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# The Integration of Science and Technology in the Development Planning and Management Process in the ESCWA Region

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## INTRODUCTION

The importance of science and technology and the need for its integration in the development planning process in the Economic and Social Commission for Western Asia (ESCWA) region is discussed in the present study, in four substantive parts and a conclusion. Each of the parts covers the integration process from a different angle; collectively, however, they present a framework for a comprehensive approach to the subject. Before introducing the papers it is appropriate to explain our present concern with improving development plans at a time when concern with privatization in the ESCWA region (and worldwide) is on the increase and with central planning of the economy in decline.

To begin with, the concept of planning addressed here is not of the central Soviet variety. Instead it refers to one facet of management where central Governments, because of the nature of the economies concerned, play an active role in the investment process.

Most of the economies in the ESCWA region are oil-producing economies which rely heavily on oil revenues. Even the economies of the non-oil-producing countries in the region are often greatly affected by the volume and flow of oil revenues to the region. Governments in all the countries concerned thus play a strategic role in national investment expenditure. They also play an active role in formulating industry, trade, education and science and technology policies. Science and technology is immensely important with respect to all of these policies. These policies also affect technical change in the region's societies and technological changes in the region's economies; changes which constitute the main concerns of this study.

Thus, as Governments in the region are likely to play a significant role in the management of the economy, it is time that this role is examined in the light of technical and technological changes that are affecting economic development, with the aim of improving the roles and policies of the various Governments.

Following the introduction, part one of this study considers the state of science and technology in the region and explains why the integration of science and technology in development planning is important. It examines the institutions and the apparatus that should be involved in the integration process and makes suggestions about what needs to be done.

Part one is divided into five sections. The first section examines the place of science and technology in development planning and the role of planning in the development process in the region, taking the case of Jordan as an illustrative example. In the second section the paper examines the main components of the science and technology system in the region and points out the most strategically important components as well as their present limitations. The third section highlights the role of consulting and contracting firms in the acquisition of technology and explains how they act as the principal chain for linking the science and technology system to the investment process and to production activities. In the fourth section the paper describes the characteristics of industrial technical services in the region and discusses the requirements for the externalization of these services and the importance of this externalization in raising the demand for local technological capabilities. Finally, in its fifth section, the paper discusses the advantages of integrating the science and technology system in the process of technology acquisition and identifies two important policy measures for achieving this integration -- namely, the participation of local technological capabilities in the acquisition process and in technology negotiations.

Part two argues that the main institutional and intellectual frameworks for science and technology policy in the ESCWA countries, in common with most other developing countries, were inherited from the 1960s and 1970s, and therefore may be inappropriate for the 1990s. This suggestion is based on the evidence which has now emerged regarding the experiences of many developing countries and on the inevitable implications of the sweeping technological changes that are taking place in our time. Based on an analysis of the industrial sector, the study finds that the patterns and processes of technological change that have become increasingly evident during the 1980s indicate that new approaches are needed -- approaches that focus on the continuous nature of technical change, the central role of production enterprises in generating it, and the pervasive accentuation of technological capabilities that they must draw upon.

Part two begins, in its first section, by briefly reviewing the different approaches to science and technology policy in the 1990s, and also decribes some relevant experiences -- both inside and outside the region. The second section analyses the process of technical change, as well as new realities and perspectives. It also discusses the role of technology in technical change and some of the recent characteristics of technical change, with particular reference to the role of information technology and organizational change. The third section discusses technical change within the context of economics and resource-base considerations, and points out how engineering, rather than research and development (R and D) is the engine behind technical change, the central role played by production enterprises, and the role played by industrial firms in creating human capital. Finally, the economic context for the operation of firms, markets and Governments is discussed.

The third part is also made up of three sections. In the first section the study reviews the experience of a number of countries in the field of R and D, exploring how it has evolved and been integrated within the organizational structures of production enterprises. The second section reviews in detail the various approaches followed in the integration process, including integration through planning and improved resource allocation, integration through organizational and managerial change on the R and D supply side, integration through change in policy affecting industrial demand for R and D, and integration through building bridges between R and D institutions and industry. In the third section, the more radical approaches to integration are covered, and some fundamentally different structures for integrating R and D with production and technical change are examined. This approach, the section argues, is supported by the growing understanding of the process of technological development. The suggestion presented here is that it is better to shift policy emphasis towards changing the structure, which is already disconnected, than to try to maintain it and establish links. Maintaining this structure, it is argued, would cause "the inherent weakness to become increasingly evident". The section then sketches several approaches that may be adopted in this new strategy. They include: integration through strengthening the R and D function in firms, as well as other technological capabilities; integration through changes in the roles and activities of institutions; and integration through the creation of new firms -- "spinning off" and "spinning out".

The fourth part is an attempt to "develop a framework for technology-integrated development planning". It approaches the exercise by looking at technology as the driving force in the process of production, growth, trade and competition. The paper deals with technology in this regard as the "master key" to sustainable socio-economic development.

Firms, or production enterprises, are regarded in this study as the most effective agent for introducing technological innovations. The framework developed in part four is a holistic one. Technology transfer and technology development are linked to development strategy at all levels of investment decision making. The methodology developed is for managing technology in the context of public- and private-sector enterprises and at the sectoral and national levels. Part four also discusses methods of developing technological capabilities and of drawing up a "progression path" for technology strategies. The analysis focuses on the degree of sophistication of the components of technology, the status of the technology infrastructure and the dynamism of the technology climate.

This part includes the following sections: new world order of technological change; review of the existing situation in developing countries; the technology resource characteristics; the technology structure of production systems; the sophistication of technology components; the advancement of technology capabilities; the progression of technology strategies; the development of technology infrastructure; the dynamism of the technology climate; the identification of technology needs for sustainable development; required technology-assessment procedures; and imperatives for technology integration.

To conclude, it is to be noted that although the title of the study refers to selected ESCWA countries, the analysis and discussions of the study apply to all of the member countries in the ESCWA region. The "selected countries" referred to in the title stems from the fact that case-studies covering certain ESCWA countries were carried out and subsequently presented, along with this study, at the workshop organized in conjunction with this study. The proceedings of the study will be published at a later date.

## Part One

# THE INTEGRATION OF SCIENCE AND TECHNOLOGY INTO DEVELOPMENT PLANNING

## I. INTRODUCTION

The objective of part one is to draw attention to certain aspects of the processes of integrating science and technology (S and T) with development planning, with special emphasis on science policy and the science and technology system (STS).

Science policy is essential to sound planning, as it provides a kind of road map; every country has tens of thousands of new and old activities involving science and technology, and it is science policy that brings about coherence and harmony between and among the various institutional services (scientific, economic, legal, financial, political and cultural).

The STS provides the instruments for articulating these many thousands of different activities into a meaningful, operational whole. The STS is a dynamic rather than static structure; it must constantly undertake technical operations to exist.

Very briefly, the STS consists of all organizations, firms and institutions that are engaged in research and development (R and D), and in the dissemination, management, application, financing, and planning of science and technology.

## II. ORGANIZATION OF THE PAPER

This paper highlights selected aspects of the subject under consideration. Five topics were selected -- primarily for their economic importance and for their role in assessing the feasibility of undertaking significant change at a relatively low cost. The five issues selected for special emphasis are summarized below.

### A. The place of S and T in development planning

This topic is central to the study because almost every ESCWA country prepares a development plan. These national development plans provide a good mechanism for the progressive adoption of science policies and the incorporation of an STS within the country. An examination of Jordan's 1986-1990 Development Plan illustrates this point.

### B. Articulation of education and the world of work

The largest investment made by the ESCWA States thus far in S and T has been in manpower development. This is, of course, an essential and strategic investment -- but for this investment to bear fruit, the educational system and the human resources made available have to be integrated into an STS. An examination of the extent of this articulation provides an illustrative example. The strategic importance of this topic arises from the fact that while the financial cost of articulation is small, the returns to the national economy are considerable; this is an area where considerable economic returns may be obtained for a limited financial investment.

C. The strategic role of consulting and contracting firms

Consulting and contracting firms are crucial instruments in a science and technology system. They are central to: the processes of selecting, adapting, adopting, applying, accumulating and acquiring technology; the promotion of forward and backward linkages; and the employment and integration of the technologies in use with national R and D. Additionally, through their staff engineers, they can contribute to the development of the curricula of national universities to bring these curricula into harmony with the technology in use.

These features are briefly illustrated by a number of references to case-studies. With more than 10,000 consulting and 100,000 contracting firms existing in the Arab world, it should be feasible to achieve rapid progress in this direction given adequate policies and procedures. Savings in terms of foreign exchange of the order of $50 billion annually are readily realizable.

D. Externalization of industry-related services

A major development industry is to be found in what is known as "externalizing", deintegration and "outsourcing"; major firms have been subcontracting increasing proportions of non-core, in-house activities. These non-core activities involve consulting, engineering design, R and D, financial management, personnel, printing and publishing, renovation and maintenance (R and M), manufacturing, and so on. These services are known under various names: industry-related services (IRS), professional services, business services and technical services. The manufacturing firm designs its products, then finds a subcontractor for the manufacturing of the components of the final product; however, the firm controls the quality of the manufacturing processes. In so doing, it reduces its costs because small manufacturing firms, which carry lower overheads, can be more efficient than large firms. It will be argued that the Arab countries have some of the world's largest industrial firms that are still self-contained; if they were to externalize their non-core activities, they could bring about a major revolution by providing enormous technological capabilities to small and medium-sized firms which would not otherwise have been able to afford such services. The relevance to the ESCWA countries of this transformation of the modes of production is discussed with reference to the implications of these processes vis-à-vis technology transfer, and to the industrial development of the ESCWA States.

E. Integration of S and T with project negotiations

The importance of giving adequate attention to the S and T aspect in contract negotiations is emphasized throughout the paper, and additional observations are made in this section. Since the Arab world is -- and will continue to be -- a major importer of industrial products and services, the development of skills and policies to guide negotiators is of considerable importance. Capable negotiators could make an enormous range of technologies accessible to firms in the ESCWA countries; this access would also reduce the cost of projects.

## III. PRIORITY ISSUES

There are hundreds of thousands of organizations (industries, large and small firms and government departments) in the Arab world which supply and consume technology products and services; furthermore, there are tens of thousands of unexploited opportunities every year for the transfer of technology from firms outside the world. Many opportunities could be utilized nationally and regionally with a view to promoting the articulation and marketing of STS services. The primary targets of an effective science policy and a useful STS are the basic and substantial sectors of the national economy.

Properly designed policies and science and technology systems should promote the relationship between the suppliers and the consumers of technology, the diffusion within the ESCWA countries of already available and useful technologies, and the transfer of technology associated with current imports.

The interface between development planning and science and technology is complex; these complexities arise as much from the cultural, political, intellectual and social requirements of technological activity as from the scientific and technical aspects.

The sections outlined below are issue specific; the contents, however, may overlap. In each case, the objective is to illustrate the enormous range of opportunities available to make a breakthrough and the low cost of the effort required.

### A. The place of S and T in development planning in the region

Development planners are concerned with macro- and micro-economic policies that contribute to economic growth. At this Workshop,[1] we are interested in the development of science and technology and its integration into the national economy; this also implies the integration of S and T into the activities of organizations and institutions that undertake economic activities.

Here we find a wide variety of consumers of technology services: hospitals, municipalities, the military, mining companies, telecommunication companies and so on. The inputs of the STS change with the evolution of a project or programme -- from conceptualization, technology assessment and evaluation to implementation, product development, product design, R and M, marketing, quality control and so on.

It is assumed in this paper that development planning covers a broad spectrum of activities, including those listed below:

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[1] The Workshop on Integration of Science and Technology in the Development Planning and Management Process, held in Amman from 27-30 September 1993.

1. Basic needs

Here the problems consist of providing shelter, food, clothing, education, and health services -- generally to persons with a per capita income of less than $300. More than 50 per cent of the population in the ESCWA countries live below this level. Famine conditions, malnutrition, crowded living accommodations (more than two persons per room), a life-span of less than 60 years, and an average formal education of less than five years all apply to more than 110 million Arabs in 1993. The solution to each of these problems requires expertise in technology policies and the development of appropriate systems.

2. Industrial development

ESCWA countries already have a large array of advanced industrial installations in place to produce cement, ceramics, petrochemicals, paper, electric cables, aluminium, phosphorus, and fertilizers, and to assemble tractors and television sets. Many Arab firms already operate on a global scale. With minor exceptions, these plants have been imported as "black boxes"; some operate far below installed capacity, and their operations are dependent on foreign inputs of spare parts, industry-related services and supplies, thus increasing the cost of their output. The development of capabilities in consulting, contracting, repair and maintenance, product design, standards, improvement of labour productivity and quality control is the objective of this Workshop.

Policy can play a significant role in the "absorbing" of these "black boxes" into the ESCWA economy and in initiating or facilitating their use as vehicles for the transfer of technology. It will be shown that the practice of "outsourcing" offers a powerful tool for achieving such an objective.

3. Agricultural development

ESCWA agriculture suffers from endemic problems: low yields, poor diversification of products and extensive use of ill-adapted technologies. Further, effective and high-quality extension services are not widely available.

4. Urban development

The ESCWA countries face extensive and growing problems in city planning and urbanization. These problems arise partly from the high cost of the California car-based living styles that have been blindly adopted in most ESCWA States; this urban style of living is unsustainable because of its high economic and social costs.

Furthermore, there are enormous technology gaps in every ESCWA State between the capital city and the rural areas, where more than 50 per cent of the population live. The slow rate of development of rural areas and small towns -- partly due to the low rate of technology diffusion within the individual country -- has resulted in high rates of migration from rural areas to capital cities -- induced by the low rate of economic development in the rural areas. These rural-urban migrations have exacerbated the problems of the city; however, modernized versions of traditional ESCWA cities may offer relevant solutions that are also cost-effective.

## 5. International competitiveness

The cost and quality of many of the industrial products and services produced in the ESCWA countries are below the international standard; this is the case whether one is discussing car manufacturing or food industries. Many of the economic problems facing ESCWA countries are associated with the high cost of production -- specifically, the high cost of low efficiency and mismanagement, which the ESCWA consumer must bear in the end.

