenting of new organisms, including new plant varieties. As was seen earlier, for example, developing countries are often the source of the germplasm which is used as a source of genetic material to produce new plant varieties. While germplasm itself cannot be patented, it makes an important contribution to the rent that is ultimately reaped by the patenters of new plant varieties. Furthermore, the existence of patents means that developing countries will have to pay higher prices for improved seeds than they would have done in the absence of patents. In addition, the extension of property rights in this area has produced a tendency for the privatisation of knowledge that previously was in the international public domain. For example, whereas previously universities and public reasearch institutes tended to rapidly publish and disseminate the results of their research, there are new restrictions on the flow of this knowledge as a result of the possibility of applying for intellectual property rights. To the extent that this has happened, developing countries have been deprived of an important source of information which is a significant input into biotechnology research. In areas such as this there may well be developing country interests at stake which could profitably be articulated and represented through developing country co-operation.

VIII. CONCLUSION

As has been shown, biotechnology, virtually as old as the human race, has had its potential power significantly enhanced by the advent to new biotechnology which has provided substantially increased control over the fundamentals of life. New biotechnology indisputably constitutes a fundamental revolution. No longer are human beings pawns in the evolutionary game; they have acquired the ability to control the game itself, or at least aspects of it. The fruits of this revolution are gradually feeding into new technologies which in turn are beginning to impact on a large number of commercial areas. However, as with other technological revolutions, the effects of the biotechnological revolution are both gradual and uneven. The incorrectness of both the high hopes and the frustrations regarding the potential impact of biotechnology has been dramatically illustrated by the ups and downs of the shares of the major biotechnology-based companies on developed country stock exchanges. In reality the biorevolution will be slow in coming and its introduction will be patchy. But there can be little doubt that a revolution is in the making and that developing countries can ill-afford to ignore it. This chapter has attempted to outline the main contours of the emerging biotechnology revolution, paying particular attention to the implications for developing countries and the ways in which they might begin to prepare themselves to make use of the new potential which biotechnology has provided. If it has increased awareness of both the hopes as well as the limitations provided by biotechnology, it will have served its purpose.

CHAPTER SIX

New and Advanced Materials. Implications for Industrial Policy in Developing Countries

by Lakis Kaounides*

I. INTRODUCTION AND SUMMARY

The secular expansion of industrialized market economies in the post-war period showed signs of coming to an end as early as the late 1960s. Following the exhaustion of incremental innovations and productivity gains based on inflexible mass-production techniques employing dedicated machinery and broadly aimed at mass markets, the last 15 years have witnessed ongoing rationalization and modernization of production processes. Existing outdated and obsolescent fixed capital has been truncated and industries, including mining and primary metals, have been engaged in prolonged, painful and deep asset restructuring. The retardation of economic growth accompanied by a fragmentation and volatility of market demand has necessitated the reorganization and transformation of the production process across many industries which have begun to employ more flexible microelectronic based automation technologies and Just-in-Time organizational change in order to survive and maintain profitability and a competitive edge in the new market circumstances.

Much attention has already been focused on the impact of information technologies on telecommunications, the development and diffusion of Flexible Manufacturing Systems (FMS) in the engineering batch- and mass-production industries, the trend towards systemic Computer Integrated Manufacturing (CIM), the increasing scientific and knowledge content of production and the primary importance of organizational change if maximum gain is to be derived from new technology. There is a need for an understanding of the nature and direction of such changes, how they translate into specific sectors, national branches and firms and what their implications are for industrial strategies of developing economies.

Furthermore, such an enquiry needs to be closely integrated to an understanding of the revolutionary implications of the arrival of advanced materials on the world industrial landscape. Increasing, if belated, attention is now being accorded to radical new scientific and technological developments in the 1980s, which have heralded the arrival of new highly engineered advanced materials. These comprise a number of distinct but connected clusters of advanced materials in the form of engineered plastics, advanced ceramics, composites, advanced metallic alloys and superconductors. In fact, the scientific and experimental breakthrough in superconductors in the last two years has generated unprecedented international excitement in national scientific communities, industry and governments alike. The successful commercialization of the new superconductors could imply, in itself, a new technological revolution with wide repercussions on all existing basic industrial technologies, microelectronics and computers, and significantly, energy generation and distribution. Hence, the current intense international race to commercial application and the observed large scale government support in this area in developed market economies.

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The characteristics and importance of the revolution in materials science and the advent of advanced materials are briefly summarized below:

- In the last 8-10 years materials scientists have been able to use highly advanced mathematical modelling, computer science, experimental techniques and advanced instrumentation to examine and develop a deep understanding of the structure and properties of matter. The result has been that materials scientists can now intervene at the molecular and atomic level and rearrange the microstructure of materials in order to attain the required properties. This is what lies at the core of the revolution in materials in the late 1980s. It reverses the previous sequence whereby materials availability and properties constrained the development of end products. One can now start with the required properties and performance characteristics in use and develop and process the material appropriate for the particular application.

- Such scientific and engineering design advances imply a vastly accelerated rate in materials and product invention and innovation, rapid obsolescence of existing products and processes, and reduced life-cycles for new materials. No one material will dominate the market place for long periods, as has been the experience until now. Further, marketing strategies for advanced materials will therefore be different to existing ones based, for example, on the product-cycle idea.

- Materials science is now an interdisciplinary science requiring inputs from solid state physics, chemistry, metallurgy, ceramics, composites, interface science, mathematics, computer science and engineering. In fact, rigid separation of the different disciplines is now inappropriate and barriers between them are fast eroding. Materials and product design now require large and simultaneous teamwork across several fields. The scientific content of production has vastly increased. Scientific knowledge is growing very fast straining the ability of materials design to incorporate it.

- Materials research and development now require that materials scientists become closely involved in the processing and fabrication stages of production. Hence the separation of materials science and engineering has been lifted. Materials science and engineering have now merged. The controlled processing path the material follows will affect microstructure and thereby properties and performance in use. Materials science cannot be separated from design and manufacture.

- Increasingly the design and processing of a material must be integrated with the design and manufacturing process planning of the end user. Materials design, component and/or product design engineering and manufacture are merging and require close integration and iterative interaction between materials producers and users. The application of CAD/CAM systems and the trend towards computer integrated manufacturing further facilitate and reinforce the integration of the design and manufacturing process across materials producing and using industries.

- New advanced materials require the redesign of the end product and its manufacturing process, involving expensive retooling, in order to take full advantage of the material's properties, directional performance under stress, and shapes. Advanced materials are more expensive than conventional materials, hence their cost-effectiveness requires a "total systems" approach to cost where long-term gains are included in the calculation. Currently most advanced materials systems are employed in, and have been developed for, high technology sectors where performance requirements override cost considerations.

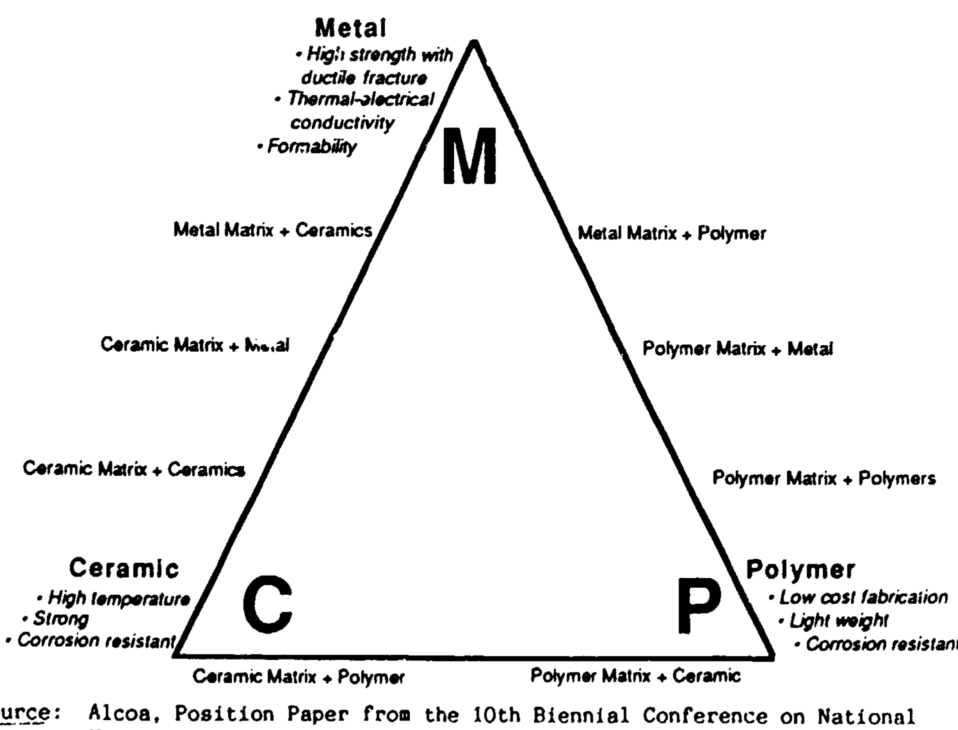
- Technical advance in high technology industries, such as computers and electronics, aerospace, nuclear energy, high-temperature processes and bio-technology are currently constrained from the materials side. Such industries are placing ever more stringent requirements on materials properties and performance. Increasing performance requirements are now beginning to be placed on materials throughout industry and this trend will accelerate in the 1990s.

- At the same time the development of new materials and devices engineered at the molecular level are beginning to revolutionize communications, information analysis, chemical and structural analysis, medicine and industrial processing to such an extent that major alterations in manufacturing technology and lifestyles are underway.

- It is likely that the materials which will dominate industry in the 21st century will be "materials systems" synergistically combined so as to maximize the properties of the component parts (see Diagram 1). Composite and laminate materials systems <u>tailored</u> for specific applications and environments will increasingly displace monolithic or homogeneous materials, such as metals, from several applications. "Materials systems" imply the eventual demise of a number of existing basic industries and their replacement by others. Further, the future for metals may reside in complex metal matrix composite forms. Some metals will decline in use, at first in developed countries and eventually in developing countries too.

<u>Diagram 1</u>

Advanced Material Systems



Source: Alcoa, Position Paper from the 10th Biennial Conference on National Materials Policy

- The early incorpor :on of such materials into new products and processes confers her value added, leads to improved competitive positions and acce..rates market penetration. Hence a successful advanced materials sector contributes to national competitiveness directly through its own global market performance, but also in terms of initiating and maintaining international competitive advantage in industries incorporating new materials in products and processes. Many governments have recognized the potentially harmful effects on output, employment and trade of falling behind in advanced ceramics, polymers and composites.

- Advanced materials will affect the global location of industry and trade flows in a variety of ways. The processing technology and design procedure necessitates closer interaction with and proximity to end users and markets. The implementation of Just-in-Time inventory control and Total Quality Control imply closer proximity of materials suppliers to end users. Advanced materials have, in some cases, been developed in order to eliminate import dependence of developed countries on imports of strategic and critical minerals. As this becomes a reality, such metals will no longer be imported. But developed countries' import dependence will shift to strategic advanced materials components and raw materials entering the production of such components. The demand for some metals will be negatively affected as advanced materials gain a firmer foothold in the next century and composite materials systems begin to dominate material use in the long run.

- The industry is displaying a distinct tendency towards internationalization and fast transfer of technology across national boundaries. Mergers and acquisitions, joint ventures, consortia, technology and distribution licensing agreements are all techniques that are increasingly employed by large TNCs, in chemicals, metals etc. to diversify, reduce risk, merge complementary technical and scientific capabilities, enter advanced materials by acquiring smaller specialized companies in order to gain experience and/or take advantage of perceived market opportunities in a global context.

- Metals and chemical companies are reassessing their strategies and have begun a transformation towards becoming high-technology materials companies. There has been a marked and increasing tendency for forward integration by materials producers and backward integration by materials users. Hence, the materials markets will increasingly be dominated by large vertically integrated international materials companies. Nevertheless, there is - and will be - ample room for smaller companies to specialize and serve special niche markets in developed countries. Flexible specialization and catering to specific market segments has been a hallmark of the current materials markets.

- The quantum leap in scientific and engineering understanding in employing the newly integrated disciplines of materials science, advanced manufacturing, composite testing, design and engineering has placed vast scientific and financial requirements which are proving to be beyond the capabilities of even the largest firms. This has led to the formation of strategic consortia between industry, government and universities in several developed countries. This increasing government involvement in advanced materials research and commercialization is a

- central feature of the materials revolution. Support is provided via the provision of research funds, formation of consortia, development of standards, testing and characterization, the provision of lab facilities and highly-advanced instrumentation for industry's use, and the national co-ordination of materials research. This is an important lesson for developing countries embarking on the materials sector. Developed countries well understand that a successful advanced materials sector, scientific expertise and the availability of the necessary experience and infrastructure in the production and use of such materials, will enable their economies and industries to dominate world markets in the 1990s.

- However, nearly all new materials are facing serious processing constraints. Unless new, improved, high volume processing can be developed, the diffusion of advanced materials will proceed very slowly, if at all in some cases, and in any case slower than current predictions. The vast effort underway though, will eventually yield commercial processing techniques to back up new materials design.

- Finally, it should be noted that there are substantial and cumulative learning effects for early entrants in materials science, processing, fabricating and use. It cannot be assumed that late entrants can avoid intermediate steps and easily jump onto the scientific and technological frontier at some point in the future. This is a point of fundamental significance to developing economies, whether the appropriate country-specific strategic response to the materials revolution is deemed to be in the area of production or use or both. It must be born in mind that in most cases production of the new technologies would be impossible or inappropriate, and hence the relevant consideration would be the conditions for the successful utilisation of the new technologies in the medium term. Nevertheless a central message of the materials revolution and the quantum leap in the knowledge content of production is the urgent need for human resource development, institutional change and enhancement of the scientific and technological capacity of developing economies in the 1990s.

II. NEW TECHNOLOGIES IN A HISTORICAL AND DEVELOPMENTAL PROSPECTIVE

1. Primary commodities, trade and development

Minerals and agricultural commodities in the world economy are inextricably linked to the issues of specialization, trade and economic development of Third World primary producers. It is, nevertheless, a sobering fact that despite some progress on manufacturing exports, the majority of developing economies remain largely dependent on primary commodity production and exports for a major part of their foreign exchange earnings. The primary commodity export sector, with its varying, but generally low, degrees of downstream processing, has remained for most developing countries the backbone of their development process.

Recent UNCTAD calculations (Tables 1 and 2) indicate that agricultural and mining production is the single most important component of GDP for all developing countries, except the fast growing manufactured exporters, and that for most the share in GDP is more than 30 per cent as compared to less than

10 per cent in the developed market economies. Moreover, for more than 80 developing countries the share of primary commodities in total export earnings is above 50 per cent. In many cases, and especially for low income countries, it is also accompanied by a high degree of export concentration on one or two primary products.

A central organizing idea in development in the postwar period has been the leading role assigned to the primary export sector as an 'engine of growth'. Primary producers participating in the international division of labour and engaging in mutually beneficial trade would obtain both static and dynamic gains, generating higher income, savings, and investment leading to a diversified industrial structure and sustained growth.