It is clear from the above that a wide range of technologies and planning is needed to address the developmental challenges that any society faces. All economic activities should benefit from the availability of a science policy and STS.

## 6. Case-study: Jordan's Development Plan for 1986-1990

Most Arab Governments prepare development plans that are meant to cover a significant portion of the economy. Though they generally exclude military expenditures, the development plans are still extremely important vis-à-vis the national economies.

Development plans are important because they represent a deliberate attempt to introduce new programmes, policies and activities. The main objectives of these plans are related to social, economic and political affairs, and science and technology is essentially the main instrument through which these objectives may be attained.

Jordan's 1986-1990 Five-Year Plan has been selected to explore and illustrate how science and technology is perceived and incorporated into the Plan.

The Plan devotes 21 pages to science and technology as it relates to three very different, trans-sectoral topics: legislation and management, science and technology, and the environment. This is a good start; science and technology is an activity that pervades all economic activities.

The Plan's introduction to the science and technology section seeks to present an assessment of past performance -- but it fails to do so because it confuses imports of packaged technology in "black boxes" (cement and dominium phosphate plants, telecommunications installations, etc.) with the establishment of standards and the growth of consulting and contracting services.

The "assessment" does not inform us of changes in the proportion of technology-free imports, the extent to which the standards that were adopted were actually enforced, and how these standards influenced exports. Information and analysis of any shifts away from the traditional technology-free mode of imports should be as important a feature of plans as the change in gross domestic product (GDP); however, no such analysis is presented.

The Plan then discusses 11 items under the title "Characteristics and Problems". Most of the items consist of aspirations which are in fact devoid of any technical content. A more analytical and quantified presentation of these items would have been more useful. For example, the Plan is fairly committed to the establishment of standards; under item six, it says that there is a need to intensify the efforts devoted to establishing standards as well as legislation for implementing these standards.

It would have been very informative and useful if the Plan had provided information on: the percentage of Jordanian production, imports and exports covered by standards; the type of standards that were enforced; Jordan's estimated economic losses resulting from the import of products without the enforcement of standards; and whether (and why) Jordan's exports could be increased in quantity and value if standards had been applied.

The Plan also includes a section called "Goals"; however, there is no mention of whether or not there is an authority responsible for enforcing goals. The statements listed under "Goals" are generally diffused. Item six states that there should be efforts "to control and organize the transfer and import of advanced technology....".

An examination of the rest of the Plan, however, reveals that none of the ministries or departments actually importing large quantities of technology products (the total price tag of the Plan was $10 billion) was even remotely concerned with the transfer of technology.

The fourth section of the Plan is entitled "Organizational Measures". There are 19 items under this topic, and they all emphasize the supply side of technology; none deals with the demand side, or with the integration of supply and demand.

The first item in this fourth section reveals why the previous sections did not represent a serious, well-defined Plan. It calls for the establishment of a "working group" to prepare "an appropriate national structure" for planning science and technology. In other words, Jordan did not have the formal organization to manage such an activity.

It can thus be concluded that the 1986-1990 Jordan Development Plan was silent concerning the treatment of science and technology and the measures that should have been adopted to enhance the utilization of its capabilities; it was also silent on the measures that should have been taken to implement the $2 billion-a-year projected investments in a manner that would have increased national capabilities and led to the accumulation of acquired technologies.

The science and technology section in Jordan's Development Plan lacked two essential ingredients to make it useful: it had no science policy content; and it did not reflect the construction or promotion of a science and technology system.

## 7. Negotiating technology transfer

Development plans usually involve a large amount of investment; each project provides excellent opportunities for technology transfer. The scale of the projects involved in a development plan justify the additional expenditure of time and money to organize national capabilities with respect to the transfer of technology. Naturally, it is most economical to carry out the transfer of technology during the implementation of each project.

If technology-transfer planning is properly conducted, it should result in:

(a) A reduction in the share of foreign exchange in each project;

(b) An increase in the local capacity to provide R and M services in subsequent phases of the project;

(c) An accumulation of local technological capabilities with a view to exporting such services at later stages.

In order to achieve any of the above, considerable analysis and negotiations need to take place with foreign firms which are being sourced to transfer technology. Any plan would therefore offer considerable opportunities for the enhancement of a country's capabilities to negotiate technology contracts and organize the transfer of technology.

The 1986-1990 Jordanian Plan contained a five-year programme to invest some 19 million Jordanian dinars (JD) (or about $60 million) in studies and new facilities. The total allocations for the Plan are JD 3,115 million (nearly $10 billion). The disparity between these two figures reinforces the earlier conclusion that the Plan did not intend to develop and/or apply a science policy.

### B. Articulation of education, manpower and the world of work

ESCWA countries devote substantial resources to education, both at home and abroad. Because of the importance of this subject vis-à-vis the process of integrating S and T with national planning, the nature of the difficulties facing the ESCWA countries in this regard will be illustrated in some detail, with the aim of identifying practical measures that may be useful in dealing with them.

It has been established that as a country industrializes, the ratio of the accumulated investments in manpower (health and education) to the accumulated investments in physical assets (infrastructure, housing, industry, and agriculture) increases.

Currently, this ratio in Organization for Economic Cooperation and Development (OECD) countries is around 1.0. In developing countries, however, it is closer to 0.1.

The second feature of industrialization is that the per capita gross investments in education and physical assets increase; it is, for example, approximately $100,000 per job in industrial societies.

It goes without saying that the competence and specialization of manpower and the availability of physical assets have to complement each other for each to be useful. It is of little use to educate and train open-heart surgeons if they are not provided with the facilities to apply their skills; similarly, it is of little use to educate chemical engineers in carbon fibers or genetic engineering if they are not employed in areas close to their respective fields of specialization.

Industrial countries have established a large variety of skills and competencies; the significance of these skills depends on the effectiveness with which S and T is integrated into the economy. In order to manage such complex economies, a wide range of mechanisms for articulating the various producers and consumers of skills are necessary. A large volume of statistical information is also needed.

In the following section, the topics discussed include: learning and statistical information; labour productivity in the ESCWA region; the articulation of curricula with the demand side; the channels and costs of articulating supply and demand; and the role of professional societies in the process of articulation. The discussion will aim at two things: first, to describe the state of affairs in the region; and second, to identify some low-cost solutions for dealing with the problems.

### 1. Learning and statistical information

In contemporary industrial societies, learning is truly a lifelong activity. Extensive continuing education systems have been established. Learning is no longer restricted to formal and informal activities. Industrial operations are often organized in a way that promotes learning at all levels of the various occupations; learning from experience is an important component of the system. In the ESCWA countries, on the other hand, education is still restricted to the first 20 to 25 years of a person's life.

Learning from experience is essential in a society anxious to integrate its S and T into its development. Learning from experience is contingent upon the collection and diffusion of massive amounts of relevant statistical information. Such behaviour is especially important in an industrial or industrializing country.

Learning from experience is practised today on a large scale; the more dedicated the effort the greater the reward. David Garvin finds that the processes of institutional learning involve:[2]

(a) The capacity to modify behaviour in response to the new knowledge and insights acquired through the learning process;

(b) The capacity to transfer knowledge throughout the organizations through the circulation of personnel and other means;

(c) The capacity to compile, analyse and audit a vast amount of statistical data that reflect the performance of the organization.

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[2] David Garvin, Harvard Business Review (July-August 1993), reprint No. 93402; quoted by Christopher Lorenz, "Lessons of experience", the Financial Times (6 August 1993).

By contrast, planning methods in the ESCWA countries reflect limited institutionalized capacity for learning from experience or from research studies. For example, a report prepared jointly by ESCWA/United Nations Industrial Development Organization (UNIDO) Industry Division and the Arab Industrial Development Organization's (AIDO's) Global Studies Department entitled "A framework for a masterplan for the development of technological capabilities in the oil refining, petrochemical and fertilizer industries in the Arab world" (1987) defined the existing technological limitations in this vital industrial sector and made significant recommendations. These recommendations appear to have been ignored, and little has changed in this sector since 1987. A great deal could have been achieved in the six years since the report was published had the recommendations been applied.[3]

2. Labour productivity

Three leading Arab economic institutions -- the Arab Fund for Economic and Social Development (AFESD), the Arab Monetary Fund (AMF) and the Organization of Arab Petroleum Exporting Countries (OAPEC) cooperate to publish the annual Unified Arab Economic Report. The first report in this series was published in 1980, and there has been an annual publication ever since. The fourteenth publication (the 1992 Report) is thus the result of the accumulated wiqdom of the analysts who prepare it. The perception and analysiq of the Arab economies as presented in the Report reflect the quality and sophistication of prevailing economic thought.

The 1992 Report devotes one page to education, half a page to the subject of the labour force and one page to human-resource development. There is no mention of labour productivity anywhere in the Unified Arab Economic Report. It does, however, include supply-side statistics on the average number of years of formal education received in the Arab countries; in 1990, these ranged from a maximum of 5.6 years in Qatar to 0.8 years for Yemen and Sudan. The figure for the Syrian Arab Republic was 4.2; Iraq, 4.8; Jordan, 5.0; Lebanon, 4.4; Egypt, 2.8; Algeria, 2.6; Tunisia, 2.1. The figure for the Republic of Korea was 8.8 years; and for Singapore, 3.9. (An examination of OECD data would reveal that the figure for OECD countries is about 14.0.)

The report does not discuss the quality and significance of these low levels of formal education received in the ESCWA countries or their implications for their development prospects.

UNIDO's Industry and Development: Global Report 1992/1993 gives some data on labour productivity and wages (per worker) for 1970, 1980, and 1990 in North Africa and Western Asia as a percentage of the North American level in constant 1985 dollars; these figures are provided for 29 different categories of industry. The average labour productivity in the region declined from 32.33 in 1970 to 24.85 in 1980 and to 18.65 in

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3 It is often forgotten that oil was discovered in the Gulf of Suez as long ago as 1820, and that the oil resources of Iraq began to be exploited in Ba'quba more than 100 years ago. The oil sector in the ESCWA countries is therefore not a recent addition; for to all intents and purposes, it is as old as those in Russia and the United States.

1990. Wages also declined, but not to the same extent -- from 24.15 in 1970 to 19.98 in 1980, remaining at 19.98 in 1990.[4]

The decline was recorded in every one of the 29 categories except for the following four (the figures provided represent the years 1970, 1980 and 1990, respectively):

(a) In furniture and fixtures, labour productivity increased: 29.74, 32.70 and 30.66;

(b) In glass and glass products, labour productivity was maintained: 20.70, 21.29 and 20.80;

(c) In metallic products (excluding machinery), labour productivity was maintained: 28.16, 23.31 and 28.43;

(d) In non-ferrous metals, labour productivity increased (following a decline): 21.26, 15.19 and 33.82.

Clearly, none of these four categories represents either important economic activities or new technologies.

By contrast, labour productivity in:

(a) Japan increased from 57.49 (1970) to 71.14 (1990);

(b) Western Europe remained nearly level at 43.60 (1970) and 41.79 (1990);

(c) East and South-east Asia increased from 12.20 (1970) to 17.66 (1990);

(d) Latin America and the Caribbean countries remained nearly level at 29.50 (1970) and 29.22 (1990); the same is recorded for the Indian sub-continent: 5.09 (1970) and 4.48 (1990);

(e) Tropical Africa declined from 15.7 (1970) to 10.0 (1990).

The first important feature to note is the dramatic decline, relative to the United States of America, in labour productivity in the ESCWA countries. The decline of 42 per cent over a period of 20 years is certainly startling, especially after the 1975 conference on the development of the Arab industrial labour force placed such great stress on increasing labour productivity.[5]

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[4] United Nations Industrial Development Organization, Industry and Development: Global Report 1992/1993, table 11.52, p. 90.

[5] See the Report and Recommendations of the Second Arab Conference for the Development of the Industrial Labour Force, held in Baghdad, 29 November-4 December 1975. The ministerial-level Conference was organized by the Arab Labour Organization and IDCAS -- now AIDMO (the Arab Industrial Development and Mining Organization).

Nearly 20 years have elapsed since the Baghdad Conference was held in 1975. There has been ample time for the implementation of the recommendations adopted then. However, as may be seen from the performance noted in the UNIDO Report, there has been a massive decline in labour productivity in comparison with international standards.

Interestingly, an International Labour Organization (ILO) seminar on the subject of employment policies in the Arab Countries[6] did not even mention labour productivity:

The second point to note is that in 1970 the Arab countries were not far below Europe or Japan in labour productivity. The decline occurred after the oil boom, after "the investment" of $2,000 billion in Gross Fixed Capital Formation (GFCF), and after a massive expansion in the educational system at all levels.

A third observation is that even at its present low level, labour productivity in the ESCWA countries is still comparable to that in Latin America and ahead of East and South-east Asia's (and other regions') labour productivity.

The fourth interesting feature of the data provided earlier is that it "generalizes" the findings of Dr. Hindawi on the Syrian cement industry; he found that the more engineers and technicians a cement plant employed, the lower its labour productivity.

This is a unique phenomenon which could be related to the increasing dependence on turnkey and client-in-hand forms of contracting, which became favourites with the increasing number of professionals and the increasing financial resources. This is an excellent empirical illustration of the lack of articulation between education and the labour market.

### 3. Articulation of curricula with demand side

Higher education in the ESCWA countries is managed by bureaucracies. The interaction between the universities/governing bureaucracies and professional groups is very limited. It is usually the professional groups that possess useful expertise, and that could make significant contributions to developing curricula, R and D activity, standards for admission and graduation, standards for instruction, and the quality of instructional facilities.

There are no known objective, quantitative assessments of higher education in the ESCWA countries, even though such studies are greatly needed.

In general, engineering degree programmes at Arab universities are basically sound, although students are not exposed to the economic, managerial, legal, environmental, informational or social aspects of the discipline. The contents of the engineering school curricula are also still behind the times; teaching methods are, with

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[6] Problemes de Politique de l'Emploie et de la Main-d'oeuvre dans les Pays Arabes: Propositions pour l'Avenir, held in Geneva in January 1983.

some exceptions, bookish and divorced from R and D, and student awareness of ongoing technology projects in the ESCWA countries and of international scientific advances leaves a lot to be desired.

In the absence of detailed and systematic field studies, we rely on the example of Egypt to illustrate the status of academic programmes concerned with engineering education in the region.

Dr. Farkhonda Hassan spoke at the 1988 Cairo meeting of the American Association for the Advancement of Science (AAAS) on "The role of scientific and engineering associations in development." Dr. Hassan blamed Egypt's failure to derive its due from its vast number of professionals on "the theoretical training received in Egyptian universities and the quality of science teaching at the school level".

Dr. Hassan stated that although the number of trained professionals was large, they had little impact on national development. He attributed this situation to "the lack of awareness among people as well as policy makers".[7] This cannot be the case, since roughly half of all cabinet ministers in Egypt hold a Ph.D. or an M.D., and many of them are precisely those same engineers. The failure to utilize these resources is clearly not due to the lack of awareness by policy makers.

Although Dr. Hassan may be right in saying that Egyptian universities education leaves much to be desired, the problem may lie elsewhere. The fundamental problem might be, as Moore has shown, that Egyptian (and by extension Arab) engineers have opted out of being involved in a modern industrial economy, and have been satisfied with working in a surrealistic world of make-believe.

If the above is true, there is no particular reason to improve education; improvement calls for hard work, competition and interference with the working of the prevailing political economy. The acceptance of a surrealistic world of importing services and products in a technology-free mode eases the lot of those professionals who are fortunate enough to occupy key positions in cabinets and parastatals.

It is useful at this point to enquire whether the education of engineers under the technology system prevailing in the ESCWA countries is counter-productive; in other words, Arab Governments may have to get rid of either their engineers and schools of engineering or their current technology policies. The two are incompatible.

Zahlan has shown that there is an enormous difference between educating and utilizing manpower. The effective employment of technical manpower is dependent on the adoption of appropriate technology policies. He has shown that ESCWA countries have adopted technology policies that favour the use of foreign products and services, and do not require the development and employment of national organizations. The problem lies in the system, not with the manpower. The main "sustainer" of the existing

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[7] Clement Henry Moore, Images of Development: Egyptian Engineers in Search of Industry (Cambridge, MIT Press, 1980).

technology-free-transfer system (TFT system) is the political economy and the willingness of Arab scientific workers to work within that political system.[8]

4. Channels and cost of articulation of supply and demand

As the previous pages have noted, a significant feature of the ESCWA countries is the limited articulation between the educational systems and the world of work. This subject is so crucial that it warrants further exploration, particularly because the process of articulation involves social and cultural change rather than capital investments in physical facilities; in other words, reforming the present system will not require any physical inputs. There is fortunately already considerable experience within the ESCWA countries in (the manner of) achieving this articulation.

Some of the papers presented to the Joint ESCWA/UNIDO Workshop on the Integration of Science and Technology in the Development Planning and Management Process in the ESCWA Region, held in Amman (1993), deal specifically with the successful development of such articulation. The problem is not that no such articulation exists; nor is it that Arab professionals are unaware of the importance of improving articulation. The problem is rather that the scale of the efforts to date has been minuscule in comparison with the challenges and requirements of the ESCWA countries' economies.

Effective articulation between universities and the users of technology is complex and depends on a number of direct channels of communication. The most important of these are briefly described below:

(a) Employment of university graduates. This is a universally recognized one way channel and it has already been demonstrated that this channel is not functioning properly;

(b) Consulting services. These are provided by university professors to consulting firms, contractors, government departments and industrial firms. Experience shows that the development of successful relationships between individual professors and consumers of such services requires patience and lengthy interaction. This channel is poorly developed in the ESCWA countries; there have been many attempts to develop it further, but to date the prevalence of current technology policies that favour high-technology-free imports reduces the need for local inputs;

(c) R and D contracts. University professors and departments could provide extensive services within the framework of "contract research" for technology consumers. Most universities in OECD countries have established specialized offices that market the consulting services of faculty, and these offices seek to attract R and D contracts.

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8 United Nations, Economic and Social Commission for Western Asia, Technology Policies in the ESCWA States, "The science and technology syndrome in the Arab world", by A. B. Zahlan (New York, 1986): for analysis of the relationship of manpower requirements to different technology policy scenarios, see: A. B. Zahlan, "The requirements of the ESCWA countries for manpower", Arab Thought Forum (Amman, 1990) (in Arabic).

The Proceedings of the ESCWA Expert Group Meeting on Strengthening Research and Development Capacity and Linkages with the Production Sectors in Countries of the ESCWA Region (1987), provide a good sketch of the prevailing situation: funding for R and D activities is limited (less than 0.5 per cent of gross national product [GNP]), and the linkages between R and D and the production sectors are weak.

Professor Nockrashy's Workshop paper presents a very interesting account of his experiences in articulating suppliers and users of R and D.[9]

(d) Training and continuing education. The high rate of technology change and obsolescence has led to large investments in the continuous upgrading of staff skills in industrial countries; universities and university professors provide a great deal of the educational inputs. Continuing education is still a novelty in the Arab countries, however;

(e) Publications. The publications of the professional staff of technical firms (including the staff of consulting firms and agricultural research stations) and the publications of university researchers create an important link through which individuals become acquainted with each other.

Direct channels of communication, when established between researchers who are active in complementary fields, often leads to consultancies, R and D contracts and training courses.

This channel is not active in the ESCWA countries, since publications in academia and in industry are rare, and because there are few opportunities for young scientists and engineers to meet and exchange information;

(f) Royalties from patents. The patents resulting from faculty research are beginning to generate a small but growing income for many universities in industrial countries. For example, Stanford University and the University of Wisconsin each earn more than $10 million a year from such royalties. Specialized foundations such as the Research Corporation in the United States market such university patents on behalf of universities and researchers. This tends to be an inactive channel in the ESCWA countries, as is shown in Nockrashy's paper.

Many obstacles contribute to keeping academia and the world of work apart -- risk factors, poor communication between the two parties, and the fundamentally different cultures of the two worlds of learning and work. This is true today, though during the golden period of Arab civilization, Arab scientists and mathematicians found no barrier to moving back and forth between the two worlds of theory and practice.

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[9] A. S. El-Nockrashy, "A case-study on national system for productive research and development management" (E/ESCWA/NR/1993/WG.2/3), presented to the Joint ESCWA/UNIDO Workshop on the Integration of Science and Technology in the Development Planning and Management Process in the ESCWA Region, held in Amman in 1993.

In OECD countries there are different relationships in different countries. In the United States, the business/academic frontier is crossed by both parties with little difficulty. In Europe the situation is changing; European Governments are making a considerable effort to facilitate these crossings.

The above-mentioned linkages between university professors and users of technology throughout the economy do not come about spontaneously. Universities and industry, as well as federal and local Governments, all have to play a more significant role in promoting and mediating these processes. Following are some of the factors which promote articulation:

(a) Professional societies must assume the important responsiblity of bringing together fellow scientific workers employed in disparate institutions. The meetings organized by professional societies provide a crucial -- and low-cost -- two-way communications channel between scientific workers.

These two-way flows of information and contacts have many important consequences. On the one hand, they influence academic programmes and university research, and provide early "warning" concerning new scientific advances to the users of technology; on the other hand, they provide an important input to the processes of (a) establishing priorities in advanced fields and (b) shaping the direction of research programmes;

(b) Research parks provide another important channel of communications between universities and the consumers of technology: no such development has taken place in the ESCWA countries. Industrial parks have also been crucial to the promotion of articulation.

Arab universities have had some experience in cooperating with technology consumers, especially in the field of agriculture (where schools of agriculture have been important sources of technology to farmers), as well as in some industrial fields. Some of the papers presented at this Workshop address aspects of this subject. Nevertheless, the subject is still in need of systematic and extensive surveys and evaluation.

## 5. The multidisciplinary aspect of modern science and the unidimensional aspect of the planning methods employed

This issue was addressed in some detail in a paper presented at the ESCWA Workshop on Implications of New and Advanced Materials Technologies for the Economies of the ESCWA Countries (Damascus, 21-24 September 1992). The main point made in that paper was that many areas of technology are intensively multidisciplinary, and that it will be impossible for the ESCWA countries to acquire these technologies without a radical change in the culture that dominates academia and R and D policies. Unidimensional expertise is of little importance in many new areas of science and technology.

## 6. The role of professional societies in the process of articulation

It is useful to re-emphasize and elaborate on some of the remarks made above concerning the importance and roles of professional societies. The continuing absence of strong and effective professional societies is a guarantee that present technology policies will remain unchallenged.

Without the existence of professional societies it is impossible to marshall professional opinion, distill and organize the views of the scientific community, and then transmit them to the relevant ministry with the scientific authority needed to back the stated opinion. Presently, the existing system is maintained by individuals, loyal to authority, in a state of paralysis.

There are a number of serious constraints upon Arab higher education and the collective behaviour of professional groups:

(a) Professors can only teach the subjects that they themselves studied as Ph.D. students; in other words, university professors are not expected to be capable of learning or discovering anything new;

(b) There is no multidisciplinary education in the ESCWA countries. Professor Gamal Eldin Nassar presented a paper on "The role of Egyptian engineering organizations in professional, training and educational aspects" at the Cairo AAAS Meeting in 1988.[10] He reported on a study undertaken from 1978 to 1981 by the Egyptian Ministry of Housing and Reconstruction in collaboration with the World Bank to "improve the capacity and efficiency of the domestic construction/contracting industry". One of the outcomes of the study was a recommendation to start providing management training to engineering students. Dr. Nassar reports that it was not permitted "for faculties of engineering in Egypt to introduce management disciplines, officially, in its curricula". An engineer thus cannot be taught management sciences, although this is central to the practice of engineering. Moreover, all the new fields in science and technology, such as materials science and solid state physics, do not exist in most universities in the ESCWA region.

Higher education in the ESCWA countries is an activity that is of little benefit to the end-user; there are few bridges relating the various academic disciplines to the professions that employ the graduates. There are weak two-way relationships between the universities (which were supposed to be fountainheads of R and D) and advanced education and the economy. In fact, the universities are not fountainheads of R and D, and the organizations responsible for the provision of technical services and the manufacturing of products do not guide academic programmes to become progressively more relevant and better attuned to national needs;

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[10] Gamal Eldin Nassar, "The role of Egyptian engineering organizations in professional, training and educational aspects" (Cairo, 1988).

(c) Engineers involved in consultancy and contracting work do not publish reports on their projects to make them known to future generations of engineers; similarly, medical doctors do not undertake significant research programmes with policy implications. This matter is aggravated further by the fact that some 75 per cent of all consulting work and 50 per cent of all major contracting work is undertaken by foreign firms. Consequently, engineers are being educated without any reference to the projects that are being carried out in the ESCWA countries at an annual cost of some $100 billion, excluding R and M;

(d) Professional manpower is employed in complex organizations. There is permanent tension between the bureaucracies and the professionals with respect to the latter's professional responsibilities. There are two sources of conflict. The first arises from the fact that professionals place high value on autonomy, while organizational regulations and procedures call for discipline. The second factor arises from the importance of self-motivation in all scientific professions; in bureaucracies, by contrast, these goals and rules are imposed on staff. Successful technical organizations in industrial societies have been able to segregate professionals in substructures where they enjoy (to a great extent) the opportunity to pursue their own goals.

In industrial societies, professional societies alleviate these conflicts by mediating and diffusing the tension; the individual professional would otherwise find himself unprotected in face-to-face confrontations with the bureaucracy.[11]

Studying the behaviour of professionals in ESCWA countries and elsewhere in the third world is still a fairly new concept. A recent study by Allam of a sample of 148 engineers in Egypt showed clearly that bureaucratization has overcome professionalization except among research engineers. He found that bureaucracies which employ engineers place considerable emphasis on obedience to superiors. He also found that such a bureaucratic relationship with the engineer correlates with obsolescence in terms of his knowledge. Engineers employed in R and D activities tend to resist knowledge obsolescence.

Allam made two important observations:[12]

(a) "... Egyptian engineers, therefore, may not be given enough autonomy to enable them to fulfil their professional needs. Rather, their activities must contribute to the overall goals of the organization. Such goals are set in advance by the State";

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[11] Eliot Freidson (ed), The Professions and their Prospects (London, Sage, 1973).

[12] Etimad Muhamad Ali Allam, "Organizational and professional correlates of knowledge obsolescence among Egyptian engineers," Ph.D. dissertation (Pennsylvania State University, 1981), p. 78.

(b) The Egyptian engineering syndicate was established as a labour union and has a negligible role in updating engineers.[13]

## C. The strategic role of consulting and contracting firms[14]

The projected demand for construction services for 1993 is estimated to be between $128 billion and $140 billion. This includes all construction-related activity -- infrastructure, housing, R and M, industrial construction, and defence-related construction. This is the largest sector of the economy of the ESCWA States. Some of the most successful integration of technology has been in the construction industry.

Although there has been no systematic policy effort to integrate S and T with any of these key sectors, one finds that the large number of Arab engineers who graduated during the past 50 years have had a strong impact on the share of Arab contractors in the internal market of the ESCWA States. The large number of engineers can be said to be the product of deliberate educational policies.

It is useful to present some background information on why the construction industry is critical to any national economy:

(a) It is universally considered to be a "locomotive" of the economy because of the high multiplier factor (three to four) associated with it -- as long as it utilizes mainly local manpower and materials;

(b) It is the key to all other economic activities; any investment of any type -- whether in housing, agriculture, industry, petroleum or telecommunications -- involves construction (especially consulting and contracting services);

(c) Construction is based on very flexible technologies that require a wide range of know-how and of firms to apply these technologies. More than half of the construction done in industrial countries is performed by firms with less than 10 employees; however, large firms capable of accumulating, applying and managing multibillion dollar industrial contracts are still needed;

(d) The relationships between large and small firms have been standardized through various contractual relationships; large contractors subcontract between 25 and 75 per cent of their multibillion dollar contracts, thus playing an important role in the diffusion of technology;

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13 Ibid., p. 12; see also A. B. Zahlan, Acquiring Technological Capacity: a Study of Arab Consulting and Contracting Firms, (London, Macmillan, 1991); and, A. B. Zahlan "Patterns..." in A.B. Zahlan and Rosemarie Said Zahlan (eds), Technology Transfer...(Pergamon Press).