Table 1. The share of the primary sector in the GDP of developing and developed countries

Share of primary sector in total GDP (%)	Developing countries		Developed countries	
	Number of countries	As % of total sample	Number of countries	As % of total sample
Above 50	12	14	-	-
40 - 50	17	20	-	-
30 - 40	16	19	-	-
20 - 30	22	26	1	5
10 - 20	10	12	6	27
1 - 10	8	9	15	68
Total	85	100	22	100

Source: UNCTAD, TD/328/Add.3, 1987.

Table 2. Non-oil primary commodities: Export dependency of developing countries, 1982-84

Percentage of non-oil commodity exports in total export earnings (annual average 1982-84)	Number of countries	
	All developing countries	Low-income countries
90-100	23	11
75-90	25	10
50-75	36	11
Sub-total 1: Over 50%	(84)	(32)
20-50	24	9
10-25	11	2
0-10	26	2
Sub-total 2: Under 50%	(61)	(13)

Source: UNCTAD, TD/328/Add.3, 1987.

Empirical evidence, however, often points to a 'freezing' of production structures and the general lack of generated intersectoral linkages. The reasons for this are of a complex socio-economic nature and merit more serious consideration than can be given here. One group of problems often cited for the disappointing performance of commodity exporters relates to commodity export and price instability, slow or declining growth in real export earnings and/or volumes, and a longrun deterioration in the real prices of their commodities. In 1986, the barter terms of trade for non-fuel primary exports were below half the high levels in 1950, according to the World Bank, which also predicts that by the year 2000 non-fuel commodity prices will only be 8 per cent higher in real terms than in 1986 and hence 25 per cent below 1980 levels. Following the relatively strong market position of commodities in the 1970's accompanied by a large expansion of capacity, the 1980's have witnessed massive overcapacity and over-supply in many commodity markets, coupled with a slump in prices until recently.

Export subsidies, support schemes and devaluations have encouraged production for export in many developing countries, especially in agricultural commodities, at a time when markets for such products in developed countries were displaying slow growth at best. Cyclical problems have been compounded by secular and structural changes adversely affecting these markets, such as substitution, declining intensity of use of specific industries, shifts in the product composition of GNP and tastes. Exchange rate movements compounded these trends, leading to severe problems for many developing countries, in particular in Sub-Saharan Africa where import capacity and government revenues and expenditures have been dramatically curtailed and per capita income has been dropping since 1980.

2. Downstream processing

The evidence suggests that a number of developing countries have increased the degree to which they process domestically produced raw materials before export, during the last two decades. Hence the post-war pattern in which primary raw materials from colonial and newly independent economies flowed to developed countries for further processing and use in mass produced final goods has undergone some change. Part of this can be explained as the deliberate aim of developing economies to obtain greater economic benefits from their natural resources through downstream processing and enhancement of value added before export, together with greater government tax revenues, the promotion of horizontal and forward linkages, expansion and diversification of the industrial base and reduction of the enclave nature of both mineral and plantation projects.

Increased downstream processing is a major economic and political objective of primary producers. Processing remains at the core of development strategy whether it be as an input to domestic capital goods production in the case of minerals or as means of enhancing and stabilizing real export earnings to be ploughed back into domestic industry as a basis for a resource-based industrialization strategy.

The higher degree and greater global share of processing activities undertaken in developing countries have, of course, also resulted from underlying economic forces. Escalating energy prices, increasing environmental regulations and compliance costs, and higher labour costs in the

1970's in developed countries meant that energy-rich, resource-rich developing regions (together with Canada and Australia in some minerals) became attractive locations as the smelting capacity in developed countries was rendered increasingly uneconomic. This has also been the case for petrochemicals, synthetic fibres and other energy-intensive basic industries. This process whereby labour-intensive or raw material-intensive activities began to be restructured and redeployed to developing countries in the 1970's, was broadly in line with changing patterns of comparative advantage in the context of the internationalization of production. Increasing domestic raw material capacity in developing countries together with the redeployment of processing industries and labour-intensive branches, such as textiles, shoes etc., was viewed as part of converging interests of developing countries, transnational corporations (TNCs) and governments in developed countries. In the early 1980s, however, overcapacity appeared in several sectors and there were growing voices of concern over import penetration of manufactures from newly industrializing countries (NICs) and protectionist barriers began to be erected to protect developed countries' basic industries facing severe difficulties.

3. The restructuring of the primary metal industry in the 1980's and technological responses

In the 1980s the world mining and primary metals sectors experienced a prolonged period of depressed prices, serious decline in demand, financial losses and fierce competition amidst large overcapacity. During 1985 and 1986 the prices of several major metals fell, in constant dollars, to levels prevailing in the 1930s. Naturally the severity of the recession fell unevenly across minerals and industrial branches within national economies. Nevertheless all mining and metals branches underwent deep restructuring. Old and inefficient capacity was permanently shut down, labour contracts were renegotiated, employment was reduced and remaining capacity modernized. The rationalization measures have resulted in lower average costs globally in each branch as well as shifts in the relative competitive position of national branches on the cost or supply curve.

Focussing on the important US industry key strategies in the fight for survival and profitability in mining and metals can be identified.

Firstly, a major effort for cost cutting has been underway. Domestically owned high cost, inefficient and obsolete capacity has been shut. Remaining capacity has been modernized or rebuilt. The case of steel, the most seriously affected industry, is instructive. Since 1981, 42 million tons of domestic outmoded capacity has been shut down, and a massive modernization programme was instigated. Between 1982 and 1987, continuous casting capacity increased from 20 per cent to 59 per cent of raw steel output, energy consumption fell by 18 per cent, labour costs were lowered by 40 per cent and total costs fell by 30 per cent to an average of $431 a ton. In copper, several obsolete mines and smelters closed down, and aggressive modernization measures have reduced costs and increased productivity. In pit-crushing equipment, large continuous conveying systems, computerized truck dispatching and heap leaching followed by solvent extraction and electro-winning were the main technologies, the latter enabling copper to be produced at 30 cents per pound. Copper smelters have been modernized, with most of the smelters currently employing state of the art flash-smelting technology. Cost cutting and rationalization will keep on reducing costs into the 1990s. The aluminium sector too has shed between 25-40 per cent of corporate employment, shut down inefficient capacity, and modernized and technologically upgraded high value added fabricating operations. Plant closures in the US mining and metals industry led to a loss of 492,000 jobs between 1981-87 (i.e. 46 per cent of the decline of all manufacturing jobs). Interestingly, given the analysis below, although fewer production workers remain, more flexible collective bargaining agreements have been negotiated, and workers today are multiskilled and expected to perform a greater variety of tasks as well as impart greater efficiency and value to the products.

Secondly, metals companies have been moving downstream to higher value added production, and are beginning to reduce their dependence at the 'commodity' metal stage of the industry where profits are being squeezed and competition from low cost overseas suppliers is high. Thus, some companies are purchasing imported ingot, reducing domestic smelting and moving towards higher value added and more specialized materials production. Together with this strategy there is a much stronger emphasis on marketing, product quality, and customer service. This closer attention to demand and integration with the customer is a marked tendency in all materials industries.

Thirdly, metals industries are diversifying into new and related businesses, including advanced materials, such as new alloys and composites aimed at high growth market segments.

The combination of these measures has resulted in a smaller but more efficient, viable and restructured primary metals industry in the late 1980s, bearing little resemblance to the conditions under which it entered the decade. Mining and primary metals industries have responded technologically and organizationally to higher costs, declining profits and import competition. Of course, productivity gains need to be sustained if future competitiveness and survival within developed countries is to be maintained.

The process of redeployment of mining and bulk commodity metal processing to developing countries is therefore neither fully predictable nor is it irreversible, at least in the medium run. Whether the long run future in basic metals production belongs to the Third World, even with or despite the employment of computer-aided mining and processing techniques is again an open question, as much an economic and technological issue as a political and social issue in both groups of countries.

In addition, there is the issue of the development of substitute technologies by developed countries in order to reduce import dependence on a large number of strategic and critical materials. Major research efforts have been undertaken since the 1970's the results of which are now becoming evident. One group of such technologies is related to advanced materials. Advanced materials would act directly on the demand for metals such as cobalt, tungsten, and chromium in aerospace and defense applications, and hence global production, trade patterns and import requirements of developed countries. At the same time such industries utilize cheap and plentiful raw materials domestically available to produce high value products. Issues raised here relate to the availability of domestic reserves and of capacity for new raw materials, the impact on existing mining and metals industries within developed countries, and the requirement for new recycling technologies and industries for waste retrieval from new materials.

The arrival of advanced materials thus aggravates the problems and uncertainty surrounding minerals and complicates the restructuring process nationally and internationally. Further it introduces a large question mark as to the long run trends in the demand for specific metals and ores and hence disturbs hitherto accepted notions of the desirability of downstream processing as a long run objective of the development process. In fact, the analysis in section IV points to a more complex framework which is emerging, even if some metals can respond and survive into the 21st century, which is highly likely.

The restructuring of metals and other primary commodity industries in the 1980s was undertaken in conditions of the generalized application of new automation techniques and management-labour relations. These, together with advanced materials, raise serious questions about the future role of the Third World in the international division of labour and the conditions under which export oriented industrialization strategies can be successful.

4. Restructuring and microelectronics: From fordism to post-fordism

In the last 15 years a major discontinuity has appeared in the post-war pattern of mechanization and work organization which was based on inflexible, mass-production techniques. Industry is undergoing fundamental restructuring in the process of which there is a transition away from Fordist production practices characterizing the post-war period toward increased flexibility. The emerging paradigm is variously described as post-fordism or flexible specialization or Just-in-Time (JIT).

Fordist mass production methods employ the principles of increasing division of labour, fragmentation of tasks, mechanization of tasks and employment of dedicated machinery, and moving production lines together with Taylorist principles for managerial control of work via the separation of direct from indirect tasks, complete job specification and removal of any worker control over the work flow. Profitable production under this system in which labour skill, initiative and creativity are minimized, requires uninterrupted, high volume output of standardized products aimed at mass markets. Production is supply driven, and utilizes substantial work in progress and finished goods inventories, to offset faults and quality problems and to meet fluctuations in demand. Dedicated plants and production lines make sense in conditions of very high volumes, small product variety, long product life-time and a stable macroeconomic environment in which incomes and tastes can accommodate what is emerging out of mass-production lines.

However, for a number of reasons market demand has become increasingly fragmented and unstable with consumer preferences necessitating higher quality, greater variety, low volume production of products with shorter life-cycles. Hence the inflexible manufacturing methods and accompanying inventory systems characterizing Fordist production lines have become to some extent unsuitable in conditions of product differentiation, consumer sophistication, and fast changing market circumstances. Firms increasingly need to be more flexible and in close contact with the market for recognizing and speedily responding to changing demand patterns. Greater variety needs to be produced in small lot sizes.

All branches of manufacturing are currently undergoing deep restructuring accompanied by a transformation of production technologies, management practices and patterns of work organization. The arrival of microelectronics has facilitated the development, application and diffusion of stand-alone automation and integrated flexible manufacturing systems. These developments have serious repercussions for developing economies. The industrial structure of developed countries is shifting towards high growth, high technology, knowledge-intensive branches of industry with large intersectoral linkages to the rest of the economy. Mass production and batch-production industries within the capital goods and engineering sectors are automating and reorganizing their production lines with the incorporation of flexible manufacturing techniques. Mature, declining sectors are being modernized by the adoption of microelectronics-based automation technologies such that (a) they are beginning to retain their cost competitiveness within the industrial structure of developed countries and (b) acquire higher potential for future incremental innovations and productivity gains to maintain their competitive advantage. The difference between technologically progressive and stagnant industries may be becoming blurred.

It is within these global circumstances that advanced materials have made their appearance and will increasingly diffuse within manufacturing industry in developed countries. Developments in all high technology sectors are currently constrained by improvements on the materials front. In so far as solutions are being found further impetus will be given towards the technological and scientific transformation of industry. But the advanced materials sector itself, it must be realized, is a highly scientific and knowledge-intensive sector, which must be viewed as a major new technology which can potentially transform the technological base of all industries. As such it is of equal importance to the microelectronics revolution, and the two will increasingly become organically linked in their march within and between sectors. Advanced materials will alter the global division of industrial labour including the location of mining and processing activities, and place in question the very survival of some resource-based industries in the long run.

In this overall context developing countries need to address the following questions. What is the appropriate industrial and institutional response in the face of such major discontinuities and disruptive changes? What is the rationale and conditions under which it is appropriate to remain in primary commodity production and downstream processing in the 1990s? What role should be accorded to developing an indigenous scientific and technological capacity in the 1990s? Given the advent of microelectronics and advanced materials does this reduce or increase the necessity or feasibility of establishing domestic capital goods and engineering sectors? What should be the extent and form of the role of the state and markets in the necessary domestic industrial, educational, infrastructural and scientific transformations at this conjuncture? If the developing countries are to participate in a fast changing division of labour on the basis of dynamic comparative advantage and given that industrial products and processes will be incorporating information technologies, and the materials inputs to production will increasingly shift to high performance advanced materials, how urgent is the need for action now?

Before dealing with some of these issues more specifically in sections IV and V, the following section III will provide a synoptic review of major recent developments in the emergence of new materials.

III. ADVANCED MATERIALS

1. Quantum theory, the new physics and the revolution in materials science

1.1 Quantum mechanics and modern technology

The revolutions in quantum theory (Davies 1988; Gribbin 1984) and the theory of relativity in the first three decades of this century ushered in the new physics. Einstein's special theory of relativity, first published in 1905, concerns itself with the theory of space, time and motion. Fundamental physics was further shaken in the 1920s with the arrival of the quantum theory of matter which explains molecular, atomic, nuclear and subatomic particle processes.

Quantum theory first arose out of an attempt to explain some technical aspects of subatomic physics at the Bell Telephone Company in the early 1920s. Out of these experiments came an amazing new theory of matter which led to the collapse of centuries old scientific belief. The theory, which is now known as quantum mechanics, is an intricate mathematical framework which holds together most of modern physics and provides the detailed foundations of what is known of subatomic particles, atoms, molecules, crystals, light, electricity, lasers, transistors, the behaviour of electrons in computers and television tubes, laser light movement in fibre-optic cable and so on.

Quantum theory, or quantum mechanics, which is simply the physics of how electronics behave in solids, has been a vastly successful, practical branch of physics which at a stroke explained a large number of physical phenomena such as chemical bonding, the structure of the atom and nucleus, the conduction of electricity, and the mechanical and the thermal properties of solids. From such theoretical understanding a vast number of modern technologies such as the electron microscope, the transistor, the superconductor, and atomic power were obtained. The theory is now being taught at most university science courses, and is found in many routine practical, day to day applications, including engineering practices. All sciences and methods of enquiry have been permeated by quantum mechanics, and the full implications of the theory still have to be realized or fully worked out.