14 The observations are based on extensive studies undertaken on the Arab and international construction industries: A. B. Zahlan, The Arab Construction Industry (London, Croom Helm, 1984); Acquiring Technological Capacity: a Study of Arab Consulting and Contracting Firms, (London, Macmillan, 1991); and an extensive unpublished study on Arab contractors and international competition undertaken jointly with TEAM International for the Arab Union of Contractors (1992).

(e) Consulting and contracting firms "integrate" various important economic institutions and activities: financial services (which are crucial to the functioning of large firms), industries that produce equipment and materials for construction, manpower training, university education, information services, transport systems and so on;

(f) The capital and skill requirements for entry into the industry are modest, enabling many young people to start careers in construction; the construction industry thus serves as an initial training ground for other, more complex sectors.

### 1. Economics of the Arab construction industry

In the case of the Arab construction industry, about 75 per cent of the activity depends on the importation of: labour (25 per cent); technical services (12 per cent); imported equipment (25 per cent); and supplies and materials (13 per cent; this figure excludes capital goods for industrial plants). These estimates vary from country to country, but represent the overall state of affairs in the ESCWA region.

It should thus be possible, without excessive investment efforts, to:

(a) Reduce the utilization of foreign labour to less than 1 per cent;

(b) Improve the R and M of construction equipment and the manufacturing of some parts sufficiently to reduce the importation of construction equipment to below 50 per cent of the present level;

(c) Reduce imported technical services to below 3 per cent;

(d) Reduce imports of supplies and materials (through import substitution and better marketing within the Arab world) to about 6 per cent. The relatively high "leak" percentage could then be slowly reduced as the industrial base of the ESCWA countries improves.

Decreasing this "leak" factor would increase the multiplier factor associated with the construction industry from its present negative value to a figure in the vicinity of 2.5. Increasing the multiplier factor would release foreign exchange which could be used to import capital goods and technical services related to the technologies where the ESCWA countries are still inadequately prepared.

### 2. The performance of consulting and contracting firms in the ESCWA region

The share of construction contracts executed by national firms has grown from almost nothing during the colonial days to some 60 per cent of the national market in the ESCWA countries in recent years.

This share, however, has remained at the same level for some time, mainly for the following reasons:

(a) The absence of public policies towards financial services. Arab contractors do not benefit from the same financial services as their competitors in the Republic of Korea or in OECD countries. This makes it very difficult for Arab contractors to get past the $200 million project range, meaning that much of the large infrastructural contracts remain out-of-bounds for Arab contractors;

(b) The weak role of financial institutions vis-à-vis the operations of Arab contractors has contributed to their relatively weak capacity in financial management; by contrast, the substantial role that financial institutions play in the operations of OECD consulting and contracting firms has contributed significantly to the improvement of their financial management;

(c) The absence of strong national policies to encourage subcontracting and joint ventures between Arab and foreign firms has reduced opportunities in the area of technology transfer in industrial projects.

Most industrially significant projects are contracted outside the ESCWA countries. Examples of some of these multibillion dollar projects include: the development of the Qatari gas fields; the $1.5 billion ethylene plant in Kuwait; the expenditure (over the next 10 years) of $100 billion on R and M and new plants for oil production throughout the ESCWA region; several $300 million cement plants in the Syrian Arab Republic, the United Arab Emirates, Saudi Arabia, and Egypt; and so on.

In a study of the role of Arab development funds in the promotion of Arab consulting firms,[15] Hatem Muhammad El-Haj found that only 16.5 per cent of the consultancy fees spent by the Arab Fund for Economic and Social Development (from its establishment until 1985) went to Arab firms.

Arab Governments and development funds almost exclusively utilize the services of international consulting and contracting firms for serious technology, with limited provisions being adopted for technology transfer to national or regional firms.

Although the causes of the present excessive dependence have been well documented, and procedures and strategies for the development of consulting capabilities are well known, little has been attempted to overcome the present disequilibrium.

For example, the following massive projects have had little -- if any -- impact on engineering curricula in the ESCWA countries: the gas-field project of Qatar, the many multibillion dollar petrochemical complexes, the 120 million tons-a-year Arab cement industry, the underground transport system in Egypt and elsewhere, the phosphate industry, and others.

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[15] Hatem Muhammad El-Haj, "The role of Arab development funds in the promotion of Arab consulting offices", Al-Mohandissun, No. 20 (January 1986), pp. 70-75.

The above is probably why the planned investments during the next 10 years of some $100 billion in R and M and in the expansion of Arab petroleum installations have not caused a ripple in the markets of the ESCWA countries.

3. The weakness of forward and backward integration

A direct consequence of the prevailing policies in industrial construction is the resulting dependence on foreign firms for R and M, for spare parts, and for the design and construction of new plants. This can be seen in all major areas of infrastructural and industrial construction: from dams, to harbours, to cement plants (the ESCWA countries constructed more than 100 plants that produce more than 500,000 tons of cement per year, but they still are dependent on imports for all aspects of cement technology; the story is similar for the phosphate, iron and steel industries and others).

This pattern of technology dependence leads to other side-effects, including the failure to initiate obvious and desirable downstream industries. The absence of the necessary technical competence makes the entry into downstream industry more difficult and expensive. The Arab phosphate industry is one good example.

The weak integration of S and T with the phosphate sector is noticeable in the absence of the following downstream industries that utilize phosphate as an input: phosphates are important ingredients in industrial detergents; they are constituents of a wide variety of yeasts; they are used in animal feed (of which the Arab world imports large quantities); phosphate products are ingredients in toothpaste, chromatographic materials; and so on.

None of the above-mentioned downstream industries -- all requiring science, technology and technical skills but only a small amount of capital -- are developed in the ESCWA countries. One does not have to go far to find the reason for this; there are practically no university training courses or R and D in the phosphate industry field in the ESCWA countries -- nor have the phosphate industries in Morocco, Tunisia, Algeria, Jordan, the Syrian Arab Republic or Iraq sponsored the promotion of the skills and know-how needed to create such downstream industries.

4. Public-sector procedures: programming and negotiations

In order for private and public firms to be able to bid for contracts, they need to know about the opportunities to do so in time -- firms need information concerning new opportunities. Small firms require far more time to prepare a bid than do large international firms with extensive track records. International firms make considerable efforts to acquire information and to participate in commercial workshops, conference and seminars on markets of interest to them.

To illustrate the above: prosperous ESCWA countries -- as well as all OECD countries -- are given special, extensive attention in industrial countries. To assist the business community, a number of major political, economic and financial institutions in industrial countries organize conferences on the economies and markets of oil-producing countries. These conferences are organized to serve the needs of major contractors and subcontractors in the West.

Participants in the above-mentioned conferences contribute a fee and thus share in financing their organization; the collection, analysis and presentation of information is thus modestly expensive. Firms in ESCWA countries may need different types of information services.

Small firms also face procedural problems, induced by the manner in which the public sector programmes its investments. Very often, Governments bunch together a large proportion of their investment projects or programmes at the same time. Small firms do not have the capacity to enter more than a few bids or to implement more than a few projects at a time.

The large firms that are able to bid or to execute a number of projects simultaneously prefer larger contracts; once a firm develops its management capabilities, it can easily manage a large contract. Furthermore, large firms cannot afford to enter a foreign market for only small contracts, as working in the international market involves considerable overhead expenses. Many of the larger projects have thus been awarded to foreign firms, even though local competence exists.

If the investment programme were to be rescheduled to average the load, it would become feasible for local firms to undertake most of the work. The practice of grouping together investment programmes reduces the chances of consulting and contracting firms to expand their portfolio in a systematic and rational manner.

Another important difficulty arises when local contractors possess 70 to 80 per cent of the required expertise to undertake the work. Local contractors in the region generally lose out under these conditions. However, it would be possible for the public sector to encourage these contractors to enter into joint ventures with foreign firms which could supply the missing expertise and could guarantee performance. The Koreans (and others) have been utilizing this method extensively for technology transfer. A competent local firm with a good track record in contract management should also be able to recruit the individuals that possess the missing expertise.

## D. Externalization of industry-related services (IRS)

During the past 30 years the standards and quality of products and the efficiency of industrial production have increased. Management of the production process has been through a revolutionary transformation. Science and technology has become deeply integrated into the process of management; total quality control, zero defect, just-in-time delivery of inputs, extensive outsourcing and the integration of the various phases of engineering-product development have revolutionized industrial activity. These developments have in some ways made the industrialization of developing countries easier, and in others more difficult.

In this section the importance of industry-related services (IRS) will be examined, with specific attention given to the technology in the ESCWA region.

Industrial activity is no longer vertically integrated within the firm, but is based rather on a complex network of relationships involving extensive service transactions and subcontracting. The family of firms that provide industry with technical services constitute an important and growing component of the service sector.

IRS include consulting and contracting services; since these have already been discussed, the emphasis will be on industrial subcontracting and management. IRS involve, among other activities, the preparation of software, the undertaking of R and D, consulting, testing, quality control, auditing, publishing, market studies, legal and insurance services, and information.

In its analysis of the economic performance of various developing countries, UNIDO's Industry and Development: Global Report 1992/1993 concludes that:

> "The foremost obstacle to ... using borrowed technology is the development of the capacity to absorb and adapt it to the special conditions of the country concerned. ... The capacity to absorb technology is the crux of the problem. ... It becomes evident at this point that the parallel development of producer services is essential to strengthening the technological capacity and increasing the productivity and competitiveness of an economy...".[16]

Michael Porter, in his seminal book The Competitive Advantage of Nations (New York, Free Press, 1990), stressed that although it is companies and not nations that are on the front line of international competition, it is the resources provided by the home base that play a central role in international success. Much of the inputs that a nation provides its firms are transmitted through the agency of IRS.

OECD statistics show that the value added of IRS has increased from 51.3 per cent to 56.3 per cent over the period 1980-1990. The largest contributors are producer services, financial and insuranca services, and professional and business services.

The globalization of industrial activity has allowed firms to practise outsourcing -- to subcontract firms in different countries to manufacture many of the components required for the production of a photocopier or a car.

Volkswagen, the fourth largest car maker in the world, procured components for 53.8 billion deutsche marks (DM) (or $32.2 billion). For several weeks preceding the writing of this paper, international news was obsessed by Volkswagen's recruitment of Jose Ignacio Lopez de Arriortua from General Motors (GM); Lopez is a genius at reducing the cost of subcontracting parts. It was Lopez who brought Opel back from severe economic loss to profitability -- and he was doing the same for GM in the United States when Volkswagen recruited him. The Lopez affair is an illustration of the fierce war going on worldwide: reduce cost or die. Outsourcing is one way to do the former.

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[16] United Nations Industrial Development Organization, Industry and Development: Global Report 1992/1993 (Vienna, 1992), p. 181.

Outsourcing reduces the capital requirements of a firm and increases its flexibility. The firm retains the capacity to design its products, specify standards, select its subcontractors and exercise quality control over its purchases. The improvements in transportation and communication have redqced the importance of distance to the operations of a firm -- hence the prevalence of just-in-time management.

Outsourcing has also been instrumental in the industrialization of developing countries; it is now possible for a firm to develop its capabilities piecemeal. It is no longer necessary for a developing country to acquire industrial capabilities through the difficult and restrictive route of planning -- from the outset -- the complete manufacturing process for the ultimate range of its production according to its abilities and the demand for its services. For a firm to be able to go into manufacturing, however, it must be assured of high- quality IRS.

Industry-related services provide the vital support that enables plants to operate successfully and a systemic role in the national economy; furthermore, the cross-linking and the development of efficient mechanisms for the articulation of economic activities is practically impossible without the constant participation of national IRS.

Industry-related services are thus integral components of the science and technology system; they provide the instruments for accomplishing the integration of national firms with each other and into the national economy. Without developing an effective STS, a country ends up with a collection of expensive islands of industrial activity.

When national firms participate substantively in the design and construction of a particular industry, national IRS acquire part or all of the technology that goes into the new investment. National IRS are then able to supply additional services, when needed, during successive phases of the project.

Specifically, for example, IRS are needed for: plant optimization; R and M; servicing during both emergencies and accidents; adapting plants and processes to new technologies and or to the manufacturing of new products; the extension and updating of a plant; the improvement of production methods; the improvement of products; the design of new products; and the upgrading of facilities.

All these and many other services are routinely required by industrial firms. However, when the firms have to be operated with the assistance of a constant supply of foreign expertise and manpower, the added costs of these imported services make production prohibitively expensive. Most developing countries cannot afford the foreign-exchange requirements of the importation of services. This factor is often cited as a cause of low capacity utilization in industrial plants in developing countries.

### 1. Management, the destabilization of industrial firms and rapid technology changes

Industrial firms everywhere are being subjected to the intense pressures of competition resulting from rapid changes in technology. The massive in-house R and D sponsored by leading science-based firms such as IBM are not sufficient to guarantee such firms a safe place in the market. Large firms, as much as small firms, are seeking new managerial methods that will allow them to retain entrepreneurial flair and flexibility.

Some of the largest firms that long dominated world markets eventually went under because they became too inflexible and could not respond to change; others, such as IBM, are facing difficulties because they have not been able to make good use of the inventions and innovations developed in their own laboratories. Some firms went bankrupt because they could not market and/or protect their own inventions.

The constant and rapid technology changes that are sweeping the world are a threat to those firms and those countries which are slow (incapable of responding in time); they, in effect, hand over opportunities to those that have a "ready-to-use" management system already in place.

The integration of science and technology into the management system of a firm is thus crucial to its survival. Developing countries may have to learn an important lesson from this: that fitting into the international system of subcontracting and outsourcing may be a safer method in the early stages of industrialization.

### 2. The import of industry-related services in the ESCWA countries

The ESCWA countries are major importers of IRS. According to the United Nations Conference on Trade and Development's (UNCTAD's) Handbook of International Trade and Development Statistics (1988), the Arab States import technical services totalling $35,769.40 million (some 10.6 per cent of Arab GDP); this figure does not include the imports of the United Arab Emirates, Qatar or Lebanon, though it is worth mentioning that the first two are heavy importers of services.

It is interesting to note that the import of services was 143.6 per cent higher than the import of capital goods. By contrast, imports of services in the same year by the United States, Japan and the European Economic Community (EEC) as a percentage of their GDP were 1.6, 2.2, and 4.3, respectively.

The largest importer of services among the ESCWA countries is Saudi Arabia ($19.3 billion; 16.3 per cent of GDP; and 251 per cent of capital goods imports); but even the least developed among these countries are relatively substantial importers: Mauritania ($202 million; and 174 per cent of capital goods imports); North Yemen ($271.1 million; 140.5 per cent); South Yemen ($202 million; 270 per cent); Somalia ($101.8 million; 82 per cent); and Sudan ($229 million; 79.8 per cent) (all figures are for 1987).

### 3. Opportunities for the development of IRS in the ESCWA countries

World-scale industrial concerns have been established throughout the ESCWA region: ARAMCO, SONATRACH, IPC and KPC; phosphate firms in Morocco, Jordan and Tunisia; the Suez Canal Co.; and several in Saudi Arabia -- and there are numerous others.

These substantial concerns have developed excellent and extensive in-house technical services to support the operations of the firm. These IRS are non-core activities and totally dedicated to the operations of the firms; they are not available to other medium-sized and small firms in the country.

In OECD countries it is usual, when IRS is internally supplied, that the firms do not fully utilize their technical resources. When these IRS are outsourced, they not only serve the original mother firm, but make their services available to other clients. A beduction in the overhead costs of the firm is then achieved, because eventually the firm pays only for the services it consumes. The externalized department earns its fees from the original mother firm as well as from new clients who can now afford to secure such high-quality services.

The externalized department benefits because it can now increase its revenue by marketing its services throughout the country and elsewhere; the mother firm reduces its overhead costs because it only pays for the services it needs and no longer has to absorb the high cost of such departments for the (only occasional) use of their services.

In developing countries where foreign exchange is at a premium, the access of medium-sized and small firms to IRS is difficult. This is why many plants operate below capacity; they cannot afford to import IRS and spare parts. Once these services become locally available and firms can pay in local currency, the situation changes completely. Even the manufacturing of spare parts under licence may become feasible.

## E. Integration of S and T with project negotiations

The experience of the ESCWA countries during the past 30 years demonstrates how difficult it is to change economic and cultural patterns. The dependence of the ESCWA countries on imports and exports is considerable, however, so it is to their benefit to seek to improve the efficiency and effectiveness of the negotiation process.

It is argued here that it is necessary to find suitable methods for integrating the acquisition of S and T capabilities into the project negotiation process, with a view to improving the returns on expended capital and effort.

How products and services are imported and exported and how these transactions are related to labour and professional organizations determines the extent to which the country will acquire the associated science and technology benefits.

What must be emphasized here is that there are some both obvious and not-so-obvious factors that influence technology transfer.

One of the simplest methods of promoting the transfer of technology is: to require foreign consulting and contracting firms to subcontract a proportion of the technical work; to employ local manpower (and, when necessary, to train them); to relocate part or all of the staff working on the project to the host country; to purchase technical services from the country in fields other than those of the particular project; and so on. All these methods are widely utilized by clients of international firms.

In discussions with a number of international consulting and contracting firms that work throughout the ESCWA region, the author learnt that it is very rare for an Arab Government to request that technology transfer be included in the consultants'/contractors' contracts with Arab States.

To illustrate the above: the same firm designed an underground transportation system for a major ESCWA country and for Singapore. The latter is a rather small country that does not possess the manpower resources of the ESCWA country; yet Singapore required that all the design work be undertaken in Singapore and that the prime consultant utilize local consulting firms -- this was despite the fact that the local consulting firms were mostly foreign. The Singapore Government rightly considered that any transfer to any firm based in the country would contribute to the development of the technology base, even if the staff of the firm were foreign. By contrast, the ESCWA country in question did not request that any part of the work be undertaken locally or that any particular proportion of the work be subcontracted to national firms.

The ESCWA countries can adopt a number of options:

(a) Governments could unpackage contracts, if necessary with the assistance of international consulting firms, and then provide technical support services that would enable national firms to bid for parts of the contracts. The work of local contractors could be guaranteed through the supervision provided by qualified consulting firms;

(b) The specialization required in large-scale and industrial consulting and contracting requires that firms work on a regional and international level; no small country could provide an adequate volume of business to sustain the constant accumulation and utilization of such specialized technologies. The size of the total Arab market is large enough to promote competition;

(c) Competition is essential in assuring that clients receive high-quality services at a fair price.

**Part Two**

# APPROACHES TO SCIENCE AND TECHNOLOGY POLICY IN THE 1990s: OLD MODELS AND NEW EXPERIENCES

# I. INTRODUCTION

In most of the countries of the ESCWA region -- as in many other industrializing countries in Latin America, Asia and Africa -- much of the institutional and intellectual structure currently used for dealing with science and technology policy was laid down in the 1960s and 1970s. Many of the relevant institutions were created during that period; and if in some countries such institutions were not created until the 1980s, their basic features usually involved only relatively minor variations in the underlying design principles developed during the previous two decades.

More important, perhaps, is the intellectual framework that has defined the broad roles and functions of these institutions; this, too, was largely inherited from the 1960s and 1970s, even if it was applied effectively only in some countries during the 1980s -- often following the efforts to crystallize and diffuse the main features of this framework before, during and after the Vienna Conference on Science and Technology for Development in August, in 1979. With various United Nations agencies playing major roles in generating and synthesizing the relevant information, knowledge and understanding, this intellectual framework drew on three main sources of experience: (a) the institutions, intellectual frameworks and operating procedures of the centrally planned socialist countries; (b) certain elements of the public-sector experience in North American and European capitalist countries; and (c) recent research that was providing an initial understanding of the experiences of some of the industrializing countries themselves.

Of course, this institutional and intellectual legacy did not result in homogeneous practice throughout the region. As elsewhere, there has been considerable variation in the detailed arrangements and procedures for science and technology policy in particular countries; nevertheless, there are several common features, three of which are especially important:

1. Despite the existence of very wide-ranging definitions of the scope of "science and technology policy", it has usually been much more circumscribed in practice -- consisting primarily of only policy for research and development. Policy for some aspects of higher education may have been included in some countries, and possibly elements of a policy for technology imports as well. However, the central focus of S and T policy has usually been R and D. While policy statements might be made on a wider range of issues, the practical activities of policy-making (sometimes organized within the framework of five-year planning) have concentrated mainly on strengthening the institutional structure for undertaking R and D, increasing the public R and D budget, and allocating this budget for different R and D activities.

2. The operating agents whose activities were to be influenced by policy have usually been specialized S and T institutions. Almost always operating in the public sector, these have primarily been various types of R and D institutes (and higher-education institutions in some countries) that have been expected to undertake R and D on behalf of other organizations such as enterprises or government agencies, and to provide technology (or trained S and T manpower) for those organizations which have

been seen merely as the "users" of these outputs from what has sometimes been described as the "S and T system".

3. In most countries, "S and T policy" has come to be seen primarily as the responsibility of a specialized government institution. The precise nature of this institution might vary -- a national council in some countries, a ministry of science and technology in others, or a specialized department of the national planning agency in yet others. However, despite these variations, the central principle (indeed, a major aim of many of the institutional-development efforts during that period) was the unification and centralization of policy responsibility for science and technology.

This section suggests that it is time to question these and other key features of the S and T policy system -- specifically the system for industry-related[17] technology policy. There are two main reasons for this. First, experiences inside the region seem to suggest the need for new approaches; second, experience drawn primarily from outside the region suggests that the institutional and intellectual legacy of the 1960s and 1970s may no longer be appropriate for the 1990s.

### A. Selected aspects of experience in the region

Corresponding to the basic features outlined above, there is a set of important disconnections and weak links in the S and T policy system. Some of the more important are well known (not only in the ESCWA region), and thus need only be briefly summarized here.

First, since it so often concentrates on R and D policy, S and T policy is commonly linked only very weakly to policies related to other aspects of technological development -- for example, to the accumulation and development of the types of engineering capabilities and project-management expertise needed for the majority of industrial investment projects that draw mainly on established, state-of-the-art technology, and only marginally on recent R and D-derived technology.

Second, with S and T policy heavily focused on influencing only the activities of specialized S and T institutions (mainly public-sector R and D institutions), it commonly has very limited links with the technological activities of other organizations that play a key role in the process of technological development -- particularly the technological activities of production enterprises. Indeed, the intellectual framework underlying the overall approach to policy sometimes precludes the perception that such organizations have any significantly active technological role at all; they are presumed to be merely the "users" of the outputs of the "S and T system", or the choosers of technology produced mainly by foreign suppliers.

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[17] This ranges beyond the manufacturing industry, also covering mining, utilities and construction. Quite explicitly, the paper does not address the issues of S and T policy concerned with important areas such as health and medicine, or agriculture, fisheries, etc. Nor does it address the policy issues concerned specifically with basic or fundamental research.

Third, with responsibility for S and T policy becoming unified and centralized in specialized government agencies, the weak links between S and T policy and other areas of policy have become increasingly evident. For example, even where S and T policy and planning have been nominally associated with the larger economic planning policy processes, the real relationship seems often to have been weak.

Taken together, these patterns have sometimes resulted in science and technology policy paying little attention to the non-R and D technological activities of the main agents (enterprises) involved in some of the largest and/or fastest growing segments of industrial investment and production. However, even within the (de facto) limited scope of science and technology policy itself, there are sometimes very weak links between the different areas of policy concerns whose interconnections are potentially important. For example, where policies on technology imports exist, they are seldom strongly linked to the core focus of policy for S and T -- i.e., R and D policy.

Finally, of course, disconnections within the policy-making system have often been matched by disconnections among the areas of technology generation, acquisition, diffusion and use "on the ground". For example, R and D activities in specialized R and D institutes have often been very weakly linked to the production enterprises that are supposed to be the main users of their outputs;[18] and the training of scientists and engineers in the higher-education sector in some countries is only very weakly linked to the patterns of employment in the economy.

## B. Experience outside the region

Two developments during the 1980s have combined to highlight the importance of taking quite different approaches to science and technology policy. First, there has been a substantial increase in the research-based understanding of how the process of technological change takes place in both industrialized and industrializing societies. This indicates that many of the presumptions in the 1960s and 1970s were misleading; and this has important implications for the approaches to policy inherited from the 1960s and 1970s. Second, key features of the technical-change process have in any case changed fundamentally during the 1980s. Consequently, even in several areas where our understanding of the process in the 1960s and 1970s was not too drastically adrift, it is no longer very helpful as a basis for policy development in the 1990s.

The remainder of part two concentrates on experience outside the region, highlighting some of the possible implications for approaches to science and technology policy within the region. However, two points should be emphasized. First, as indicated already, the main focus here is not on suggestions that specific policies on particular issues should be different from what they have been in the past. Instead, it is suggested that the basic issues addressed in the first place may have to be different, and that institutional structures that are utilized to "do the addressing" may also have to be

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18 For a perceptive review of this issue in the region, see United Nations, Economic and Social Commission for Western Asia, "Strengthening research and development capacity and linkages with the production sectors in countries of the ESCWA region" (E/ESCWA/NR/87/23), 1987.

different. Second, because this is an input to a workshop involving participants from various countries in the region who have considerable knowledge of the details and practicalities of S and T policy in their countries, the main purpose here is not to attempt to prescribe particular new approaches that should be taken; it is rather to stimulate questions about the current approaches and discussion about possible alternatives.

The next chapter of this section outlines key features of the process of technological change in industry, focusing on the combination of new perspectives and new realities that suggest the need for new approaches to technology policy. Chapter III outlines selected features of the resource base underlying the technical-change process -- again stressing the combination of new perspectives and new realities. Finally, chapter IV outlines some of the possible implications for policy and management.

## II. THE PROCESS OF TECHNICAL CHANGE: NEW PERSPECTIVES AND NEW REALITIES

### A. Technical change: a continuous, not intermittent, process

In the 1960s and 1970s, technical change was seen essentially as an intermittent phenomenon. Such views were encouraged by two sets of "models" of how technology is incorporated into economic activity.

First, economists' models of investment and economic growth emphasized the importance of investment in physical capital as the vehicle for incorporating technology in production. They also tended to view such capital-embodied technical change as involving infrequent and relatively large "lumps" of investment -- in effect, distinct new plants and factories.[19] At the same time, these views about intermittent injections of large lumps of capital-embodied technology were often set within perspectives in which (a) the technical characteristics "embodied" in particular "vintages" of capital were assumed to be fixed by the time of investment projects, and (b) no further technical progress was presumed to occur in the subsequent lifetimes of those facilities.

This theorizing was consistent with the practical experience of most economists and financiers working in development banks and ministries of industry or planning in developing countries; their somewhat limited contact with the realities of industrial technology tended to centre on large investment projects for setting up new plants and factories. Also, the project feasibility studies which they examined at their banks and ministries almost invariably had at their core a set of technical (and hence economic) characteristics which remained fixed through the projected 10-20 year lifetimes of the projects.

Second, common models of innovation led in very similar directions. They focused on individual product and process innovations -- intermittently occurring phenomena that emerged from a sequence of research and development activities. In the 1960s and early

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[19] Following Salter (1966) and others, such "lumps" of capital-embodied technology were described as vintages and, as Salter described it, such a vintage consisted of "a new outfit of capital equipment".

1970s, therefore, most of the empirical analysis that sought to clarify the main features of the innovation process focused on individual innovations -- distinct new products and processes that were examined in isolation from both preceding and subsequent paths of technical change (e.g., Sherwin and Isensen, 1967; Myers and Marquis, 1969; Langrish, et al., 1972; and Science Policy Research Unit, 1972). These perspectives also incorporated a feature that was very similar to the economists' distinction between the malleability of technology up to the time of investment projects and its rigidity thereafter: the separation between (a) the various stages leading up to innovation -- the first commercial application of the new technology -- during which the evolving technology was creatively shaped; and (b) the subsequent stage of diffusion, during which it was presumed to remain fixed as a succession of users simply "adopted" and "used" it as it spread through the economy.