The most pervasive influence on our lives today derives from the onset of the microelectronics revolution. But the material basis for this originates in quantum mechanics through solid-state physics. Theoretical insights revealed that some materials like silicon and germanium can perform as either insulators or conductors. By controlling and transforming the electrical resistance offered by such semiconductors, the transistor was produced which eventually led to today's semiconductor chips. The microcomputer and a large array of consumer durables such as hi-fi equipment, pocket-calculators, television sets, programmable washing machines and so on depend on the properties of semiconductors and are the direct outcome of the solid-state revolution. Superconductors are also a result of solid-state physics. And it should be mentioned that quantum rules now govern the whole of chemistry, viewed as the science of molecules. Understanding the chemistry of life itself is rooted in quantum theory, including the discovery of DNA and aspects of recent genetic engineering and biotechnology developments.

1.2 The structure, properties and performance of matter

The arrival of powerful new instrumentation and experimental facilities, providing scientists with greater knowledge as to the correlation of structure and the mechanical, electrical, optical, magnetic, surface and interface properties of materials is only one aspect of the advanced materials revolution in the 1980s. Clearly, radical new characterization technologies together with accumulated and ever move precise knowledge of structure-property interactions enable a more precise design of desired materials.

Together with a better understanding of quantum mechanics in the last few decades, has come the use of fast, powerful, number-crunching computers, which are only now enabling scientists to take full advantage of quantum theory. What is required is theoretical understanding and an ability to mathematically model, predict, calculate and test the predicted properties of the material under construction. To calculate the properties of even the most microscopic of crystals (a clustering of atoms) requires trillions of calculations involving the solution to hundreds of quantum mechanical equations. This can now be done given deep theoretical understanding of the structure of matter, advances in computing power and science, and mathematical modelling, in addition to the crucial developments in characterization, interface science and materials testing.

What this means is that materials scientists in the 1980s have enough knowledge on the bonding of atoms to design entirely new materials and predict their properties. That is, one can start with properties required and design and construct the material that has these properties, atom by atom. This is indeed a revolution and a fundamental reversal in the hitherto followed sequence of conversion of natural materials to end products, the latter being constrained by the properties of the existing materials. Now, entirely new materials by design can transform end products in existence or usher in entirely new products and uses.

Industrial users are concerned with the performance of a material in actual use in a particular application. Performance is determined by structure and properties. The mechanism that links all three is processing. The processing or fabrication path by which the material is manufactured modifies the internal structure thus determining properties and performance.

Therefore, in order to be able to design materials with theoretically predicted properties, materials science and engineering have to develop an understanding of both microstructure-property relations and how structure and properties, and hence ultimate performance, can be controlled and modified by processing. The structure of metals, for example, evolves in response to the imposed strain, strain rate, temperature and time. A whole array of metallurgists, physicists, chemists and mathematicians are required to obtain empirical understanding, theoretical understanding and develop models predicting processing-microstructure relationships in order to decide on the appropriate processing path to yield the desired properties. It should also be noted that the computational advances mentioned above would eventually enable new products with unique characteristics to be designed, developed and tested quickly in computer-assisted modelling experiments rather than pilot plant prior to manufacture.

An example of the interdisciplinary requirments for materials research and development, be it at private, university or government establishments is given in Table 3, for a ceramic component. Several professionals from a number of disciplines need to collaborate in the integrated process of design and manufacturing of the new product. Rigid boundaries between and within scientific and production engineering disciplines are increasingly eroded.

Table 3. Hypothetical multidisciplinary design team for a ceramic component

Specialist	Contribution
Systems Engineer	Defines performance
Designer	Develops structural concepts
Stress Analyst	Determines stress for local environments and difficult shapes
Metallurgist	Correlates design with metallic properties and environments
Ceramist	Identifies proper composition, reactions, and behaviour for design
Characterization Analyst	Utilizes electron microscopy, X-ray, fracture analysis, etc., to characterize the material
Ceramic manufacturer	Defines production feasibility and costs

Source: OTA, June 1988.

1.3 The integration of scientific, engineering, manufacturing and marketing capabilities

From the vastly enhanced scientific and knowledge content as well as interdisciplinary efforts required in materials development and production (and use) in the 1980s, further serious implications follow.

Engineering and materials science divisions have now been eradicated with a resulting two way interaction and integration. Moreover, it is now becoming necessary to integrate materials science with manufacturing, product design and performance, as a simultaneous process. This is to be contrasted to the sequential and disconnected product and process development path hitherto followed in materials industries. For example, in metals, the product development process followed the sequence of new alloy creation by the alloy technologist, who then handed it to the ingot caster, who then passed it to the fabricating technologist and then, finally, it reached the product designer after an average wait of 7 years. This serial, lengthy one way process of material development and production is out of date in today's market place and competitive environment requiring the creation, testing and application of complex new materials technologies in record times. It is not simply a question of speeding up the R&D and innovation cycle. Rather, the new conditions in materials science necessitate a simultaneous approach to materials research, advanced manufacturing techniques, product design, performance and marketing, including, in a crucial way, a close interaction and integration with end users. The scientific and engineering capabilities of the materials producers need to be in close touch with the performance requirements and engineering and manufacturing processes employed by the end user industry, e.g. automobile or aerospace. Although new materials development has to a large extent been demand driven, generalized application would and does require that end users be educated as to the properties and quality reliability of a new material.

In short, what is emerging is not only a breakdown of a firm's traditional internal divisions and procedures in research, development, engineering, manufacturing and marketing, but an enforced integration of product design to the manufacturing technology and product design of the end-user. This explains the observed forward integration of materials producers and backward integration of materials users. These observations acquire added significance when viewed in conjunction with the increasing application of microelectronics-based flexible automation technologies across manufacturing and the trend towards a systemic integration of all aspects of the production process in computer integrated manufacturing.

New materials, which in general are more expensive than existing materials, especially metals, necessitate a different approach to costs by end users. To take advantage of the properties and performance characteristics of a new material, end-users need to redesign both product and manufacturing techniques. Hence a system wide total approach to costing must be taken, where potential savings in tooling, assembly, fabrication, maintenance and life-cycle costs could offset the higher advanced material cost. It is no accident that many current applications of advanced materials are in areas, such as military or aerospace, where performance is more important than cost.

An important view in industry[1/] is that the performance requirements for materials in current and future use require the development of combinations of materials or engineered 'materials systems' for which microstructure is so designed as to maximize the properties of the constituent parts as well as that of the whole. Such complex materials needs further strengthen the integration of materials science, product design, manufacture and a planned, cohesive marketing capability in close contact with materials end users. Further, it signals the transformation of existing monolithic materials producers into integrated, large materials producers. It is those

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1/ E.g. P.R. Bridenbaugh, Vice-President, Research and Development, Alcoa, in several publications.

companies that combine the necessary scientific and engineering expertise and experience, together with appropriate marketing, sales and collaborative strategies with end users that will emerge dominant in the next two decades.

Advanced materials systems with their attendant vast scientific and engineering requirements and testing, instrumentation and research expenditures are proving beyond the means of individual companies. Hence, already this has led to large collaborative efforts and consortia between industrial companies, universities and governments. This will increasingly become one of the major features of the materials revolution.

Finally, a cautionary note on the implications of the materials science and engineering revolution. Nearly all the new materials discussed above and below are currently coming up against severe processing constraints. That is, if they are produced they do so in small volume, high cost fabricating processes. Unless new, improved, high volume processing techniques can be developed in the near future, many of these materials will either remain curiosities or find shelter in very specialized applications in aerospace and defence. Unless this severe bottleneck is solved, the diffusion of advanced materials will only materialize, if at all in some cases, very slowly and, in any case later than current predictions make out. Nevertheless, this should not be a recipe for simply concentrating on processing innovations and cost reductions in existing materials, putting off involvement in the scientific and technological changes in advanced materials. Such research is actively pursued by many governments, universities and corporations worldwide and bound to eventually yield commercial processing techniques to back up new materials design. It should also be noted that there are substantial and cumulative learning effects for early entrants in materials science, processing, fabricating and use. It cannot be assumed that entry would be easy, automatic or beneficial for late comers, as the information technology revolution is currently pointing out.

2. A taxonomy of advanced materials

2.1 Advanced metals

Advanced metal alloys are now generated by manipulating defects in the crystalline structure so as to produce desirable properties in terms of ductility, low brittleness, and performance at high temperature vibration and corrosive environments such as in aircraft engine applications (Keav 1986). In fact most research and development of advanced metals has been guided by the increasingly stringent requirements for high temperature performance as producers are striving for higher energy efficiency in aerospace. The performance requirements of advanced aerospace systems continue to increase. Hence the mechanical properties of the material inputs must also improve. These properties are a result not only of defect-free materials but also of the presence of irregularities such as voids, gas-filled pores, second-phase particles and the segregation of alloy constituents. Ability to institute careful processing control of such defects results in a better performing material with assured quality, hence facilitating the attainment of more exacting design requirements and much improved aerospace system performance (Froes 1988). New alloy developments and new advanced processing techniques for cost-competitive metal production have also responded to demands for higher performance materials coming from most other industries, such as oil companies drilling in deeper, hostile environments, and the chemical processing industry's search for improved process efficiency and corrosion resistance. It should also be pointed out that advanced metal product and process innovation, spurred on by steel and aluminium, are competitive technological responses of metals industries to saturation of traditional markets, recession, cost and price squeeze pressures in commodity metals and competition in traditional markets from advanced engineered materials such as composites and plastics. Hence it is an attempt to remain competitive and cost efficient in existing markets as well as expand markets and acquire a competitive edge in new applications. The current emphasis in the steel industry, for example, is on processing techniques that can lead to cost reduction and product improvement.

Advances in steel

Amongst new processing techniques (Advanced Materials and Processes, 1989, 1; Metals Outlook-Forecast 1989) introduced to meet greater microstructural control and international competitiveness are new vacuum melting and degassing techniques, once the province of stainless steels and aerospace alloys, now benefiting carbon and alloy steels, continuous casting, controlled rolling and other thermomechnanical treatments that reduce costs through reducing traditional heat treatments.

Near-net shape continuous casting of strip, rod and thin slabs will be given increasing emphasis as a means of enhancing competitiveness in the global market. There are also improvements in coatings for steel together with induction heating processing thus reducing energy costs and improving quality and yield. There is a search on for new cost effective high-temperature stainless steel alloys. Duplex stainless steels have been improving and are used increasingly in severe corrosion environments, and in chemical processing.

High strength low alloy steels (HSLA)

HSLA steels are sophisticated mass produced materials that enter the construction of large structures such as ships, oil platforms and cranes. By adding miniscule amounts of at least two metallic (such as niobium, aluminium, titanium, vanadium) and two non-metallic (such as carbon and nitrogen) components to the iron elements during hot rolling, a very fine grain structure is produced, conducive to high strength and good weldability. The extremely fine and stable distribution of tiny precipitates (about 50 atoms in diameter) prevent grain coarsening during heat treatment as in welding. This fine grain structure which is effectively pinned down by carbide or nitride particles gives rise to both high strength and fracture toughness (Easterling 1988).

HSLA steels provide opportunities for developing countries with existing or planned steel capacity, summarized as follows (Advances in Materials Technology Monitor, UNIDO, Issue Number 1, November 1983): More effective utilization of existing equipment capacity; production without licensing agreements; added value for production; upgrading of local engineering standards; import substitution of costly heat-treated alloy steels; and improved competitiveness in world export markets.

Superalloys

Advanced metals have generally been aimed at high-temperature, extreme conditions applications. Superallys are nickel-based materials developed for just such uses. Nickel is melted down and mixed with aluminium, and small amounts of chromium to impart anti-corrosive properties, and other metals such as titanium and tungsten for hardening. The superalloy is then cooled, to form a gamma-phase nickel-aluminium, and then further cooled in its solid state.

Superalloys have made much of modern high temperature engineering possible. They form essential components of the gas turbines that power jet aeroplanes. In fact it is these engines that have provided the technological pull for the development of superalloys. In addition to their use in gas turbines, they also serve in rocket engines and spacecraft, nuclear reactors, submarines, steam power plants, petrochemical equipment, and in corrosion-resistant applications. Superalloys development flourished in the 50s and 60s. By the mid-70s the main thrust came from tremendous processing improvements and this is the case until today.

Despite these improvements, doubts exist as to the ability of nickel based supperalloys to meet the future requirements in high-temperature applications such as the gas-turbine. New metallic materials systems and associated technologies may meet some of the future requirements of advanced gas turbine engines. But not all, and these will require non-metallic systems, on the development of which depend future technical change in gas turbines. The use of ceramics and composites presupposes that they attain the same reliability as the metal components they are replacing (Future 1987).

2.2 Advanced ceramics

Traditional ceramics such as glass, pottery, tiles, bricks, plumbing fixtures and dinnerware are familiar objects in everyday applications. Advanced ceramics, on the other hand, are a result of recent technological breakthroughs which have provided a new class of materials that display distinct advantages over metals or some plastics in a number of demanding applications because of their density, resistance to stress, corrosive and erosive properties, and high-temperature operational ability.

Advanced ceramics comprise of a large number of materials deriving from the oxides, nitrides and carbides of silicon, aluminium, titanium and zirconium, which are processed or consolidated at high temperatures. These inorganic and non-metallic advanced materials have been developed in the last 10-12 years in response to needs arising from specific industrial and high-technology applications.

Applications: Advanced ceramics have widespread applications, hence their importance; seven broad groups can be identified.

- Electronics: Advanced ceramics are used in integrated circuit (IC) packages, capacitors and resistors, and have therefore enormous potential in the high growth market of electronic components. Another highly important application will be in integrated optics (i.e. optical guided-wave devices that perform processing functions on the light beams they guide) which will play a revoulutionary role in fibre-optics communications systems, probably the major telecommunications technology of the future. They will also increasingly be used in sensors in robotics, cars, automation, medical implants (bioceramics) and many other industrial and consumer applications.

- Engines: An important structural application of advanced ceramics in the form of silicon nitride, silicon carbide and zirconia is in gas turbines, diesel and gasoline engines. Several hundred million of dollars have hitherto been spent on demonstrating technical feasibility in terms of new materials and engineering technology. Nevertheless, there remain significant problems in terms of cost, reliability and manufacturing capacity. Technical experts give the following time frames for applications:

Period	Advanced ceramics in engine development
1984-87	Ceramic parts
1987-90	Ceramic components
1990-95	Systems
1995-2000	Small gas turbine engines

- Cutting tools and machine parts: Existing cutting tools are reaching their limits with the need to use tougher new alloyed metals. Tools made from advanced ceramics are showing distinct advantages over metallic counterparts, facilitating higher speed, reduction of costs (by 60-75 per cent) and enhanced productivity gains. Nowadays they are almost a necessity in NC machine tools.

- Industrial products: Their resistance to corrosion and erosion has won them new applications in the metals industries, chemical processing, oil and gas industries and precision jigs in the manufacture of electronic components.

- Consumer products: Commercial application currently in use, especially in Japan, include sporting equipment, scissors, knives, etc.

- Energy: here applications include batteries, fuel cells, solar collectors.

- Space, aerospace and defence: Heatshields and tiles for space missions and re-entry vehicles, infrared windows, radomes, armour, military engines, etc.

Advanced ceramics posses properties that make them superior in many demanding high-temperature, high stress, corrosive applications which subject materials to intense wear and heat. They can be lighter than metals thus offering energy saving potential. Their use may also offer cost advantages to the user industry via process and product redesign. Advanced ceramics (and composites) could be viewed as structures rather than materials. Overall systems costs taking into account integrated design, fabrication, installation and life cycle costs would render advanced ceramics competitive with conventional materials and metals in many applications (Table 4).

Advanced ceramics are viewed as a key competitive technology in the current and future global market. Early studies (Mark 1987; Bell 1984; Kent Bowen 1986; OTA 1988a) by the Congressional Office of Technology Assessment and the US Argonne National Laboratory, identified advanced structural ceramics as of major importance to the national economy, predicting that failure to remain competitive in this field would cost the economy tens of billions in terms of GDP and hundreds of thousands of jobs by the turn of the century.

The use of advanced ceramics in industrial processes could result in dramatic gains in fuel efficiency permitting the raising of their maximum operating temperature from 1,800xF to 2,700xF. There are tremendous gains then to be had in terms of engineering efficiency, higher productivity and lower costs in a multitude of industrial applications. What is more, advanced ceramics are seen as a means of reducing import dependence of western economies for a number of strategic minerals such as chromium, cobalt, tungsten and manganese. In fact, this has been a major reason for the research thrust in this area since the 1970s. But, although the resource base for advanced ceramics is plentiful and widely available, the fear is that import vulnerability would simply be transferred to advanced ceramic components in critical and high-tech or military applications.

Table 4. Characteristics of advanced ceramics

Advantages	
High melting point	Good dialectric properties
High stiffness	Thermal/electrical insulators
High hot strength	Semiconductor properties
High compressive strength	Ion-conductor properties
High hardness	Magnetic properties
Wear and corrosion resistance	Biocompatibility
Low density (light weight)	Abundant raw materials
Limitations	
Susceptible to thermal and mechanical shock (brittle)	
Gaps in understanding and experience	
Difficult to fabricate	
Poor reproducibility	
High cost	

Source: E.J. Kuber, Structural ceramics: Materials of the future, Advanced Materials and Processes, 8, 1988.

These materials have the potential therefore to change global patterns of materials production, sourcing, trade flows, global and domestic location of industry, and industrial structures. For example domestic location is already changing due to lighter weight of components away from traditional lines of transport towards agglommerations of ceramic firms near airports for air shipment of products. Global location would be determined by the need to cater for domestic niche markets and flexible and fast response to needs of manufacturers employing just-in-time methods of flexible production.

Statistics for market potential vary widely and should be treated with caution. Table 5 gives estimates for global markets and a breakdown of ceramic sales in 1987.

Commercialisation Barriers

Research in this area is aimed at enhancing the scientific pool of knowledge, improved characterisation of this class of materials, and developing processing technologies for reliable, reproducible, low cost competitive ceramic products. In fact the major problems arresting the widespread use and diffusion of these materials are the poor manufacturing techniques and brittleness.

Ceramic materials are very susceptible to small flaws such as cracks, voids and inclusions. This increases the importance of controlling processing and finishing as closely as possible. Flaws can occur at any stage of the multistage fabrication process from powder production, powder conditioning, shaping and designification, and cannot be corrected at later stages. In fact

Table 5. Worldwide advanced ceramic market projections (in $ million)

Industry	1985	1990	2000
Automotive	53	634	5,700
Electronic	1,708	3,740	11,360
Integrated optics		1	111
Advanced energy systems			360
Cutting tools	14	92	500
Other industries	80	225	690
Other aerospace	20	30	65
Bioceramics		10	30
Total	1,875	4,732	18,818

Source: Business Communications, Inc., Stamford, CT.

flaws will always exist in ceramic parts the design of which therefore becomes a statistical process as compared to metals in which it is a deterministic process. It is important therefore to identify those conditions in the early processing stages that create defective products and to detect critical flaws in the fine powder itself. In-situ non destructive techniques become important to monitor the process, characterisation and end-product inspection to remove defective parts. Another method to reduce the probability of failure is to so design the microestructure of the materials as to increase resistance to fracture (increasing toughness). This can be achieved through a refinement of the polycrystalline grain size and shape, transformation toughening and composite reinforcement.

The other major problem with advanced ceramics lies in the difficulties encountered in their additive manufacturing processes. The material is formed to its final shape simultaneously with the forming of the internal microstructure. A central need in designing such materials is to consolidate as many components as possible into a single structure. This is due to the fact that finishing and fabricating are extremely difficult due to the hardness of the material, and are also very expensive. Hence the aim of design and fabricating is always near-net-shape processing so as to produce a final product that requires very little machining. In metals, near net shaping processes used include powder metallurgy and advanced casting techniques. In general advanced ceramics are in direct competition with metals and are more expensive than the latter. This necessitates that near-net-shaping of ceramics must be a top priority if they are to be cost-competitive with metals in the future. Major components of production costs include finishing and machining operations, together with non-destructive testing instrumentation and techniques. All in all a crucial barrier to wide commercialisation of advanced materials remains the development of low cost, reliable and reproducible fabricating of components to final net shape.

Progress requires further research on processing, microstructure and desired final properties interaction, the design of brittle materials (which is severely lacking at the moment), process control, non-destructive evaluation, understanding crack growth process and life prediction. Another important point is that the fabrication process remains very skill- if not labour-intensive. Research efforts are aimed at reducing both the labour and craft skill content of the production process.

2.3 Engineering plastics

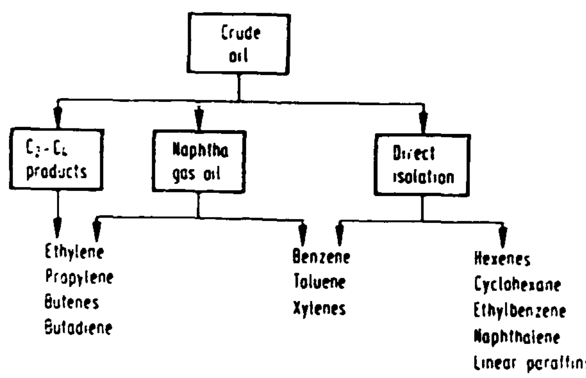
Polymers (Balazik/Klein; Baer 1986) or, as they are commonly known, plastics, are organically derived and synthesized materials that can be moulded at high temperatures and will then retain their shape when cooled. 'Commodity' plastics such as polyethelene, polystyrene and polyvinyl chlorine have been the backbone of a large and growing plastics industry since the 1930s. Commodity plastics are high volume, low cost per unit materials in contrast to what are known as engineering polymers or plastics which are of recent origin and are characterized by low-volume output and high unit value.

Engineering or high-performance plastics possess exceptional strength and/or heat resistance in comparison with commodity plastics, and are increasingly used in automobiles, aircraft and many other applications. They include polyphenylene oxide, polyethylene terephthalate, polyacetal and alloys and blends of these polymers. Performance polymers with decomposition temperatures as high as 530xC include fluoropolymers, polyarylate, poletherekeketone and others. Such materials can be reinforced with a variety of fibres to form polymer matrix composites with applications to both exterior and interior components of aircraft, automobiles and other structural applications with high expected growth rates. Research is underway for the use of polymer materials in optical fibres, semiconductors, electrical conductors and so on placing them in direct competition with metallic and ceramic materials.

Another important subdivision of plastics is thermoplastics, which can be repeatedly resoftened and rehardened, and thermosets which cannot be resoftened after hardening by raising the temperature. Resins are organic liquids or solids that are plastic materials which can be used to build more complex plastic compounds.

Clearly the major plastics producers are large oil companies since the principal raw materials for plastics are petrochemicals (ethylene, propylene, and benzene) derived from petroleum. About 85 per cent of the basic industrial chemicals are used in industrial polymer production, with most of the organic intermediates deriving from oil and natural gas. This is a point that needs to be stressed since in discussing materials issues the large shift from inorganic to organic mineral inputs (and their geographic distribution) are often ignored. This implies import dependence of developed countries' plastic industries on oil and feedstock control from abroad.

The modern plastics and synthetic fibre and rubber products are mainly obtained from petrochemical feedstocks. Chemical production normally locates in the proximity of oil refineries. Trends in the industry's production of industrial organic minerals favour the location of chemical plants near natural gas or oilfields. The diagram overleaf shows the major petroleum based industrial organic chemicals:



Source: H. Ulrich, Raw Materials for Industrial Polymers, 1988

Polymers are at the root of many natural products such as wood cellulose, starch, resins, and proteins. A better understanding of their molecular make-up has led to the development of synthetics. Polymer based plastics are a large share of the total materials market but conventional plastics are reaching saturation point in their conventional applications.

Advanced polymers or engineered polymers are being developed of such sophistication that they are pushing into markets dominated by metals. The major use of the new polymers is in composition both as fibre and matrix. The majority of composite materials make use of polymers, but composite products are only a small fraction of the class of products known as engineering polymers. Again, the materials revolution has meant greatly increased knowledge of the microstructure - properties relationship in polymers, advanced in synthesis and new processing methods based on such intimate knowledge, leading to materials of unprecedented properties.

Polymer science can now tailor make polymer molecules. The latter are made from smaller units called monomers. The way monomers are chosen and assembled determine the properties of the bulk material which comprises them. The polymer so structured or engineered can then be tailored via processing on a larger scale, like a metal or a composite, and given a desired microstructure.

The shape of the polymer molecule and its chemical make-up have an influence on the properties of the bulk material. And by varying the characteristics of polymer chains we can create a desired microstructure. But polymer scientists and engineers go beyond this simple building up of a microstructure. They start with a 'synthesized' molecule and then through processing they transform its structure and properties. One type of processing is blending. For example to increase toughness a brittle amorphous plastic can be blended with another polymer, an elastomer for example. Blending enables the materials scientists to combine the best properties of several materials. There have been recent advances in processing which extrude several polymers, and scientists are now trying to synthesize and process polymers so as to increase their performance under stress, heat, chemical attack, and even exploit their electrical properties to serve in electronic sytems. Given this ability to synthesize molecules and use processing techniques to improve mechanical properties for structural applications of advanced polymers, scientists are looking to hierarchical organisation embodied in biological tissues. In fact polymer matrix composites imitate such structures. Biology has pointed the way to designing polymers as systems for particular use: Polymers in the 21st century will not be used as monolithic materials but as materials systems in complex, delicately structured combinations of materials.

2.4 Composite materials

There are two main points about advanced composite materials. The first is that they are the natural selection for use where extreme performance requirements cannot be met individually by monolithic materials. Second, as they can be tailored to meet specific needs, stress-strain distribution, temperatures and other conditions they will become the main structural materials of the future displacing monolithic materials from many applications.

Composites effectively are strategies to synergistically combine materials so as to take advantage of the enhancement properties of fibres. For this, materials designers simply embed the fibres in a matrix of another material, so that the latter binds and protects the former. The reinforcing material contributes the main characteristics in terms of strength and stiffness but the matrix also affects the properties such as heat and electricity conductivity. The combination of fibres and matrix govern mechanical behaviour. Diagrams 2, 3, and 4 show possible fibre and matrix combinations.

The determinant of matrix material choice is the temperature the material will face in use. Polymer matrices utilize thermoset plastics which cannot melt, or epoxies which are a thermosetting material. Clearly the choice made of the matrix will dictate how the material is processed and fabricated. For a polymer matrix composite (PMC) the process is long and labour intensive.

Diagram 2: Composite Materials

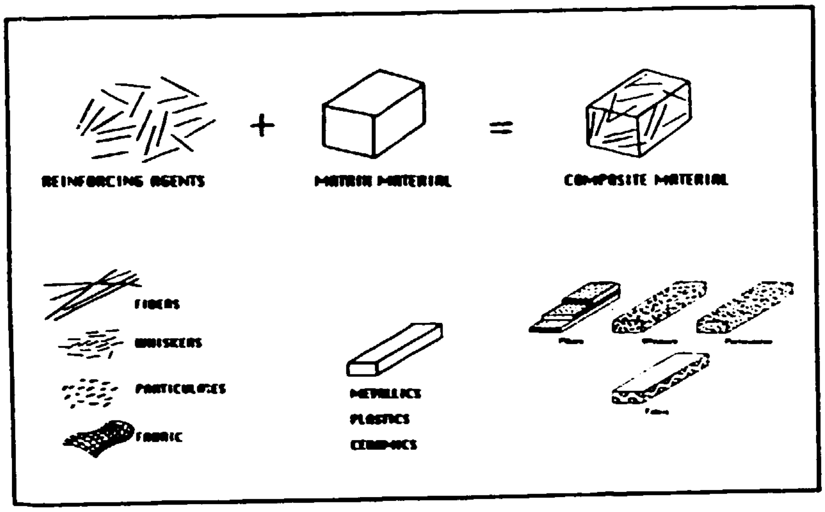


Diagram 3: Composite Materials Approaches

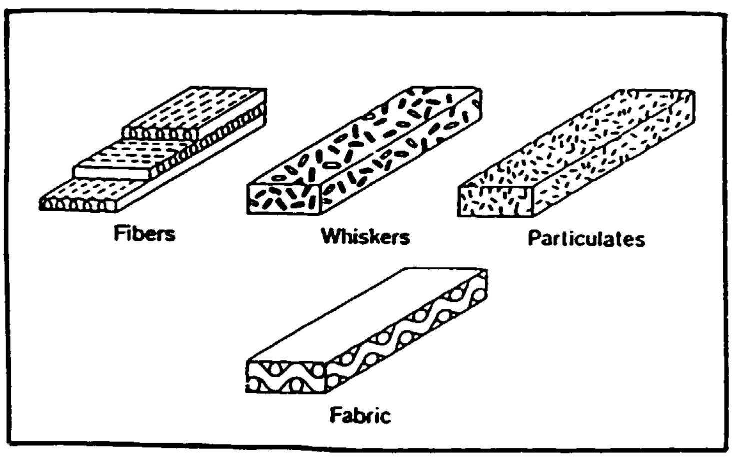


Diagram 4

REINFORCING AGENTS

CONTINUOUS FIBERS
- BORON (B)
- GRAPHITE (C)
- ALUMINA (Al_2O_3)
- SILICON CARBIDE (SiC)
- BORON CARBIDE (B_4C)
- BORON NITRIDE (BN)
- SILICA (SiO_2)
- TITANIUM DIBORIDE (TiB_2)
- ALUMINA-BORIA-SILICA ("NEXTEL")

WHISKERS

OVER 100 MATERIALS PRODUCED

METAL REINFORCEMENTS
- IRON (Fe)
- NICKEL (Ni)
- COPPER (Cu)
- NICKEL ALUMINIDE ($NiAl_3$)
- ALUMINUM OXIDE-ALUMINA-SAPPHIRE (Al_2O_3)
- SILICON CARBIDE (SiC)
- GRAPHITE (C)
- SILICON NITRIDE (Si_3N_4)

PARTICULATES (including flakes)
- TUNGSTEN (W)
- MOLYBDENUM (Mo)
- CHROMIUM (Cr)
- SILICON CARBIDE (SiC)
- BORON CARBIDE (B_4C)
- TITANIUM CARBIDE (TiC)
- ALUMINUM DODECABORIDE (AlB_{12})
- TUNGSTEN CARBIDE (WC)
- CHROMIUM CARBIDE (Cr_3C_2)
- SILICA (SiO_2)
- ALUMINA (Al_2O_3)
- MOLYBDENUM DISILICIDE ($MoSi_2$)

METAL WIRES
- TUNGSTEN (W)
- TITANIUM (Ti)
- MOLYBDENUM (Mo)
- BERYLLIUM (Be)
- STAINLESS STEEL
- NIOBIUM-TIN (NbSn)-SUPERCONDUCTOR
- NIOBIUM-TITANIUM (NbTi)-SUPERCONDUCTOR

The fibres in the form of yarns or bundles are impregnated with the matrix resin and are then assembled mainly by hand into a laminated structure. If the resin used is a thermoset the structure must be cured and often held at high temperature for several hours. PMC's possess light weight and high stiffness and stress in the direction of the reinforcement, and they are therefore used in aircraft, cars and other moving structures. But they decompose at high temperatures. Moreover, they are fabricated in a labour intensive process which is not suitable for high value, low cost industrial applications. Before they can be commercialized successfully fabrication methods need to be improved.