Thus, within both these perspectives, technical change was seen as stemming from intermittent "injections" of technology into the economy. In addition, both perspectives involved sharp boundaries between (a) technologically creative phases of activity in advance of the injections, and (b) technologically static, "post-injection" phases during which the technology was diffused and used, but not changed. Industry in developing countries was usually seen as acting on the technologically static sides of those boundaries. It was involved in the "adoption" of technologies as they diffused internationally after earlier innovation in the advanced industrial economies; and after the investment projects were carried out to implement the adoption of technology, firms in developing countries were seen as undertaking the technologically static use or operation of given facilities and systems.

Evidence of the grossly distorting simplifications involved in these perspectives already existed by the 1960s, but it attracted little attention. For example, Hollander (1965) had already shown that the economic gains from continuing technical change through the operating lifetimes of particular vintages of capital-embodied technology might be just as significant as the gains from investment in new plants incorporating new vintages. Enos (1962) had also provided striking evidence to illustrate a point made by Rosenberg (1972 and 1976): the magnitude of the economic gains from intermittent major innovations (in this case a succession of novel petroleum refining processes) may be matched by the gains from continuing improvement to each of those innovations during their subsequent diffusion and use.

Since then, a wealth of evidence has been accumulated to indicate the importance of seeing technical change as a continuous, not intermittent, process. In particular, it has become quite evident that the diffusion of innovations does not involve the adoption and use of technologically fixed products and processes. Instead, in technologically dynamic situations, it typically involves two stages of technical change in each successive application of the diffusing technology:

(a) First, the basic features of the technology to be used in investment in new production facilities will be cumulatively changing between the successive instances of adoption. Moreover, in the immediate context of each investment project, the technology will usually be improved or adapted for application in the specific situation involved. This typically entails a complex process of engineering development, reconfiguration and design of the specifications of the production systems being brought into use -- a technologically creative process which is totally obscured by simple terms like "technology adoption" or "technology choice";

(b) Second, after initial investment in the new production capacity that incorporates the diffusing technology, technical change may continue through the subsequent lifetimes of the production facilities in each adopting firm. With an intensity which varies between situations, this post-adoption phase of technical change incorporates a stream of incremental developments and modifications which further improve the performance of the technology above the levels initially achieved and/or mould it to continuing change in input and product markets. The analysis of "learning curves" in industrial production has commonly shown the significance of the economic gains from this continuing improvement in apparently "given" technologies. However, this "learning" perspective has typically obscured the underlying processes by suggesting that the improvement arises as a more or less automatic product of experience through "learning by doing". In practice, the effect of that experience has very little significance, and the so-called "learning curves" are generated by continuing paths of creative technical change that are obviously associated with growing experience, but not simply as an automatic result of it.

As integral components of the so-called diffusion process, these two types of technical change are widespread and pervasive. They are a feature of technologically dynamic industry in both developed and developing countries, although some countries appear to pursue these paths of change more intensively than others; for example, the intensity of continuous change seems to be much greater in Japanese than American or British industry, and much greater in Korean than Brazilian or Indian industry.

These paths of continuous change are also common across widely different industries -- e.g., the semiconductor industry and the brick industry, the machinery industry and the chemical industry, and the textile industry and the steel industry. They also appear to be common across the differences within industries -- for example, in the production of high-performance coated steels in large, integrated plants and in the production of standard construction reinforcing bar in small-scale "mini-mills", or in the production of semiconductors at the informatics technology (IT) "frontier" as well as in the assembly of circuit boards at various distances behind it. There are, of course, differences between industries and technologies in the rates of continuous, incremental change that are attainable over short-term periods. There are also differences in the lengths of the periods of incremental improvement that occur between the more radical innovative steps; for example, successive novel vintages of semiconductor technology have followed each other much more rapidly in the last two decades than successive radical steps in brick-making technology. Nevertheless, across those kinds of differences, the intra-vintage phases of continuous, incremental change are key components of the technological competitiveness of firms and industries.

Consequently, perspectives on technical change that focus only on intermittent injections of technology into the economy and neglect these other technologically dynamic dimensions of the diffusion process concentrate on only a small part of the way technology and technical change affect the competitiveness of firms and industries.[20] Not surprisingly, perceptions about the continuity of technical change have been associated with fundamental alterations in the basic frameworks used in theoretical and empirical analyses of innovation and technical change. In particular, during the 1980s attention came to focus much less on individual innovations, and much more on paths of technological learning, trajectories of innovation, and cumulative sequences of technical change (e.g., Dosi, 1988; and Imal and Baba, 1989).

### B. The active roles of technology "users"

With increased understanding of the continuous nature of technical change, there emerged during the 1980s a clearer perception of the technologically creative role of the users of technology. This was obscured by earlier perceptions which emphasized the sharp distinction between (a) technologically dynamic phases of innovation/investment, and (b) technologically static phases of innovation diffusion and post-investment operation. Within that framework, there was a corresponding distinction between the technologically creative "producers" of new technology and technologically passive "users" who simply had to choose and operate existing, given technologies. It is increasingly clear, however, that these distinctions make little sense, and that the so-called adopters and users of technology have significantly creative roles to play in the overall process of technological change.

These roles are important in contributing to "original" innovations in the conventional sense (e.g., Lundvall, 1992; von Hippel, 1988) -- but they are also important in the two stages of technical change which, as noted above, occur during the subsequent diffusion process. First, at the stage of investment in new production facilities, the technology-using firms frequently draw on a range of suppliers for capital goods, engineering services, project management services and so forth. Technologically dynamic firms rarely play a purely passive role in these technological aspects of investment in the production facilities they will subsequently use. They may generate a significant part of the technology themselves, perhaps also incorporating it into designs of capital goods to be used; and they may interact with their suppliers in various ways in developing designs and specifications for the products and processes involved. These technologically creative roles are even more important in the second of the two stages noted above -- incorporating technical change into existing production systems. Although this will also often draw on inputs from external suppliers, the technology-using firm itself must play a significant role -- both independently and in interaction with external suppliers.

Playing these roles obviously requires more than the accumulation of skills and know-how for operating new processes according to their expected performance standards, or for producing products to existing specifications. Firms must accumulate the deeper forms and types of the knowledge, skill and experience required to generate continuing paths of incremental change which both (a) improve on the original

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[20] Debate about whether continuous paths of "incremental" innovation are more or less important than more "radical" innovative steps are about as useful as debates about angels on pinheads. Both components of the technical change process are necessary bases for achieving and sustaining competitiveness.

performance standards of the technology in use, and (b) modify its inputs, outputs and processes in response to changing input and product markets. They must also strengthen their capabilities for seeking out and acquiring technology from other firms and economies. And they must then build on these capabilities to introduce more substantial technical changes -- for example, incorporating significant improvements into processes already used or into process technology acquired from elsewhere for new projects, modifying the existing types of products, producing substitutes for those already produced, diversifying into the production of input materials or equipment, or creating improved process or materials technologies for use by supplier industries. This phase may then blur into one in which firms produce the kinds of technical change which have usually been thought of as significant "innovations".

Based on the above, even if one adopts a rather narrow view that the competitiveness of industries in the ESCWA region will depend heavily on their efficiency as adopters and users of the technology generated by innovation in other countries, and not on their ability to generate significant technological innovations themselves, this has very different implications from those that might have been drawn in the 1970s. In particular, instead of being seen as essentially passive in the ongoing process of technological change, enterprises in these industries will have to be seen as playing significantly active roles in generating and managing change in the technologies they adopt and use. This is all the more true because of three characteristics of industrial technical change that have become increasingly important during the 1980s -- its increasing intensity, its increasing dependence on information technology, and the increasing significance of its organizational dimension. These issues are elaborated a little below.

## C. The intensification of technical change

During the 1960s and early 1970s, most of the technologies acquired by industrializing countries were relatively "mature", and this often meant that in the industrialized countries the continuous paths of technical change in industry were relatively slow. That aspect of the international technological environment changed fundamentally during the 1980s. The whole spectrum of industries that were technologically mature in the 1960s and 1970s has been rejuvenated by radical changes in technology or (more often) by an intensification of more incremental forms of change -- or by a combination of both. At the same time, of course, a wide range of new industries that were in their infancy in the 1960s and 1970s have emerged (thanks to rapid technological development) to play a substantial role in international production and trade. As a result:

> "... in most areas of manufacturing, engineers are confronted with new criteria for dominant designs and must adapt to new technological and industrial paradigms, some of which are compatible with earlier approaches to design and product management... while others require a complete break with previous procedures and ways of thinking. (Chenais, 1990, pp. 15-16).

It has often been emphasized that a small number of well-known areas of rapid technological development lie at the centre of this technological transformation:

micro-electronics and information technologies; radical improvements in old materials and the development of new ones; and accelerating developments in cell and molecular biology. However, important as these are, they should not obscure the much wider diversity of intensified technical change across all industries, all activities within them, and most of the technologies they use.

Part of this diversity involves process-centred change with its implications for rising productivity -- increasing efficiency in the use of capital, labour, energy and materials. However, other parts are reflected in intensified product-centred change which, apart from reinforcing process efficiency, has (a) shortened the time gaps between major technological discontinuities, (b) reduced lifetimes and leadtimes for less radically novel products, and (c) widened the diversity of smaller product differentiations. At the same time, combinations of process-centred and product-centred change have been directed more intensively at reducing environmental costs per unit of industrial output -- an objective that is being achieved increasingly by forms of technical change that also reduce other unit costs.

Industry in the ESCWA region therefore faces a world in which the technological basis for competitiveness is totally different from that of the 1960s and 1970s. The point is not simply that there now exist a large number of "new technologies" that were not available before. The more fundamental point is that the whole structure of technology underlying the competitiveness of enterprises involved in mining, manufacturing, energy supply and other utilities, communications and construction is now changing much more quickly. This new technological environment of the 1990s constitutes a most formidable challenge.

### D. The intensity of information technology in technical change

Within the overall complex of intensified technical change, the importance and pervasive impact of electronics and information technologies are well recognized and need no further emphasis here (see Freeman, 1993 for a recent review). However, two characteristics of information technology (IT)-centred technical change require a little elaboration.

First, to an extent that is perhaps greater than in other areas of technical change, the incorporation of electronics and IT elements into products, processes and organizational systems seems to require direct user involvement in technology development and design. Compared with some other areas of technology, the application of many areas of electronics/information technology requires much less standardized systems that are highly specific to the characteristics of individual firms, their products and processes, and their markets. These system specifications are often not easily transferred in the form of "redeemed" capital goods and blueprints, and their efficient introduction therefore requires much more localized technical change. Moreover, that localization must often go beyond the routine "adaptation" of systems. It has to be deeply rooted in the development and design of the hardware, and especially the software, in the immediate context of use. Also, since this frequently involves relatively complex engineering and design, the importance of tacit knowledge is often particularly great (David, 1992). In particular, however, what is frequently involved is the integration of electronics/IT elements and systems within existing products, processes and organizational procedures, so large proportions of the tacit and other knowledge needed for localized development and design must be drawn from the "user" of those elements and systems. The technology users thus frequently need to play a particularly significant and direct role in the process of technology development and design. Then, of course, subsequent dynamic assimilation of the technology (after its initial implementation) requires, as with most other areas of technology, even greater direct involvement by the user in generating and managing technical change.

Second, information technology is not just an area of changing technology, it is frequently also a powerful instrument for generating innovation and technical change. This is most obvious in the case of computer-aided design (CAD) systems, which not only permit more rapid and frequent changes in product and process design, but also allow much more intensive and extensive exploration of design options. However, the same change-stimulating role of IT is evident in other ways that "feed into" product and process design. In the various types of development and research, IT systems evidently play an enormously important role in accelerating the generation of new knowledge, in acquiring existing knowledge, and in developing new configurations of technology for incorporation into specific designs. Perhaps less evident is the change-stimulating role of IT when applied in production and management processes themselves. For example, the information that can be generated by various types of advanced process control technology, combined with the power of advanced computing, allows the acceleration of incremental process improvements. Similarly, the knowledge generated by IT applications for organization and administration permit more intensive analysis of changes in the "organizational technology" of firms.

### E. The increasing significance of organizational change

Although it has always been important, the significance of change in the organizational (or social) dimension of industrial technology became much more evident during the 1980s. Given the flood of publications on this issue -- related to Japanese management methods, "lean" production, "flexible specialization", and so forth -- there is no need here for any general review. Perhaps only one point requires emphasis.

Organizational change is frequently an important and integral component of many other types of technical change that may appear to be centred primarily on "hardware". This seems to be particularly true in changes involving IT and automation systems. For example, one survey about the diffusion of flexible manufacturing systems (Hoffman, 1988) provides evidence to show that most of the gains in competitiveness arise from the preparation for, rather than the implementation of, such systems. Bessant and Haywood (1986) suggest that the extent of the benefits from the organizational dimension of change is around 75 per cent of the total derived from flexible manufacturing.

This does not mean, however, that organizational change can simply be substituted for investment in more "hardware-centred" technical change. In the short run that is sometimes possible, especially when there is a long background of organizational inefficiency to overcome. Indeed, there are some cases where firms have found that substantial organizational change implemented in preparation for the introduction of IT systems has made the latter redundant. However, given the intensity of the overall multidimensional process of technical change in most industries, competitiveness cannot be sustained for long on the lone basis of changes in the organizational dimension of production technology.

## III. THE RESOURCE BASE AND ECONOMIC CONTEXT FOR TECHNICAL CHANGE

The increased intensity of technical change and its increasingly multidimensional nature give added emphasis to the importance of the stock of resources that societies use to generate and manage change in the technologies they use. A wide variety of different terms and concepts has been used to refer to these change-generating resources. The approach used here is summarized in figure I. A distinction is drawn between two stocks of resources: production capacity and technological capabilities. With reference to industry, production capacity incorporates the resources used to produce goods and services with given technologies -- the necessary equipment, knowledge, organizational structures, labour skills and so forth; technological capabilities, on the other hand, consist of the skills, knowledge and institutions needed to generate and manage change in the technologies used to produce industrial goods and services.