Nevertheless, PMC are the most mature of the composite technologies. The least developed technologies are those of ceramic matrix, and metal matrix systems are in between the two.

Engineering design is being transformed because of the degree of control over properties that can be achieved in composite design. The design of a component and of the material are now a unified, simultaneous process. Materials scientists can tailor the microstructure of a composite according to the distribution of stresses it will be subjected to. But the very nature of its processing, its directional properties and forms given to it must come to be reflected in the shape of the component comprising it. Not only is it a merging of two formerly distinct activities but it is enormously complex, requiring computerized modelling, testing and control and a large, interdisciplinary team of designers are engineers.

Moreover it is tailorability that distinguishes composites from other materials and will therefore lead them to dominate the materials markets from the late 1990s. Some estimates for the U.S. composites markets 1982-2000 are given in Table 6.

Table 6. US markets for advanced composite parts, 1982-2000
($ millions)

Matrix	1982	1987	1988	1993	2000	AARG(%)
Polymers						
Defense-related	1,100.0	1,716.0	1,889.4	3,153.0	4,295.0	10.8
Commercial	652.0	1,062.0	1,167.6	2,278.3	4,777.0	16.3
Metals						
Defense-related	-	NA	16.9	53.6	180.5	21.8
Commercial	-	NA	3.1	15.2	48.3	25.7
Ceramics						
Defense-related	-	-	26.8	35.0	51.0	5.5
Commercial	-	39.1	50.4	167.5	576.0	22.5
Total						
Polymers	1,752.0	2,778.0	3,057.0	5,431.3	9,072.0	9.5
Metals	-	-	20.0	68.8	228.8	22.5
Ceramics	-	39.1	77.2	202.5	627.0	19.1
Grand Total	1,752.0	2,817.1	3,154.2	5,702.6	9,927.8	10.0

Source: BCC Report GB-110 Ceramic Matrix Composites - A Technical/Economic Review

2.5 Superconductors: Ushering in a new age of technology?

At present we are in the midst of feverish international activity to translate the significant discovery, barely 2 years ago, of new high-temperature superconductors (HTS) into practical commercial application. It is widely recognized that this new family of superconducting materials has revolutionary implications for the technological and infrastructural foundation of our economies. Indeed, claims are being made that they will form the basis for a "new age of technology" (Crawford 1988).

Although it is difficult to exaggerate the potential applications of superconductivity, some of the claims seem to be erring in terms of the time scale of application. Before superconductors can have a wide technological impact and diffuse throughout the productive structure of economies, they face considerable barriers in terms of processing and bulk production capabilities. That is, they must first be produced commercially into useful forms such as thick and thin films, wire, tape, and bulk materials (Murphy et al. 1988; Dew-Hughes 1988; Shumay 1988). The development of such fabrication and processing technologies may in fact require as radical new technologies as the invention of the new superconducting materials themselves. While considerable advances have been made in this direction, much basic research and improvements remain to be done, with high returns for those corporations and economies with the research, development and manufacturing capabilities that will enable them to win the global race for the commercialization of superconductivity. The importance of these developments has not gone unnoticed by governments in developed and developing countries alike. A concerted research effort is underway involving private laboratories, universities, and state support and funding. India,[1/] for example, has set up a Cabinet level committee under the Prime Minister to promote research on ceramic superconductors, and a Programme Management Body under the director of the Indian Institute of Science and Technology, to co-ordinate the research at government and industrial laboratories, with a budget of several million dollars. Seven Indian research institutes are involved such as the Tata Institute of Fundamental Research, and the National Physical Laboratory. (Advances in Materials Technology Monitor, UNIDO, 1987/4, Issue No.11).

What are superconductors? The phenomenon of superconductivity entails the complete disappearance of electrical resistance as a material is cooled below some critical temperature. The critical temperature is that temperature at which the material's resistivity abruptly changes from a state of normal electrical resistivity to a superconducting state. Until the end of 1986 superconductivity was mainly connected with the properties of metals. It was only in February 1987 that a new ceramic superconductor was discovered, displaying a critical temperature of 94 K well above the liquid nitrogen temperature of 77 K.

Why is this discovery so important? First note that superconducting materials cooled below their critical temperature allow electric current to flow with zero resistance, hence there is no power loss and no heating. Second, note that a material in a superconducting state is not penetrated by magnetic flux lines and can therefore repel magnets, what is known as the Meissner effect. The achievement of liquid nitrogen superconductivity was a major breakthrough introducing a new technology, since it lifted the constraints of very low temperature superconductivity requiring liquid helium as a refrigerant. Liquid nitrogen is much cheaper and operating temperatures can now be much higher, hence reducing also the complexity and cost of support, maintenance and operation of the cryogenic installation. Hence the prospects for large commercial applications are very real and substantial.

Applications. Currently conventional, commercially important, low-temperature, liquid helium-based superconductors, e.g. columbrium alloys, have a $300 million world market in instrumentation and medical diagnostics (magnetic resonant imaging), with electronic components being a small part of the total market. Other estimates including the future market potential for superconductors are given in Table 7.

Table 7. World markets for superconductors
($ millions)

Industry	1987	1992	1997	2002
Integrated circuits	25	75	225	400
Laboratory instruments and sensors	<5	25	125	200
Medical diagnostics	150	300	500	750
High energy physics	25	150	150	200
Electrical power	5	10	20	40
Transportation	-	<1	5	10
Magnetic separation	5	25	60	175
Total	215	586	1,085	1,775

Source: Advanced Ceramic Materials, vol.3 No.1, 1988 based on a "High-Tech materials alert" report.

The new superconductors operating above liquid nitrogen temperatures can in themselves potentially transform technology, but the real breakthrough will come with the expected discovery of room temperature superconductivity. Such an achievement would truly revolutionize technology and lifestyles making available efficient and loss-free electricity and leading, for example, to compact small motors and actuators which can be incorporated in household consumer durables, cars. machine tool drives and power-packs to replace hydraulic systems of aircraft, and other unforeseen applications. Given that there is a lack of theoretical understanding of superconductivity for metals, and even more so for the new materials, the exact arrival of ambient temperature superconductivity cannot be predicted. Nevertheless, some scientists have recently claimed that theoretical understanding of superconductivity in new materials at the atomic level may not be as necessary to progress in this field as hitherto claimed (OTA 1988b; Easterling 1988; Wolsky et al. 1989). It may be worth noting that same top-scientific sources have in fact predicted the arrival of room temperature superconductivity within the next 5 years.

More realistically, one should be looking at practical applications of liquid hydrogen cooled superconductors, given that nitrogen is both abundant and cheap. It must be stressed though that a concentrated, large research effort is required over a period of 5-10 years before many of these can be realized on a commercial scale. The new materials must be made sufficiently strong and flexible to be fashioned into useful forms and made capable of carrying large currents (over 100,000 amperes per square centimeter at 77xK) and/or withstand large magnetic, gravitational and centrifugal forces (e.g. in spinning turbine generators). This research effort involving both engineers and scientists will be directed (Wolsky et al. 1989) at basic research to explain the phenomena and create new materials; applied research on processing methods; applications engineering for prototypes and testing; process engineering to develop manufacturing methods for mass production of cable and methods for inspection and quality control; and systems engineering for the design, development and demonstration of the integration of superconductor components into computers and electrical generation, for example. This long lead time provides an opportunity for engineers and scientists to focus their attention on to this area, to train a new generation of scientists, for government and corporations to commit resources in a long term strategic planning framework (as Japan is doing) to co-ordinate disparate research efforts from laboratories and universities and to integrate the multidisciplinary requirements in knowledge, skill and experience ranging from physics, chemistry, electrical engineering, production engineering to materials science. In some developing countries this could become an integral part of a national science and technology infrastructure building encompassing microelectronics and other advanced materials technologies such as fine ceramics. It should be borne in mind that in the medium term the greatest gains are economically to be found in small scale applications of high temperature superconductivity, especially in various industrial machines and electronic devices. In the long run potential gains of interest to developing countries would include magnetic levitation trains for journeys of between 100-600 miles, electric generation and, importantly, the ability to store massive amount of electric energy with no energy loss, medical diagnostics (magnetic resonance imaging) and geophysical exploration. Finally, it should be clear that high-temperature superconductors are essentially advanced ceramic materials, so that basic research and engineering capability in the two areas can reinforce each other.

IV. POTENTIAL IMPACT OF ADVANCED MATERIALS ON THE WORLD ECONOMY

1. Emerging trends

Even a cursory glance at economic history points to the fact that one material has always been replacing another (e.g. iron and steel for wood) where improved cost and performance characteristics have been involved. The advent of the new advanced materials goes beyond this process of inter-material competition and substitution. In section III.1 it was shown that scientists can now intervene at the molecular level, and by rearranging matter they can 'create' materials possessing vastly superior properties to existing material inputs to manufacturing. This is to be sharply contrasted to the hitherto unidirectional conversion of natural materials, be it organic or inorganic, to meet manufacturing needs. In this conversion cycle it was the type and availability of the conventional materials that essentially determined the type and amount of final products to be made. The process has now been reversed. Starting from a need a material can be designed and engineered to meet the requirements, provided processing obstacles have been resolved and low-cost volumes can be achieved for generalized application and use of the new material. This implies that not only existing needs can be met with higher performance structural or electronic materials as compared to conventional alloys, but opportunities arise for creating entirely new materials which can meet as yet undefined or unfulfilled needs. In this connection, it must be stressed that new advanced materials are rarely, if ever, engineered to simply replace an existing plastic or metal in existing application. Rather, the whole product and, frequently, production process must be redesigned to take advantage of the full array of properties of the new advanced material input. Several implications follow from the above.

1.1 Greatly accelerated materials invention and innovation

What is occurring today is not simply the creation of new materials possessing extraordinatory properties in comparison to hitherto widely employed metals and organically derived materials, although this is significant enough in itself. A revolutionary aspect of this break with past experience is the accelerated pace[1/] with which new and improved materials can be designed and marketed as a direct result of scientific, modelling and computing advances in the 1980s. This, of course, creates tremendous problems for the dissemination and absorption of an increasing amount of fast changing cumulative information on the production, availability, use and technical properties of a bewildering array of materials. Information gathering, appropriation, accessibility and, interpretation will become a variable of crucial importance in the 1990s as industries and governments attempt to make informed decision making and appropriate responses to the dangers and opportunities afforded in materials market developments.

Moreover, the acceleration in the number and variety of newly designed and marketed materials implies rapid obsolescence of existing products and processes, a phenomenon akin to the consequences of rapid innovation in microelectronics and consumer durables. Materials producers and users will increasingly face a sharply shortened life-cycle for materials and products in a fiercely competitive global market, where companies able to marshall the requisite multi-disciplinary scientific and engineering expertise plus financial R&D resources[2/] will set the pace. Here, it should be noted that

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1/ See R.F. Balazik, The Significance of Modern Materials: Impact and Policy Implications. US Bureau of Mines. This paper presents the issues with admirable clarity; it is drawn upon throughout this chapter.

2/ Again, it should be pointed out that at present most firms in the USA and Europe, as opposed to Japan, are not committing funds to research in this area, due to large uncertainty and very long time before pay off can be expected. A recent OTA report points to the fact that US materials suppliers are mainly oriented towards supplying military requirements, whereas potential end-users are not willing to invest in extremely costly laboratory experimental production processes in order to solve technical problems leading to rapid, low cost processing methods. This is so not only due to cost considerations, but also due to the large planning horizon of 10-20 years considered necessary to resolve manufacturing problems and the threat that rapid technical progress poses for scaled up laboratory manufacturing processes. In Japan a longer term view is taken in favour of acquiring necessary production experience in developing and using new materials, in order to gain a secure foothold in the evolving global markets of the future. See Advanced Materials by Design, Office of Technology Assessment, US Congress, June 1988.

Japanese companies currently sacrifice short-term profits in favour of a research commitment to production and use of advanced materials, so as to gain cumulative experience and advantages from 'learning by doing' in global markets 5-10 years from now. Such a strategic, as opposed to myopic, approach to materials design, fabrication difficulties and use will be of crucial importance for both companies and national economies in their ability to survive, respond flexibly and speedily, and gain competitive advantage in conditions of rapid change in materials technologies and products in the medium to long run.

Specific materials will dominate markets for shorter time-spans than in the past given the accelerated pace and number of substitutes entering the market. This has the important corollary of shortening the period of amortization of large R&D outlays, hence necessitating a global marketing assault simultaneously across all countries and trade blocks, as compared to the product-cycle idea. Clearly, this would necessitate different, and as yet imprecisely defined, locational and marketing strategies for materials producers and manufacturers of intermediate and final products. If this view is correct[1/] then one should expect that developing economies would not be excluded from this global marketing approach to advanced material production and use. This would contain both opportunities and constraints for such economies which are attempting to make use of their domestic resource base to meet basic infrastructural and consumption needs, as well as compete in the world export market, be it in natural rubber or aluminium products. What might resurface is a debate between advanced materials production and use versus 'appropriate' materials technologies and use for economic development.

1.2 International competitiveness of industrial branches and structures

Traditional materials are reaching their limits in many applications and it is the need for new materials in aerospace and military applications that has encouraged research into new advanced materials. Another (OTA 1985) important research determinant is the effort to reduce dependence on specific strategic and critical minerals such as cobalt, chromium, manganese and tungsten, in military and high technology applications, although the evidence shows that this is not the criterion employed for the use of advanced materials in many sectors currently in the US. It is superior performance rather than cost or import vulnerability that is sought in these high-tech applications, in which materials supplies have carved out spe‹ ic niche markets as a prelude to more generalized applications in the rest of the economy.