While the significance of this second set of resources has already been emphasized, considerable care is needed in further elaborating on the practicalities of what they consist of. What kinds of institution are involved? What kinds of knowledge and skill? The different answers to these kinds of questions have widely contrasting implications for the approaches taken to technology policy. In particular, three issues seem to be especially important:

(a) Industrial enterprises themselves, rather than specialized institutions located outside the structure of industry, constitute the heart of the organizational basis for technological change. Also, links and interconnections between these enterprises constitute a critically important part of the institutional fabric for technological change;

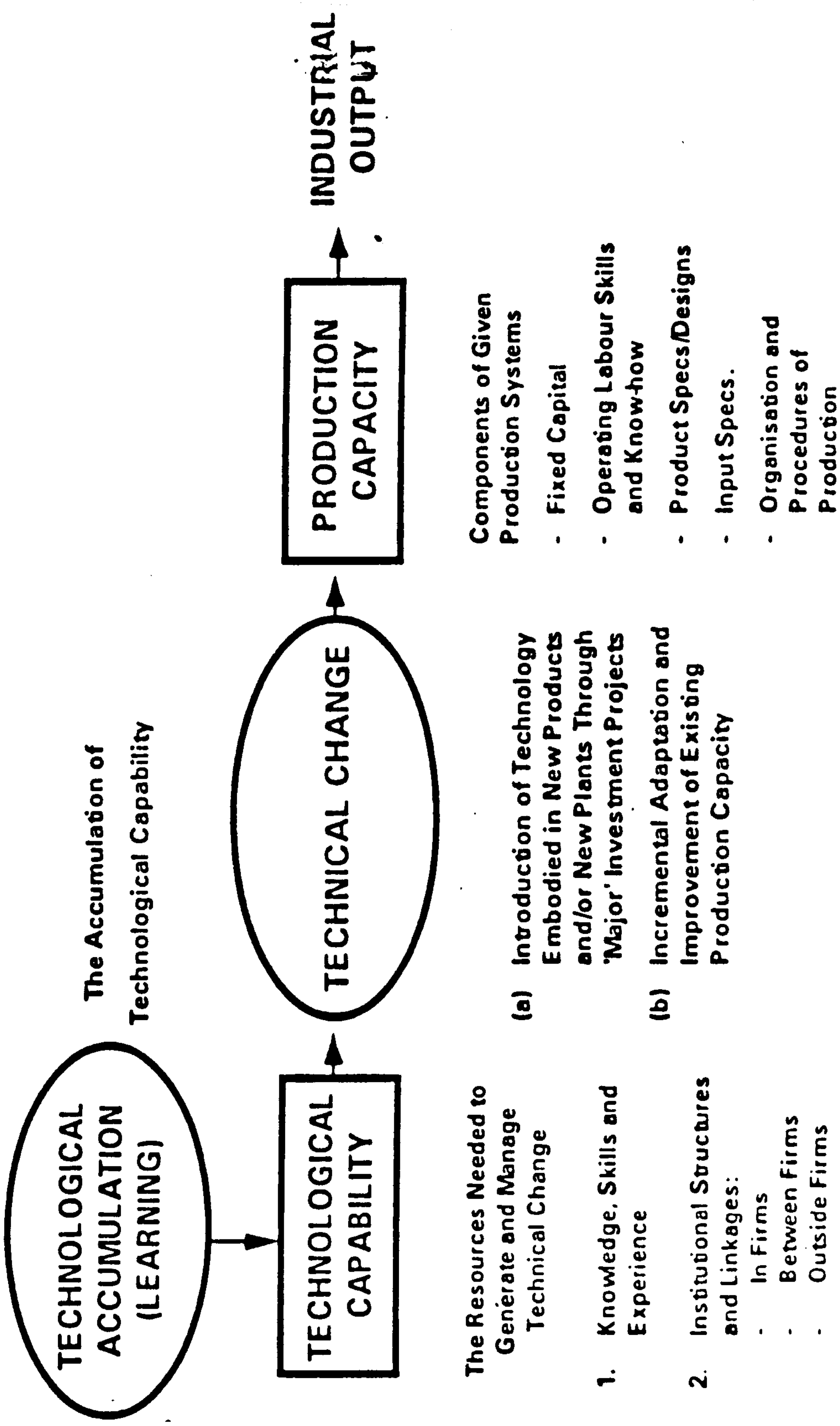
(b) The core technical activities driving the process of technical change are those concerned with various types of engineering (design engineering, process engineering, project engineering, production engineering, and so forth) rather than those concerned with R and D;

(c) Substantial capacities are needed to create the wide range of skills and competence needed to undertake these core activities, but large parts of that capacity for creating these kinds of human capital must be organized within industrial enterprises themselves, and not confined to a specialized structure of education and training institutions.

### A. The central role of production enterprises

The central role of enterprises in generating technological dynamism in industry may seem self-evident in the 1990s, but it was much less obvious in the 1960s and 1970s.

**FIGURE I.** __Technological accumulation: basic concepts and terms__



At that time, especially in industrializing countries, considerable emphasis was placed on infrastructural institutions as the prime movers of domestic innovative activity. It was expected that they would be able to generate new technology on behalf of industrial firms that were seen as being too small, too foreign or too incompetent to generate their own.

That optimism about the potential role of technological institutions stemmed partly from correspondingly simple views about the nature of technology. Apart from the elements that are embodied in people by education and training, technology was either seen as "information" that could be transmitted fairly easily between organizations, or viewed as being embodied in machinery which could be bought and sold like any other goods. However, a bit more is now understood about the complexity of industrial technology. In particular, much of it is tacit and inherently difficult to transmit; and much of it is highly specific to particular firms and their markets. These firms themselves must therefore play the prime-mover role in technological development.

This point is evident in two kinds of experience. First, in the industrialized capitalist countries, especially the more technologically dynamic ones like Germany and Japan, it has been found efficient for enterprises to fund very large proportions of total industrial R and D and to execute even larger proportions of it. The same point is also evident in dramatic transformations of the structure of R and D funding and R and D execution that have occurred over the last two decades in some of the East Asian newly industrialized countries (NICs). In the Republic of Korea, for instance, the Government accounted for nearly 70 per cent of total R and D expenditure in 1975. By 1985, despite huge increases in the absolute level of government expenditure, that share had fallen to about 20 per cent, with non-governmental sources (mainly industrial enterprises) accounting for 80 per cent. Second, in the centrally planned socialist economies, the organization of industrial R and D in specialized institutions that were separated from production enterprises was found to be extremely ineffective, except in a few strategic areas where massive resource allocations were able to generate effectiveness -- but at the cost of enormous inefficiency (Hanson and Pavitt, 1987).

However, it also became much more evident during the 1980s that it is not just isolated, individual enterprises that generate technical change; it is very frequently interaction between firms. This is apparent in connection with the development of major innovations, where some of these interactions involve suppliers and customers in the input-output chain/user-producer technological relationships (Lundvall, 1992; Organization for Economic Cooperation and Development, 1992). Many other cases, however, involve a wide range of technology collaboration arrangements between competing as well as complementary firms (Chenais, 1988; Cainarca et al., 1992; Kleinknecht and Reijnen, 1992; and Hagedoorn and Schakenraad, 1992). These kinds of interaction are also important in other phases of technical change. Investment projects to create new facilities that involve the so-called "adoption" of technology usually incorporate a host of interactions between specialized enterprises, and the subsequent trajectories of technical change in the post-investment phase will also involve complex interactions between the technology-using-cum-changing enterprise and various suppliers of goods and services. Thus, an important part of the resource bace for technical change in industry is not just the technological capabilities of individual firms; it is also the complex structure of change-generating interactions between the technological capabilities of different firms.

## B. Core activities and competencies: "engineering" more than "R and D"

In the 1960s and 1970s one would barely have paused to ask what the core competencies and activities in the process of technological change were. At that time, the nature of the resources required to generate technical change seemed obvious -- they were R and D resources. The various activities defined as research and experimental development were clearly identified in the accepted linear models as the "sources" of innovations; the advanced industrial countries had developed a well-structured system for collecting statistics on R and D to provide basic indicators of their "inputs" to innovative activity. Furthermore, international organizations (e.g., the United Nations Educational, Scientific and Cultural Organization), together with bilateral technical-assistance agencies, were busy advising developing countries that their technological capabilities (or "scientific and technological potential") could be defined adequately enough as their R and D capabilities.

All that now seems remarkably unhelpful since it focuses on only a small part of the activities and resources involved in generating technical change. Clearly, major innovations do draw fairly directly on new knowledge generated by various kinds of research, and they frequently do require the design, construction and testing of prototype products and pilot process plants. These R and D activities are only the tip of the iceberg, however -- only one part of a much wider set of activities that contribute directly to technical change.

The total iceberg must also include the wide range of engineering activities through which the results of R and D must pass before they result in the commercial, productive use of technology; it is frequently those various kinds of engineering that generate the effective requirements for new knowledge inputs from R and D. In other words, without a complex of activities concerned with design engineering, project engineering, production engineering, process engineering and so on, R and D is usually effectively disconnected from, and can contribute little to, technical change. It must also be recognized, however, that even without any direct inputs from R and D, those various design and engineering activities are frequently sufficient in their own right as sources of technical change in production -- especially as generators of the continuous paths of technical change that are now recognized as integral features of the process of technology diffusion. Next, note must be taken of a point that has received greater attention as more has been learned about the process of continuous change (kaizen) in Japanese industrial production: workers whose primary task is the ongoing operation and maintenance of existing production systems may also make significant contributions to the process of technical change.

Unfortunately, although the significance of these various change-generating activities and resources is now recognized more clearly, only very limited information is provided about them. Years have been spent in the collection of information about R and D. However, apart from the fragments of information in a few illustrative case-studies, little can be said about the scale of the various design and engineering resources which, with or without direct inputs from R and D, are required to generate technical change in particular sectors and economic contexts. Indeed, one would be hard-pressed even to describe in concrete terms what those resources would consist of in specific situations. Similarly, while a little information can be presented about the change-generating role of workers whose primary task is operation and maintenance, only limited understanding exists about the significance of that role, about how it is played, and about how it interacts with the change-generating activities of other components of the "iceberg".

Nevertheless, the large part of the iceberg that is shrouded in these obscurities constitutes the core set of competencies that are needed if industrial firms are to interact effectively in generating competitive rates and directions of technical change -- even if, for many firms and industries, those engineering competencies must be complemented by significant R and D capability. Among other things, this will require much greater emphasis on the firm as a creator, and not just an employer, of technological capabilities embodied in human capital.

### C. Industrial firms as creators of human capital

The rising "change intensity" of industrial production is being accompanied by its rapidly growing "knowledge intensity". Indeed, a fundamental transformation seems to be taking place in the relative significance of investment in knowledge and investment in fixed capital. In an ever-widening range of sectors in the developed countries, leading firms' annual expenditures on R and D are now often larger than their investments in fixed capital (for Japan, see Kodama, 1991). This requires a fundamental change in the perspectives of those who are accustomed to seeing fixed capital investment as the engine of economic growth. For a widening range of industries, that perspective must be turned upside down, and it must be recognized that, at the international technological frontier, investment in new knowledge assets is coming to exceed investment in physical assets as a major source of competitiveness.

However, it is also evident that greatly increased investments in knowledge are being made across a much wider spectrum of capabilities. In particular, many firms in the industrialized countries have greatly expanded their training and related expenditure to raise the levels of skill and knowledge they have available for generating and managing change, and they have often developed novel institutional mechanisms for doing so.[21] A particularly striking example is the case of Motorola, which, seeking to raise quality and production flexibility while intensifying technical change, raised training and education expenditure from $7 million to $60 million per year and developed its own corporate university (Wiggenhorn, 1990). Similarly striking are the very high levels of investment in education and training being made by many firms in the East Asian NICs to complement the investments made in formal education and training institutions.

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[21] Eurich and Boyer (1985), for example, provide a review of this increased role for "corporate classrooms"; and Fortune (3 June 1991) reviews "How intellectual capital is becoming corporate America's most valuable asset".

These apparent trends highlight the key role of enterprises themselves as creators of the human capital they employ. This contrasts with two perspectives on the process by which technical skills and expertise are created in industrializing countries. One of these, often associated with economic analysis of the role of human capital in economic growth, has given primary emphasis to formal education and training in institutions operating outside the structure of industrial firms. And, sometimes with only passing reference to "on-the-job training", firms themselves have been seen essentially as employers, not creators, of the human capital they require to generate and manage technical change. Such perspectives understate the centrally important role of firms as human-capital creators. That role appears to have been especially significant in countries which have been most effective in exploiting the dynamic gains of technological accumulation -- for example, Germany and Japan among the industrialized countries, and the Republic of Korea and Singapore among the industrializing.

Other perspectives have emphasized "learning by doing" as an important mechanism for creating these types of knowledge and human capital; and growing recognition of the significance of tacit knowledge has highlighted the importance of "doing" as a means of learning. However, two caveats should be noted about the role of learning by doing:

(a) First, doing one kind of activity is seldom an adequate basis for acquiring the capabilities needed for others. This obvious, but often neglected point, has become increasingly important as the knowledge base for routine production activities has become increasingly differentiated from the kinds of knowledge, skill and experience that are required to generate and manage technical change (with the latter organized in increasingly specialized R and D laboratories, design offices, project management teams, production engineering departments, etc.). As the gap between these two kinds of technological competence has widened, the doing of routine production has contributed less to the kind of learning that can in turn contribute to the capabilities for generating and managing technical change. Instead, types of "doing" that are specifically change-related have become an increasingly important basis for change-related learning (Bell et al., 1982; Bell, 1984);

(b) Second, while various forms of "doing" are central to technology accumulation, learning should not be seen simply as a doing-based process that yields additional knowledge essentially as a by-product of activities undertaken with other objectives. It may need to be undertaken as a costly, explicit activity in its own right -- various forms of technological training and deliberately managed experience accumulation that are undertaken as complements to education and training outside industry.