It appears therefore that advanced materials are initially utilized in high technology growth sectors, such as aerospace, telecommunications, electronics, computers, biotechnology and automobiles. It is in these technologically more demanding sectors that advanced materials find natural applications for their superior performance characteristics. Indeed, new advanced materials precede and are a prerequisite to the realization of new

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1/ It would be modified and further complicated by the global materials sourcing requirements of engineering and other manufacturing producers engaged in Just-in-Time production methods.

technologies in such high-tech economic activities. Superior materials enter as intermediate inputs into such complex products as aircraft, microelectronic devices and cars and are vital to their functioning. Hence product and process innovation, international competitiveness and growth of key high technology sectors depend in an essential way on the availability of appropriate advanced materials. As in previous periods in the history of technology, mechanization and industry, it is developments in materials science and engineering which set ultimate limits or offers enabling conditions for growth and innovation in technologically advanced sectors, and indeed, all industrial branches.

By their very nature as intermediate inputs, advanced materials can enter virtually every production process and emerging products. As such they contain the seeds for potentially reorganizing every production line, interfirm and inter-branch relationships, the economy wide allocation of labour and distribution of skills, and the competitiveness and growth of individual sectors, groups of interrelated industries and national industrial structures. That is they are on an equal footing with microelectronics and biotechnology, perhaps as the three major technological carriers of a secular expansion in the world economy in the 1990s.

Products that incorporate advanced materials possessing such superior qualities as light weight, enhanced stiffness, ability to operate at high temperature and adverse environmental conditions, can prolong their life, improve fuel efficiency and reduce assembly costs. Such products would thereby acquire a substantial competitive advantage over products that do not employ them and/or use inferior production techniques. Sporting equipment, electronic machinery, automobiles, military and passenger aircraft, electronic consumer durables, all acquire a competitive edge via vastly improved performance characteristics. But more than this, new advanced products require a reorganization of the processing and assembly lines out of which they emerge. This leads to a reduction in cost and hence further competitive advantages.

2. The demand for primary metals

2.1 Secular trends

Since the mid-1970s there appears to have been a marked decline in demand for a large number of metals. One part of the explanation clearly is the slowdown in economic activity in western economies discernible from about the same time, as well as cyclical downturns experienced in the 1980s. The problem though goes beyond cyclical factors or breaks and reversals in the long run growth rate of aggregate economic activity. More fundamental long-term factors are possibly at work which are causing a structural change in the amount of metal used per unit of GDP in mature industrialized economies.

Evidence[1/] of a dramatic change in the trend rate of demand growth has been found for steel, aluminium, copper, lead, manganese, nickel, tin and

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1/ Tilton 1986a and 1988; Roberts 1988a and 1988b; Reiley 1988; US Bureau of Mines. The discussion below is based on these articles, especially Tilton 1988, to whom I am indebted.

zinc, some of which are shown in Diagram 5. This has led to speculation that the materials sector in the world economy, minerals in particular, is now 'uncoupled' from manufacturing activity and the rate of growth of output. That is, even if the rate of growth in the world economy moves up in the short or long run, the demand for metals will not be significantly affected, which is distressing news for metals producers, if correct. Whether the demand for metals and minerals will grow, decline or remain stagnant as the overall economic activity is expanding depends on trends in the intensity of use of metals per unit of GDP, and, of course, whether the factors working on intensity of use are permanent or transitory.

The factors[1/] at work which influence intensity of use (IU) are the materials composition of product (MCP) and the product composition of output or income (PCI). Thus intensity of use reflects both technological factors in production and consumer preferences in terms of the type of goods and services produced in an economy. The PCI reflects the changing composition of output as a result of increasing per capita income and consumer preferences. Thus, a shift in the economy towards services, which are less material-intensive than manufacturing, would lead to a decline in IU. But if durable goods production also increases, as has been the case, then this would help to offset the decline in IU. Moreover, the invention, innovation and diffusion of new metal products would also act so as to increase the IU for the specific metal.

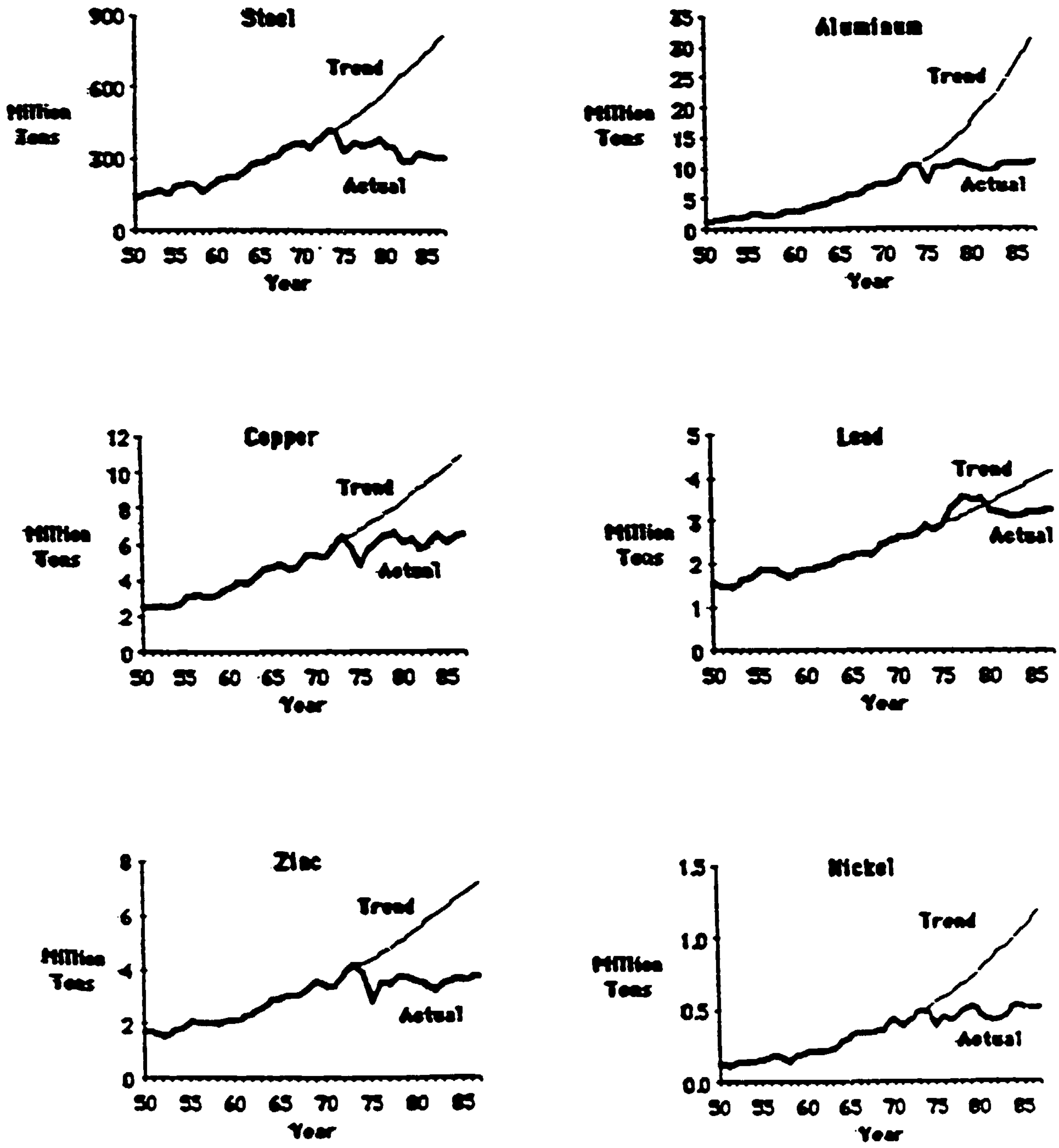
The MCP refers to metal use per unit of output in a specific industry. Thus, it describes the production technology employed and its metal requirements. Metal requirement and use per unit of output will change over time in response to relative prices, substitution between metal input requirements, and product and processing redesign. If MCP, affected by metal-saving technical change and substitution, is an important, or even the main explanatory factor in trends of IU, then this calls into question the accepted view that there is a stable, inverted U-curve connecting per capita income and a country's intensity of use. That is one cannot use this relationship to forecast future metal demand. Moreover, it cannot be assumed that as industrialization proceeds and per capita income rise, demand for metals will increase, as developed countries will also employ new best-practice efficient manufacturing processes requiring less input per unit of output (Tilton 1986b).

The available evidence indicates that the intensity of use for most metals has been declining since 1973, and at an accelerated pace for those metals where it was already declining prior to that date. The net result of a combination of a retardation in the rate of economic growth and declining intensity of use has resulted in a stagnation or decline in metal demand. This shows that economic growth can now occur without growth in metal demand. But, as Tilton suggests, rather than concluding that the two are unrelated, what this means is that a more complex relationship is underway. Economic growth still affects metal demand, but not enough to prevent a decline in some metals, which would have been greater in the absence of growth. Metal consumption can stagnate or decline if the rate of growth is lower than the rate of decline in intensity of use.

1/ For the theoretical and empirical intricacies of measuring IU, PCI, MCP, see Tilton 1988, and Roberts, December 1988b.

Diagram 5

OECD consumption of steel, aluminium, copper, lead, zinc and nickel. Actual and trends, 1950-87



Source: J.E. Tilton, The new view of minerals and economic growth, Colorado School of Mines, 1988.
Trend figures indicate what consumption would have been if it had continued at the 1950-1973 rate.

The question then is why has IU been declining? Firstly, a shift has occurred within OECD towards a smaller share of gross investment and manufacturing in GDP after 1973. A corollary to this, of course, is that if investment patterns reverse themselves again in the 1990s, metal consumption could again pick up. Secondly, there has been a high penetration of high technology products, which consume less metal per dollar of value added than traditional products, within manufacturing.

In so far as the materials composition of products is concerned, both resource-saving technology (e.g. thinner aluminium cans) and materials substitutes have exerted a downward pull at the intensity of metal used in industry in recent years. Although data are lacking, it is also likely that advanced materials such as engineered plastics and composites have also contributed to metal displacement and thus declining IU in recent years.

2.2 Advanced materials and non-fuel minerals and metals

Advanced materials are beginning to make inroads into markets dominated until now by conventional non-fuel mineral-based materials. However, there is a dearth of hard evidence, and projections into the future are fraught with difficulties, not least because traditional metals are 'fighting back' to preserve their traditional markets and the battle has by no means been won by either side as yet.

An important study has been conducted recently by the US Bureau of Mines examining the competitiveness of domestic non-fuel minerals under threat from advanced plastics and ceramics. The evidence, from wide ranging interviews with experts in the respective fields, suggests that engineered plastics are the materials which have made the greatest inroads into metals and glass, and are expected to continue to do so in the 1990s. At least a quarter of all plastics and resins produced within the US compete directly with non-fuel mineral materials. The competition between metals and advanced plastics will accentuate in the 1990s and the outcome will determine which of the materials will dominate automobile and aerospace production in the next century. In this respect it is mainly steel and aluminium that are competing with polymers. The latter have already taken 7-9 per cent of the steel consumed in the US automobile industry and are expected to double this share by the year 2000. Polymer composites are displacing aluminium in the skin of military aircraft and are expected to move into passenger aircraft to such an extent in the next decade that they will account for 65 per cent (as compared to 3 per cent now) of airframe weight. By the year 2000 passenger airframe weight may comprise of only 20 per cent aluminium as compared to 80 per cent today.

In car production the potential exists for large scale substitution of steel by polymers. Apart from processing problems of the latter, the steel industry is developing high strength and new corrosion-resistant specialty steels, so that there is a large degree of uncertainty as to the substitution process in this industry. Steel could well maintain its position as a high-tech material into the next century.

On the other hand, reinforced plastics are virtually certain to make significant inroads in aerospace, especially in military applications. This is due (a) to the fact that composites hold the greatest promise for weight reduction, (b) that batch production of aircraft in long assembly line runs is favourable to longer curing and moulding times for polymer parts, and that (c) high composite material costs may be passed on to aircraft buyers.

Metals are not expected to be greatly affected by advanced ceramics for the rest of this century. Advanced ceramics though possess properties that will ensure their significant inroads in aircraft jet engines and this will have repercussions on the use of critical metals and alloys in aerospace.

Even more recently, the US Office of Technology Assessment (OTA) concluded that advanced materials will not significantly affect the demand for aluminium and steel in the near future because these metals are ideally suited for their current applications and are easily manufactured at low cost. In addition, the two industries have responded technologically through new processes and products (alloys) which offer great resistance to potential substitution from advanced materials. But as the latter's processing technologies mature and costs are reduced, metals could be significantly substituted in aircraft, automobiles, containers and construction. Interestingly, OTA points out that the largest substitution of aluminium and copper will occur by relatively low performance, low cost, high strength concrete, unreinforced plastics and sheet moulding compounds. Once, though, advanced materials begin to make inroads into steel and aluminium, then significant substitution will occur over a period of 10-30 years. This will give rise to new industries including recycling, which will be an important factor in the rate of introduction of the new materials, especially plastics.

The rate of diffusion of new materials and substitution of existing metals depends on the total systems or total 'package' cost of introducing a new high performance material by redesigning product and manufacturing processes to reduce assembly costs. Currently high performance advanced materials are mainly used in high technology industries where performance is more important than cost. As processing technologies improve, experience gained and costs are reduced these materials can be expected to penetrate new markets where they will be difficult to dislodge. On the other hand consistency, reliability and the track record of the new materials, however superior their original design properties, is an important consideration facilitating acceptance in industrial applications. Ignorance of the potential advantages of the material, lack of experience in use and high retooling costs favour inertia in using existing materials. Another crucially important factor affecting the speed of substitution, is the required attendant infrastructure, distribution network, maintenance, availability of parts and equipment, and skills, training and experience of personnel to use the new materials in manufacturing processes. The development of a track record and infrastructure for new materials may take many years, a point that should not be lost on developing countries.

2.3 Future trends in international metals markets

Future metals demand will depend on the interplay between trends in metal intensity of use and economic growth in developed and developing economies. In so far as the latter are concerned therefore, the need is for an understanding of the long-term prospects for the specific mineral and metal in the production of which they are engaged, and within this their emerging and prospective role as both consumers and producers of the metal in question. Policy-makers need to address head on questions such as: Is the era of metals coming to a close? If so what is the time frame involved? Even if existing metals and their alloys are under serious threat in the long-run, can they maintain existing markets and/or develop new markets so that they can retain their importance in the short to medium turn? Are developed countries moving towards high-technology, knowledge-intensive sectors and high value added fabrication of materials for specialty markets, while mining and processing of commodity metals is gradually shifting to countries of greatest comparative advantage in developing regions? What is the potential market for traditional, monolithic metals in developing countries in the medium to long run, as advanced manufacturing techniques and products accompany the development of productive forces, incomes and consumer preferences? Is the break in intensity of use for metals in the 1970s and 80s about to receive another, large, irreversible downward pull as advanced materials begin to displace metallic alloys in most uses at the turn of the century? Even if advanced polymers, ceramics and, especially, composite materials begin to dominate the materials markets in the next two decades, leading to a decline of a large number of basic industries, will there still be a large market for metals in combinations with other materials? If so, what should be the role of developing countries as producers and users of metals and metal matrix composites? Will the diffusion of advanced materials in developed countries lead to the elimination of their import dependence on all or some minerals and metals, or will import dependence be transposed to a new array of materials? That is, are developed countries self-sufficient in the resource base of advanced materials, including, of course oil-based materials?

It should therefore be clear that future trends in the demand for metals will be accompanied and partially determined by deep structural changes in the global distribution of minerals processing capacity, fabrication and manufacturing industries employing 'best-practice' techniques together with 'best-practice' materials systems to increase competitiveness. A crucial variable will be the technology and materials selection of developing countries as their industry and infrastructure are being developed or restructured and expanded to high levels of technological sophistication.

A number of ideas in the manner of conjectures are in order here: As the world economy moves towards the 21st century a set of markets for materials may be developing. Over the next 5-10 years existing metals are virtually assured of a market, but it will comprise of increasingly sophisticated, engineered metallic alloys, and increasingly composites, produced with advanced technologies to meet specific markets in developed countries. Meanwhile, increasing costs within developed countries will lead to gradual relocation of processing capacity to the Third World and resource/energy rich developed countries while transnational corporations (TNCs) move out of commodity metal production and concentrate on fabricating high value added metal production near the markets within industrialized nations. Metals industries will increasingly become globalized, with joint ventures, long-term agreements and affiliate production supplying the needs of TNCs for commodity metal from a diversified, complex network into which developing countries will be integrated. Over this time horizon monolithic metals would find use in sophisticated alloys such as superalloys, HSLT steel, and aluminium-lithium in a number of specialized markets in high-technology industries but also in mass-consumer markets, like soft drinks, food cans, cars, etc. Meanwhile, the markets for monolithic metals in developing countries will remain and increase. That is, developing countries might choose, or have no choice but to choose, monolithic metals, such as aluminium, as they develop their industry, infrastructure (cables for electricity transmission) and attempt to meet basic needs. Even so the materials chosen will employ leading-edge production technologies to produce high quality, consistent material. Existing metals which have served as structural materials in the industrial growth of developed countries will probably retain their attractiveness in similar applications in the developing economies, particularly given in place smelting capacity, well into the 21st century. It is clearly impossible to give precise figures as to the time frame of these possible changes, as well as the magnitude and rates of change in the demand for specific metals. It seems that, as from now, metal demand projections must be treated with even more scepticism than in the past.

But other long run trends and warning signals have already appeared. The development of industry over the next 10 years and especially into the next century will place increasingly demanding performance characteristics on materials. In the medium-term these will be met from new processing technologies and high performance engineered metals, plastics, ceramics to meet product design criteria. But the critically important point to be made is that throughout the remaining years of this century and especially the next it will be "materials systems" solutions that will be the central characteristic of product and process design within manufacturing. That is, there is an inexorable march towards the development of extremely sophisticated composite and laminate systems combining metals, ceramics and polymers, in order to meet the stringent performance criteria in transportation, aerospace, packaging, building and construction, energy generation and transmission, telecommunications and, eventually, throughout industry in the 21st century. Thus, while developing countries will be emerging dominant in commodity metal production and use, the developed countries will be undergoing a transition from sophisticated monolithic metals and advanced materials production, use and competition to very complex composite materials systems that will necessarily characterize the materials markets in the next century.

Such emerging complexities and ambivalent trends in the markets for metals have not received the attention they deserve. Developing countries need to carefully reconsider their position and options in the metals markets of the 1990s and beyond. Analysis cannot rest on the proposition of a clear division between metals markets in developing countries utilizing existing monolithic metals, admittedly in ever increasing sophistication, while the industrial structure of developed countries shifts towards the need for advanced materials. Firstly, as the industrial base, and engineering and scientific skills and sophistication of developing countries increase, they may choose or need to choose advanced manufacturing techniques <u>and</u> select advanced materials in product design, if only to compete on cost and performance in the world markets. Secondly, the marketing strategies of TNCs may entail a global push in the use of advanced materials. Thirdly, the use of microelectronics-based manufacturing technologies in developing countries and the requirements for the successful transfer of technology, locational and sourcing decisions of TNCs and joint ventures in materials or end products incorporating them, would probably also place requirements for generalized domestic use of advanced materials. Hence objective circumstances and needs would imply a mixture of monolithic and advanced material use in developing countries in the foreseeable future.

3. Science-based materials production and emerging TNC's strategies for the 1990s[1/]

In today's metal markets "you either have to be low-cost, or high quality, or generate certain market pitches, or you will end up being a commodity producer of a commodity product" (quoted in Hergreaves 1987). The quote by Kaiser's president neatly sums up the predicament and alternatives facing today's metal producers. Above reference was already made to the restructuring of world primary metals industries, the rising importance of developing countries processing capacity due to cost advantages, and the future role ascribed by corporate circles to the Third World as producer of commodity metals and as consumers of conventional monolithic materials.

The 1980s have been a period of transition in the world mining and metals industries, with conditions in the late 1980's being vastly different from the relatively secure and technically isolated position in which metals industries found themselves as recent as 1982. Consequently, there has been a major revision of strategies and reevaluation of the contribution of each asset, division and line of business to profitability and growth (Annual Reports 1987, 1988).

In response to a perceived maturity and saturation of traditional bulk metal markets, some metal producers have begun an aggressive portfolio diversification into related and new businesses. These moves are also connected to and reinforced by the divestment or closure of marginal capacity at home, and the gradual realignment of producers away from the metal commodity end of the business toward higher-value added activities. The major US aluminium producers have decided that in the medium to long run primary metal production is to be largely relinquished to more competitive, modern, efficient foreign operators and subsidiaries, while retaining sufficient domestic plant capacity to feed their fabricating needs.

A number of issues need to be separated here:

- As a result of modernization programmes, cost cutting efforts and asset portfolio management those portions of primary capacity that have been retained at home have become 'leaner and fitter' with substantial reduction in costs, growth in productivity and improved international competitiveness, in aluminium, copper, lead, zinc and steel.

- The character of mining and metals producing firms is beginning to visibly change as companies revise plans and strategies for long-term growth. Together with the need to employ state of the art technology, changes are occurring internally at the level of management-labour relations and a shift away from rigid job classification schemes to a more flexible, multi-skilled labour force.

1/ In this section the focus is on the US Aluminium industry due to its importance as an indicator of future trends in the materials market.

- Firms are withdrawing from stages of the mining, smelting and fabricating production cycle, and concentrating on specific phases of this transformation process. Thus, while copper firms have been withdrawing from the fabrication end, aluminium firms have been abandoning upstream operations and aggressively moving into fabricating activities adding higher value added to commodity metal. One result of this is a more heterogeneous industry where large firms coexist with small specialized firms.

- Together with the commitment to aluminium production using advanced manufacturing techniques, a number of aluminium companies have also diversified into related and new business, especially in the area of advanced materials. In fact some, notably Alcoa and Alcan, increasingly view their future as engineered materials companies rather than as aluminium producers.

One form of diversification is through joint ventures, partnerships and acquisitons in order to restructure portfolios, share risks, costs and expertise and take advantage of market opportunities at home and abroad in emerging new technologies under rapid technical change. For example, as part of this aggressive diversification effort into engineered materials, Alcoa purchased TRE Corporation (which specializes in technology for components from raw materials), formed a joint venture with Metal Box in the UK to produce high performance plastics for the food industry, and a joint venture with Japan's Fujikura to produce fibre optics for the telecommunications industry in the US. Alcan is following a similar diversification strategy, in synergy with its current strengths, as in the development of metal matrix composites in the form of silicon carbide reinforced aluminium, and ceramic matrix composites with another company, lanxide. These forms of international partnerships are of increasing importance and essentially entail an international transfer of technology.

Of equal, if not more, importance is the internal transformation of corporations. Evidence form Japan indicates that non-ferrous metal producers, steel companies, glass manufacturers and chemical firms amongst others have been moving into advanced materials by means of external diversification and acquiring in-house capabilities in conjunction with their traditional expertise. This is seen as a means of technologically upgrading and rejuvenating declining basic industries and as a leverage for competitive introduction of more sophisticated high value added products and growth in the long-run. On the other hand, large firms such as IBM and Du Pont in the US, facing material constraints, have been integrating backward into advanced materials.

Some metals and chemicals companies over the last few years have begun a systematic and planned internal reorganisation (Kaounides 1989) and shift in the balance of pure and applied research emphasis, in clear recognition of the importance of the materials revolution. Within the aluminium industry, the case of the Aluminium Company of America (Alcoa) is instructive. Prior to 1982, skills and research budgets were going into electrochemistry, chemical engineering and metallurgy. In order to acquire advanced materials capabilities radical changes in company philosophy have been introduced. The balance of research has shifted towards fundamental research, with a doubling of Ph.Ds on the research staff in 4 years, the allocation of 30 per cent of the total research budget to basic scientific research and a 5-fold increase in the amount of outside funded research in order to give a boost to fundamental work, establish links with the world scientific community and influence the direction of academic work on materials. A large number of experts in other materials have been employed and the company has established a fundamental polymer research team and polymer processing lab, a ceramic powder synthesis plant and expertise in structural and electronic ceramics, a center for composites manufacturing technology and an enhanced computing capability to fully utilize the vast scientific developments in materials.

Together with other companies, Alcoa clearly recognises that success in future materials development in the 1990s necessitates a deep understanding and quantitative modelling of microstructures, how they determine properties and how these can be controlled by variations in processing. In order to achieve this the company employs an interdisciplinary group of metallurgists, physicists, chemists and mathematicians, amongst others, to develop models which can predict processing to microstructure relationships and hence indicate the appropriate processing strategy to produce materials with desired properties. This hard won modelling ability can then facilitate the introduction of computer integrated processing to develop new products and engage in fast and efficient experiments in the computer rather than in pilot plants. Moreover, it must be noted that Computer Integrated Manufacturing is central to the company's strategy into the 21st century. But to accomplish the necessary organizational and technological changes accompanying advanced manufacturing techniques in materials production today and in the future clearly requires a firm grounding in materials science and accumulated experience and knowledge in all relevant areas. A key aspect to competitive success in the next century is seen as a combination of the cumulative experience acquired over the years in material structure, alloy chemistry, electrochemical processes, solidification and surface sciences and plastic flow failure, with new knowledge in ceramics, polymers, adhesion and surface sciences. It is imperative that developing economies familiarise themselves with such corporate strategies in the 1990s.

V. APPROPRIATE INDUSTRIAL POLICIES AND STRATEGIC RESPONSE BY DEVELOPING COUNTRIES

The arguments in the previous three chapters have tended to be laborious and complex. This is inevitable since the subject matter is one of fast, complex and unclear change. For this very reason it is too early to draw precise, detailed and unequivocal policy conclusions. Rather, the objective here is to briefly enumerate the areas that should be given serious consideration by policy-makers in the course of designing concrete policies appropriate to their economies, domestic resources and global scientific and technological trends. The major problem faced by developing countries as the world economy moves into the 1990s is the development of appropriate international and internal mechanisms for surviving and prospering in major technological discontinuities and rapid, unpredictable change which will be the hallmark of a world economy driven by advanced materials, information technologies and biotechnologies. These developments may entail great opportunities for economic development if appropriate steps are taken now to harness the potential of new technologies to sustain and accelerate development.

1. The rationale of resource-based industrialization in the 1990s

A recent UNIDO document summarizes the arguments employed for increased local processing as "...industrialization strategies based on the use of local raw materials; reduction of dependence on the industrialized countries; creation of opportunities for the training of nationals and the development of skills which can be used in other sectors of the economy; limitations of TNCs ability to engage in transfer pricing; capture of a greater share of the economic rent from mineral production; and the hope of obtaining access to capital which might not otherwise be available". (ID/NG.470/ICSPEC.)

Resource-based industrialization strategies can take the form of increased processing for export as a means of generating revenues and linkages to accelerate economic development and/or the form of providing mineral or agricultural raw materials for use in domestic industry. In the case of minerals, resource-based industrialization implies the use of minerals-processing capacity for the creation of a coherent engineering and machine producing sector for the formation of fixed capital, generation and application of technical change and dissemination of skills throughout the economy.

Arguments have been put forward against the idea of promoting capital goods production in developing countries in the age of microelectronics. That is, because of difficulties of unpackaging and appropriating machine systems employing new microelectronics technologies the beneficial impact that machine-production imparted on economies in the 19th century or to Japan in the 1950s may not be found anymore. Microelectronics has changed the rationale for capital goods production in developing countries. Yet which countries are more likely to succeed in the 1990s? Those with an established engineering and capital goods sector and experience in the use of new technologies or those with neither? As the pure and applied scientific content of production increases in leaps and bounds and the ability to appropriate, use and develop new technologies requires a minimum level of skill, knowledge and experience what hope for developing countries in the 1990s and beyond if they withdraw from the production and use of electronic capital goods?

Leaving the argument on the creation of a (resource-based) capital goods sector aside and going back to the creation of a downstream processing capacity similar difficulties emerge. Developing countries are closely integrated in the world economy and will increasingly be so. Even without the old arguments about the vast capital expenditures required and low employment generation, the establishment of downstream processing capacity in conditions of rapid technical change in materials development and advances in automation technologies creates new problems.

The large fixed capital sunk in the installed capacity and the output produced will be subject to threat of rapid product and process obsolescence, without an endogenous capacity to respond technologically. If a country is intent on continuing in or entering commodity metal production such as copper or aluminium in the 1990s the analysis in section IV makes clear that the markets for its output will increasingly be the large and smaller companies dominating specialty fabricating and advanced materials production in developed countries. Such companies will be shopping around for the lowest cost sources of metal production in the world. Would export revenues be stable or increase in real terms in the long run?

Increasingly primary exporters would need to confront questions such as the following: Should we remain in primary commodity production and move to downstream processing as a long run objective or can we make better use of our scarce resources in terms of developing alternative industries to meet social objectives and achieve export success? If we stay, what is likely to be the demand for our processed commodity globally and regionally in the medium to long run? What would be our competitive position in such a market? Even if our product may face grim prospects in the long run due to substitution should we stay in the medium-term, e.g. the next 10 years, in order to maximize returns for use in economic development? If we wish to stay at the processing end of this commodity as a long run proposition, again how would demand be regionally divided, if at all, and would our processed commodity only find markets as a high value added fabricated advanced material? If so, do we simply remain (competitive) suppliers of low value added commodities to developed countries' markets? Or, do we begin <u>now</u> to build up our scientific and technological capacity in order to develop our ability to produce and use new advanced materials some of which may directly incorporate our natural raw materials? Do we enter into joint ventures, even attempting to enter into fabrication and advanced material production aimed at specific market niches within developed countries? Is this necessary in order to enhance our scientific capacity, knowledge, experience and skills in the 1990s?

The central point is this. Whether developing countries remain in primary and processing activities or not, their industrial base will need to function, operate, compete and survive in a global market increasingly dominated by microelectronics-based technologies <u>and</u> advanced materials incorporated in both processes and products subject to great scientific content and rapid change. All industries are becoming more sophisticated, including the hitherto declining textiles and other sectors. What is the Third World to produce, unless it develops the ability to apply, use and develop electronics and materials technologies?

In order to produce and compete in the world market, in order to induce foreign direct investment in manufacturing, in order to import and efficiently use new technologies, a certain minimum is required in terms of infrastructure, education, skills, experience, locally available networks of supplies, spare parts, professional expertise, etc., in the new technologies. At some point developing economies must move in this direction, within the means at their disposal. If primary producers want to remain in primary production and processing they need to ask for how long and under what conditions. If they are to stay on a long-term basis then they must ask whether they wish to remain commodity producers or move even further downstream to higher performance, higher value activities. If the latter, they need to ask if such production will be oriented towards an emerging South market for such materials and/or niche markets in developed countries. For either markets, they need to ask what form of collaboration or dependence that entails with foreign TNCs. And finally, how the strategy in the primary sector is in consonance with an industrial strategy, that is designed to meet the technological challenges of the 1990s. The integration of domestic materials production or use with a domestic or regional capital goods sector would need to be evaluated in the light of perceived needs to acquire expertise in the production and/or use of new materials and information technologies. It should be clear that production of the new technologies would be inadvisable and inappropriate for several economies. Rather, in many cases, the main problem would be to devise appropriate materials use policies within the framework of a national science, technology and industrialisation strategy. This would be the case whether or not the economy remained in primary commodity production and processing, and whether or not capital goods production was advisable and, possibly, integrated with the primary sector.

2. Policies towards transnational corporations: The potential roles of joint ventures in advanced materials production

The research and development costs of new materials and the scientific and engineering expertise in design, manufacturing and testing is beyond the means of most companies. Materials production in the future is likely to be dominated by large integrated research-intensive transnational corporations. Indeed, another major feature of the global corporate environment in materials is the growing internationalization, mergers and acquisitions, licensing agreements and joint ventures. As a result technology is flowing across national boundaries at a high rate which poses both threats and opportunities for national materials industries. Certainly the companies are pressing for a liberalization of technology transfer rather than barriers to the current free flow in search of market advantage.

Even though markets are dominated by the large corporations in bulk production of materials, there is considerable room for smaller companies. Such smaller companies will play a very important role in the future materials markets through supplying new materials and processes for specialized niche markets too small for the large companies. They account for much of the evidence of flexible specialization and production for small market segments observed in materials markets in recent years, with their production processes still labour-intensive and requiring high skill and experience content.

Another major trend and characteristic is the massive support programmes for new advanced materials research provided by governments in the US, Japan, EEC and individual European countries. Governments are providing research grants, research labs, and co-ordination of industry and university pure and applied scientific efforts. One aspect of interest is the conflict between military interests and commercial interests arising from the international transfer of technology. Erecting barriers to technology transfer may have dire consequences for the national economy in the technology race. On the other hand, the large and increasing speed of technology transfer across boundaries means that a national economy cannot take for granted an assumed technological superiority, with inflows of technology being as important as the outflows. Moreover, enhanced industry and government research effort in the development of new materials is not enough to create or preserve competitive advantage in commercialization - what is required is that an appropriate technological infrastructure is in place for quick development and commercialization of the research effort's results. Otherwise these results will be transferred and used elsewhere.

In the midst of all this international activity and technology transfer in advanced materials, developing economies need to examine carefully the need and potential gains from engaging in joint ventures and licensing agreements for the production of ceramics, and metal matrix or polymer matrix composites with large TNCs or smaller specialized companies aimed at niche markets in developed countries, in the first instance. This must be in the context of a national science, technology and industry strategy.

In the US ceramics market the trend is towards vertical integration from powder suppliers to finished components due to inherent advantages over more fragmented firms. In addition a ceramics user (e.g. car producer) prefers to obtain a complete system rather than diverse parts to be assembled in a product. Few entrants are expected and the trend is for more acquisitions and mergers within the industry to consolidate efforts in a relatively small market. The majority of the firms in the industry are seeking joint ventures at the moment. Joint ventures are very popular in the Japanese market and they are the best mechanism for penetrating this market. Licensing agreements are uncommon in this market, but the next best thing, technology exchanges between Japanese companies and foreign companies do exist, e.g. NCK Spark Plug and ICI (UK). Acquisitions, joint ventures and licensing agreements are becoming common also in the European ceramics market.

Forward integration and acquisitions have also characterized the US advanced composites industry, reflecting investments in this area by diversified chemical and other industrial firms. US firms are using joint ventures in advanced composites as part of their marketing efforts to penetrate foreign markets by assuming a local identity. The other aspect of joint ventures is the attempt to synergistically combine the differing technological strengths of two companies. The US composite industry has right from the beginning used the licensing of basic technology from foreign firms, a point of obvious singificance to developing countries. At the same time licensing agreements are an important means for the transfer of production and distribution rights for products into and out of a particular economy. In recent years many European firms have entered the US market through acquisitions and joint ventures. Japanese activity in the US is concentrated in licensing and technology agreements with US firms. But the provisions place restrictions on the Japanese presence in the US market. This is a great handicap because the physical absence of Japanese firms from the US market reduces their proximity to important technological changes. The Japanese are reassessing their strategies but it is likely that the Republic of Korea will emerge in the long run as a direct competitor to Japan in the supply of inexpensive, low performance, fibres for cost-sensitive applications in cars and construction.

Clearly large opportunities await developing countries in the areas of collaborative agreements with TNCs in order to penetrate foreign markets, acquire technology know-how and scientific capabilities, and induce domestic production of advanced materials in consonance with local raw materials supplies.

3. The organizational setting of government institutions and human resource development

3.1 The convergence of science and technological knowledge

A major finding of the analysis in sections III and IV is the vastly increased pure and applied scientific content of materials production and use. The revolution in materials science has resulted in an increasing integration of a large number of disciplines required to conduct scientific research in materials, and the concomitant convergence of materials science and materials engineering. The barriers between disciplines have been eroded and the distinction between materials scientists and materials engineers engaged in processing and fabrication of products has all but become irrelevant. Moreover, teams of 'specialists', with the distinctions between them increasingly blurred, are required in product design, development and manufacture. New materials are revolutionizing engineering practices, where product design and materials selection have seized to be independent activities but have merged into a simultaneous process. Materials scientists and engineers increasingly require knowledge not only of their own manufacturing path but also of the design and manufacturing process of the product into which the material or component will be incorporated.

This interdisciplinary approach to materials research is one of the reasons that these industries will increasingly be dominated by large research oriented firms. It has also given rise to collaborative R&D research programmes in developed countries involving government, university and industry. They have taken the form of university-based consortia, quasi-independent research institutes, and government laboratories. They are viewed as good training grounds for students, and as a mechanism of translating pure research into commercial application. In practice firms value their participation more because it gives them access to highly trained personnel and students rather than commercial results. They can be viewed as a form of "infrastructure support" of the materials environment providing new ideas and personnel. Collaborative research in this form brings together a large number of researchers of different specializations and expertise required to undertake research in advanced materials due to the multidisplinary effort required.

3.2 Institutional linkages and the need for an interdisciplinary approach

Clearly as a first step primary producers need to study very carefully the reasons for, the degree, and the forms of developed countries' government support and co-ordination activities for national materials research and development. The role of the government in supporting and co-ordinating private sector and university as well as state owned or supported research institutes and laboratories engaged in materials pure and applied research acquires added significance in the context of a developing economy in the 1990s.

The convergence of materials science, technology and production engineering, in addition to the interdisciplinary approach required in materials development must be reflected in the organization of government and institutions attempting to grapple with the complexities and practical implications of the materials revolution. Failure to adopt to the changes occurring now could prove disastrous for specific economies and industries.

The effectiveness of the organizational setting of government and institutions needs to be strengthened through improved linkages, co-ordination, diversification and the elimination of duplication. Hierarchical structures need to be flatter and more flexible, together with a less rigid separation of departmental functions and responsibilities. A comprehensive view and multidisciplinary capability in analysis and decision-making is necessary to cope with the interdisciplinary requirements of the materials and electronics era. A National Materials Council or a similar body may be created with the power to integrate horizontally various government ministries and departments, in the area of materials technology and industry, co-ordinate their activities, formulate policies and monitor their implementation. Such a body would employ multidisciplinary teams with the ability to monitor scientific and technological developments, and the capacity to assess their domestic economic implications, and formulate technological and research responses nationally and regionally. The co-ordination mechanism would need to embrace private industry and universities, scientific societies and research laboratories in a national effort to develop an appropriate scientific, technological and industrial response to the changes ushered in by the materials and microelectronics revolutions. A key area that must be addressed is the unpredictability and large discontinuities that can result from major shocks and rapid technical change. If change cannot be predicted then institutions and mechanisms must be built to effectively manage and respond to change.

It is important at this 'early' stage, that developing countries begin to build up a long run capacity to absorb, analyse and respond to successive jumps in science and technology that threatens their competitive stance. The ability to respond must be dual. There is a need for institutions and centralized ministerial think-tanks, possibly in association with UN bodies and producer organizations, which can collect, identify, and interpret trends in science and technology and translate them into social, economic and industrial policies. A flexible, pragmatic and quick response to change is required without bureaucratic interference and delays. The second requirement of flexible response is the cumulative build up of a domestic scientific, technological and industrial base to provide the necessary skills for a real response at the level of production and technology.

3.3 Specific policies promoting the establishment of a domestic scientific and R&D capacity

A minimum level of internal scientific and technological competence is a prerequisite for application and generation of new materials and processing technologies. Probably the most crucial variable is the development of human skills and qualified manpower through education and training. In the age of advanced materials highly qualified professionals abreast of developments in the frontiers of their subjects will be as much in need as the acquisition of middle level skills and technicians for the unpackaging and use of technology. It is crucial that developing countries give the highest priority to the acquisition of skills at all levels through increased domestic education expenditures and training programmes, the training of nationals abroad, co-operative programmes with other developing countries and participation in international scientific societies, consortia and trade associations. The specific forms of domestic educational and skill capabilities deemed necessary would depend on the emphasis placed on production and/or use of new materials.

There must be greater institutional linkage, between the conduct of R&D and its potential users in industry, and greater emphasis on pure research. R&D funds can be increased through collaborative efforts between developing countries, but in the future public funds devoted to R&D efforts in research institutes and universities must be increased as a critical element of a national strategy to strengthen the domestic technological capacity.

It is crucial that developing countries, especially those at an early stage of their development, obtain the necessary infrastructure that will enable them to identify market opportunities. These would then be translated into specific needs for education, training, research and manufacturing capability. Enhanced scientific capacity would enable them to monitor and perceive scientific advances, which would then be translated into specific production processes. An appropriate supporting environment in terms of facilities and specialized centres which would assist the development of manufacturing processes, and quality control would be critical for a competitive stance in the world market. Again, the decision of production or use of new materials will be a primary concern for most developing economies.

A number of channels exist through which developing countries can expand their scientific know-how and research capacity apart from the general educational measures mentioned above. A Materials Science and Engineering Centre manned with appropriate multidisciplinary teams, funding levels and lab facilities, could research into particular materials or engage in wide ranging research in materials science and engineering. Such national or regional Centres, would assist primary producers to defend their commodities (e.g. natural rubber, cotton, bauxite, copper) in the medium term, develop high value added fabricating capabilities, enter related advanced materials markets and devise strategies for an orderly transition out of some commodities and into appropriate diversified industrial structures in the long-run. For comparison, in the US the Institute of Materials Sciences and Engineering, (an arm of the US Department of Commerce) has a multidisciplinary research staff of 400 scientists, engineers and technicians, and a budget of $40 million in 1987. It co-operates with other government agencies, industry and universities. In 1987, 374 visiting scientists and engineers conducted research there, and used its specialized equipment, a source which is unavailable elsewhere in the US. Developing countries would do well to examine closely the structure of such research establishments, their links with industry and universities, and university departments in developed countries. Nevertheless, caution must be exercised in the uncritical imitation and transplanting of developed country institutions to the context of developing country needs and resources. New science institutions in developing countries and their connection to production must be rethought afresh. Another crucial determinant of scientific capacity in materials research is the formation of domestic professional societies and their close interaction with equivalent professional societies in the US, Europe and Japan.

4. Opportunities for regional co-operation and the role of UN agencies

Regional co-operation offers great opportunities in terms of collaborative efforts in education and training, pooling and co-ordination of R&D expenditures, linking of national scientific and professional societies, and the establishment of regional centres for materials science and engineering for more successfully and effectively bringing together of a 'critical mass' of interdisciplinary teams engaged in pure and applied research. The latter is very important in view of the fact that research instruments in materials science tend to be beyond the means of large firms even in developed countries and are often provided in government laboratories for industry's benefit.

Moreover, existing national and intergovernmental research associations in specific commodities (e.g. wocl, natural rubber, bauxite) can be assisted to reorientate themselves towards a broader materials science foundation to inform a national, regional and producer organization effort in materials research and development. This could be undertaken under the auspices of UNCTAD and UNIDO. Regional sector specific Materials Science and Engineering Centres could be build up from existing research institutes, e.g. the Jamaica Bauxite Institute.

UN bodies are probably crucial agents for assisting primary exporters to confront the challenges posed by the materials revolution, although little can be achieved without direct government action within developing countries.

In this context the recommendations of a December 1987 UNIDO meeting that an International Materials Assessment and Application Centre be established are still valid. Its functions would include "collecting, analyzing and disseminating information relating to the diverse materials and undertake or promote techno-economic studies, especially those related to unique resources not likely to be studies by others. It should also organize and provide advisory services and facilitate training and research and development". The analysis provided in this chapter reaffirms the urgency for the establishment of an international centre which continually monitors and examines the trends and implications of new and advanced materials from the point of view of developing economies and promotes the use of domestic materials in the light of such developments in science and technology. In accordance with the requirements ushered in by the revolution in materials science, the Centre should engage in <u>both</u> pure and applied research <u>as an integrated process on the same premises</u>, establish contacts and exchange programmes with the world scientific community and learned societies, and provide centralised research facilities and instrumentation for use by scientists and industry from developing countries. Such a Centre would be invaluable in the building up of national and regional scientific and technological capabilities appropriate to the challenges of the 1990 and beyond, in formulating materials strategies in production and use appropriate to specific economies and in assisting those economies that face severe human, scientific and financial constraints in these areas. Naturally, careful thought must be given to the institutional structure of such a Centre so as to enable it to perform a dynamic, responsive, coordinating and useful function in meeting the needs of developing economies.

In addition, UNIDO's Industrial Technological Information Bank can play an important role in developing and disseminating data bases on the design, production and use of new materials and associated processing paths.

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