In these ways, the contribution made by firms to an economy's overall pool of technological capabilities are little different from the contributions of other institutions more explicitly concerned with education and training. However, firms and specialized education/training institutions are not just substitutable alternatives for achieving the same objective. There are particular kinds of skill, knowledge and experience (especially the last) that cannot be acquired in institutions outside the structure of industry; they can be acquired only in firms and through firms' investments in learning -- whether that involves investment in learning by doing or in learning by training. This has two important implications:

(a) Because of the diffusion of skill and knowledge among firms, they are usually unlikely to be able to appropriate the full returns of their investment in learning, and there is thus likely to be significant under-investment from a social, and possibly also private, perspective;

(b) These "externalities" should not be seen simply as unfortunate problems ("failures" that hinder the effectiveness of market mechanisms). Instead they can be seen as potentially powerful channels for the accumulation and diffusion of change-generating knowledge and skills in industry, and mechanisms might be found to enhance their actual significance (in practice) by inducing firms to invest in creating these kinds of human capital deliberately in excess of their private needs.

The above highlights the importance of government policy -- both (a) policies which seek to influence (fairly directly) the technological behaviour of firms in the face of such externalities and "market failures"; and (b) other aspects of policy that seek to influence that behaviour more indirectly by shaping the economic context within which firms operate --particularly the structure of economic incentives and stimuli they face.

### D. The economic context for firms, markets and Governments

Much of the analysis of industrial innovation and technological change in the 1960s and 1970s lacked any reference to the wider economic contexts in which those activities took place. That is no longer the case. A growing body of analysis in both industrialized and industrializing countries has emphasized the ways in which the technological behaviour of firms is heavily affected by their economic environments, and by governmental economic policies that influence those environments. Consequently, it is now much clearer that discussion of "technology policy" cannot proceed very effectively in isolation from discussion of "economic policy". Unfortunately, however, consideration of the relationship between the two areas of policy has become sharply polarized in recent years.

One view asserts that innovation and technical change will proceed most efficiently in the context of freely operating markets that are (a) as independent as possible of government intervention and manipulation, and (b) international (or at least multinational) in their scope. Those conditions, it is argued, will ensure that resources are allocated as efficiently as possible, and also that the pressures of international competition will stimulate firms to generate the paths of continuous technological improvement needed to attain and maintain competitiveness.

Emphasis on that perspective is not just a reflection of a priori presumptions; it is sustained by important empirical evidence. For example, the significance of competitive pressures and rivalry as an incentive for technological accumulation emerges from studies of the origins of competitiveness (for example, Porter, 1990), and from statistical studies of the technological activities of the world's large firms (Patel and Pavitt, 1992). Conversely, an almost complete lack of competitive pressures was one reason why production units in centrally planned economies had no incentive to develop or adopt more efficient techniques.

Nevertheless, an alternative view emphasizes that markets operate very imperfectly in allocating resources to the acquisition and generation of technology. Also, as a matter of practical experience, it is evident that government intervention in competitive markets, together with government shaping of their structure and functioning, have been important in many countries in stimulating paths of technological development that are commonly accepted as having been efficient.

In many cases, trade protection has constituted one form of intervention. While some forms of protection have clearly reduced incentives to innovate and/or invest in technological accumulation, others seem to have had much more positive effects. In particular, during the industrialization of currently developed countries, Governments typically took measures to protect their infant industries from the competition of established producers in more industrialized countries. The objective was to enable firms to learn and master the technologies involved, though the extent and duration of protection varied widely. In some cases, it was provided only for relatively short periods -- as in the case of the Japanese synthetic-fibre industry in the 1950s (Ozawa, 1980). In others it persisted for long periods -- sometimes with questionable justification in terms of technological learning. At other times, however, the persistence of protection seems to have been an apparent necessity for developing effective mastery of the technology involved (e.g., in the case of the Japanese automobile industry). More recently, trade policy has been used in this flexible way during the rapid industrialization of the Republic of Korea; protection has been provided for limited periods to permit the accumulation of a level of technological and other capabilities required for competitive survival, and industries have then been exposed to the pressures of international competition (Pack and Westphal, 1986).

Moreover, such patterns of trade protection were often accompanied by other measures to stimulate the accumulation of significant technological capabilities. For example, as late-industrializing Japan entered successive new industries, a frequent and important feature of government policy was the regulation of entry. This usually involved some combination of limiting the number of firms, phasing the sequence of their entry, and designating criteria for selecting entrants that included significant issues concerned with their technological capabilities and management of technology acquisition. These entry-regulating measures were often combined with (a) temporary limits on the extent of domestic and/or foreign competition, but also (b) the predictable termination of those limits. The primary explicit objective of such measures was usually to ensure that firms set up production plants on the most efficient scale and then operated them at full capacity. However, an additional important consequence was that substantial incentives were provided for investment in the technological capabilities required to generate and manage technical change.

In contemporary industrializing countries, it is often far from clear which balance between markets and such forms of government intervention would be the most efficient in particular circumstances. Nor is it very often self-evident precisely which forms of intervention would be effective, or how the balance between markets and intervention should be phased over time. Two things seem clear enough, however, and these are further elaborated below.

First, "technology policies" in industrializing countries that try to operate independently in relation to broader economic policies influencing the technological behaviour of industrial enterprises are likely to make only a very limited contribution to the rate or direction of technical change in industry. Conversely, economic policies that give little attention to objectives concerned with creating the basis for domestically generated technological dynamism are also likely to make only a limited contribution to the longer-term efficiency and competitiveness of industry.

Second, in pursuing the interaction between technology policy and broader economic policy, excessive zeal in the pursuit of ideological and theological "purity" is likely to be unhelpful. For example, blind adherence to views that Governments should not intervene in markets would neglect important aspects of Japanese experience in which Government shaped the structure and functioning of markets in ways that enhanced effectiveness, building the capabilities needed to generate competitive paths of technological dynamism. Similarly, blind adherence to views about the importance of protectionist trade policy as a means of enhancing technological "learning" would ignore the related aspects of Japanese experience in which competitive pressures played a major role in stimulating the pursuit of those cumulative trajectories of technological development and technical change.

Additionally, with such a large part of the industrial technology used in the region being imported from other countries, the need to generate more intensive and continuous paths of technical change highlights another long-standing set of questions about integrating the acquisition of imported technology with domestic technology accumulation. (This issue will also be addressed separately in this Workshop.)

# Part Three

# THE EVOLUTION AND INTEGRATION OF RESEARCH AND DEVELOPMENT VIS-A-VIS INDUSTRIAL ENTERPRISES

# I. INDUSTRIAL RESEARCH AND DEVELOPMENT IN POST SECOND WORLD WAR INDUSTRIALIZING COUNTRIES: THE PROBLEM OF LIMITED LINKS WITH PRODUCTION

In considering the current problems of industry-oriented R and D in countries which have entered into industrialization since the 1950s, it is useful to recall the origins and the activities. It is also useful to bear in mind the contrast between those origins and the experience of earlier industrializing economies. In that earlier experience of currently industrialized countries, the timing of the emergence of industrial R and D varied between industries and countries, as did the scale of the activities involved. Cutting across those differences, however, were two related features: (a) institutional evolution; and (b) integration within the organizational structures of production enterprises.

In the mid-nineteenth century, the term R and D did not exist, nor was it known under any other name related to the science-based development of technology. The sources of innovation and technical change in industry were mainly empirical trial and error and various kinds of slightly more formalized "engineering". These activities were chiefly undertaken in industrial firms, and often as the "part-time" activity of personnel who had other operational responsibilities in the enterprise.

However, by around 1910, most notably in Germany and the United States, specialized facilities dedicated to research and development had emerged within larger firms in several industries, especially the chemical and electrical industries.[22] Thirty years later those specialized organizational entities had become clearly recognized as important contributors to technological development in a much wider range of industries. It is striking that, to a very large extent, this process of institutional evolution took place within firms, with relatively coherent links being maintained between the emerging R and D activities and all the other engineering, production and marketing activities of these firms.[23] One consequence of this evolutionary pattern was that the vast majority of industrial R and D was undertaken within firms in most of the industrialized Western countries.[24] Independent R and D institutions had also emerged, but they played a minor role -- for example, accounting for about 15 per cent of all R and D scientific professionals in the United States in the early 1920s, and only about 6 per cent by the mid-1940s (Mowery, 1983).

In the 1950s, the countries of Latin America, Asia and (later) Africa began to build up their own industrial R and D capabilities, but they did so in a very different way. In particular, the development of these capabilities usually involved neither evolution nor organizational coherence:

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22 These institutional developments are described in Freeman (1982) and Mowery and Rosenberg (1989).

23 For one illuminating description of these links and interactions, see Hollander's (1965) description of the sources of technical change in Du Pont Rayon plants in the 1920-1950 period.

24 In the Soviet Union, of course, a quite different pattern of institutional development had taken place by the 1940s, with R and D being concentrated in specialized institutions that were established independently, separate from production units -- and also often separately from key engineering activities that were concentrated in design bureaus.

(a) Industrial R and D capabilities rarely evolved out of a pre-existing base of less specialized and formalized innovative activity. They were usually created more or less de novo, often without the coexistence of other activities noted for driving the technical change process -- in particular, various design and process/production engineering activities;

(b) These capabilities were not built up within industrial firms initially. Instead, they were usually established in centralized institutions that were financed and operated by Government. Indeed, this approach was followed precisely because it was thought that industrial enterprises were too small or "too foreign" to invest in their own R and D facilities.[25]

(c) Frequently, foreign advice and assistance played a large part in the establishment of these institutions, and their designs emerged much more as a reflection of models in the industrialized world (capitalist or socialist) than as an "organic" response to the immediate environments of the industrializing countries themselves.

Thus, in most cases, industrial R and D was incorporated into these societies in the form of institutions that were transplanted "exotics" from other environments, and a fundamental disconnection from industrial activity was built into the design of the system from the start. It is perhaps not surprising, therefore, that the problem of "linking R and D with production" has been high on the policy agenda ever since.

The significance of this problem became evident in a fragmentary way through the 1960s and 1970s, but it was not until the end of that period that more systematic evidence was generated. For example, the United Nations Development Programme (UNDP)/UNIDO evaluated a substantial number of industrial research and service institutions (IRSIs) in developing countries in the late 1970s. Some of the broad conclusions reached about the contribution being made by IRSIs to industrial development merit reproduction here:

> "The consensus of opinion reached by participants in the evaluation analyses is that, except for the provision of basic services, most IRSIs can be judged as adequate to poor in terms of fulfilling their policy objectives and performing functional activities. Significant and general weakness exists in provisions of technical extension activities and in industrial liaison. Technical information services are inadequate. Small-scale industries are virtually ignored and very large industries are seldom clients. ... Very little involvement is indicated by IRSIs in technology transfer and adaptation. ... [and] ... IRSI performance appears to be particularly weak in educational and training programmes for industry workers ... Effective programmes of communicating with potential clients, vis-à-vis

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25 For example, with reference to Egyptian experience, the United Nations Economic and Social Commission for Western Asia paper, "Strengthening research and development capacity and linkages with the production sectors in countries of the ESCWA region" (E/ESCWA/NR/87/23), 1987, notes that "One of the main reasons for setting up the National Research Centre (NRC) in the mid-1950s as a central research institute to cater for the needs of the growing Egyptian industries was the lack of funds and technological capabilities to establish R and D units at a wider industrial enterprise level". P. 86.

extension services, industrial seminars and workshops, and other promotional activities are usually lacking" (UNIDO, 1979, pp. 54-55).

Ten years later, UNCTAD undertook a similar study, although it covered a smaller number of research and development institutes (RDIs) in only three countries -- Indonesia, Sri Lanka and Senegal. It appeared that the general pattern had not changed a great deal since the UNDP/UNIDO evaluation. Summarizing the results of the study of these RDIs, the report (UNCTAD, 1990) noted:

"... it emerges clearly from the empirical evidence that the majority of them have not provided the hoped for spur to technological innovation ... Thus in Senegal, R and D outputs had hardly been commercially applied. In Sri Lanka, ... the contribution of the multi-purpose RDIs to the ... industry sector regarding technological innovation was modest. ... In Indonesia, the situation is less clear. ... Despite the generally low contribution of the surveyed institutes to industrial innovation, ... [there exist] ... numerous technologically successful development works and a generally high inventive activity. The fact that a large share of this product and process development work remained uncompleted or on the shelf does not invalidate their technological novelty and potential commercial usefulness." (Pp. 18-19).

Within the ESCWA region the pattern seems very mixed. A wide-ranging study in the mid-1980s (ESCWA, 1987) noted, on the one hand, several examples of successful commercialization of R and D results in some countries, plus cases where institutes had developed significant influence through the provision of various technical services. On the other hand, with respect to various countries it also noted:

(a) "The present unsatisfactory linkages between R and D and the production sectors" (p. 91);

(b) "... in a number of cases, the results of industrial R and D either have not been utilized or have been exploited by foreign companies" (p. 103);

(c) "... the prospects for stronger linkages between the R and D activities in the research centres and universities and the production sectors have not been fully exploited" (p. 105).

More generally, the report noted that:

"There has been marked development in the scientific capabilities in universities and research centers in the past decades. There is, however, a general conviction among all concerned ... that there is a seriously growing gap between the academic research centers and the production sectors. This gap has reduced the importance of the technological base in the countries concerned. Although this base is essential for linking the activities of the research centers to the production sectors and despite the substantial investment that has been made in building it and the efforts made, over the last two decades, to strengthen it ties with the production sectors, the impact of the technological base on the development process remained marginal. This is a significant indicator that urgent consideration should be given to dealing with this internal technological gap." (P. 108)

It seems, therefore, that despite instances of effectiveness, industry-oriented R and D institutes in the region, like those in other industrializing countries, have encountered similar general problems of limited connection with the practicalities of industrial production and technical change. The next two chapters draw briefly and selectively on the experiences of other countries in trying to overcome this general problem. Chapter II reviews various approaches to strengthening links within the existing structure of institutional disconnection inherited between the 1950s and 1970s. Chapter III then reviews approaches that have been taken to secure greater integration by changing basic features of that structure. Finally, chapter IV raises questions about the possible applicability of those alternative approaches in the ESCWA region.

## II. APPROACHES TO INTEGRATION: LINKAGES WITHIN EXISTING STRUCTURES

Four common approaches can be identified from the large amount of prescription and analysis that has related to the problem outlined above:

(a) Integration through planning and the improved allocation of resources;

(b) Integration through organizational and managerial change on the "supply side";

(c) Integration through changes in the policy environment influencing industrial demand for R and D;

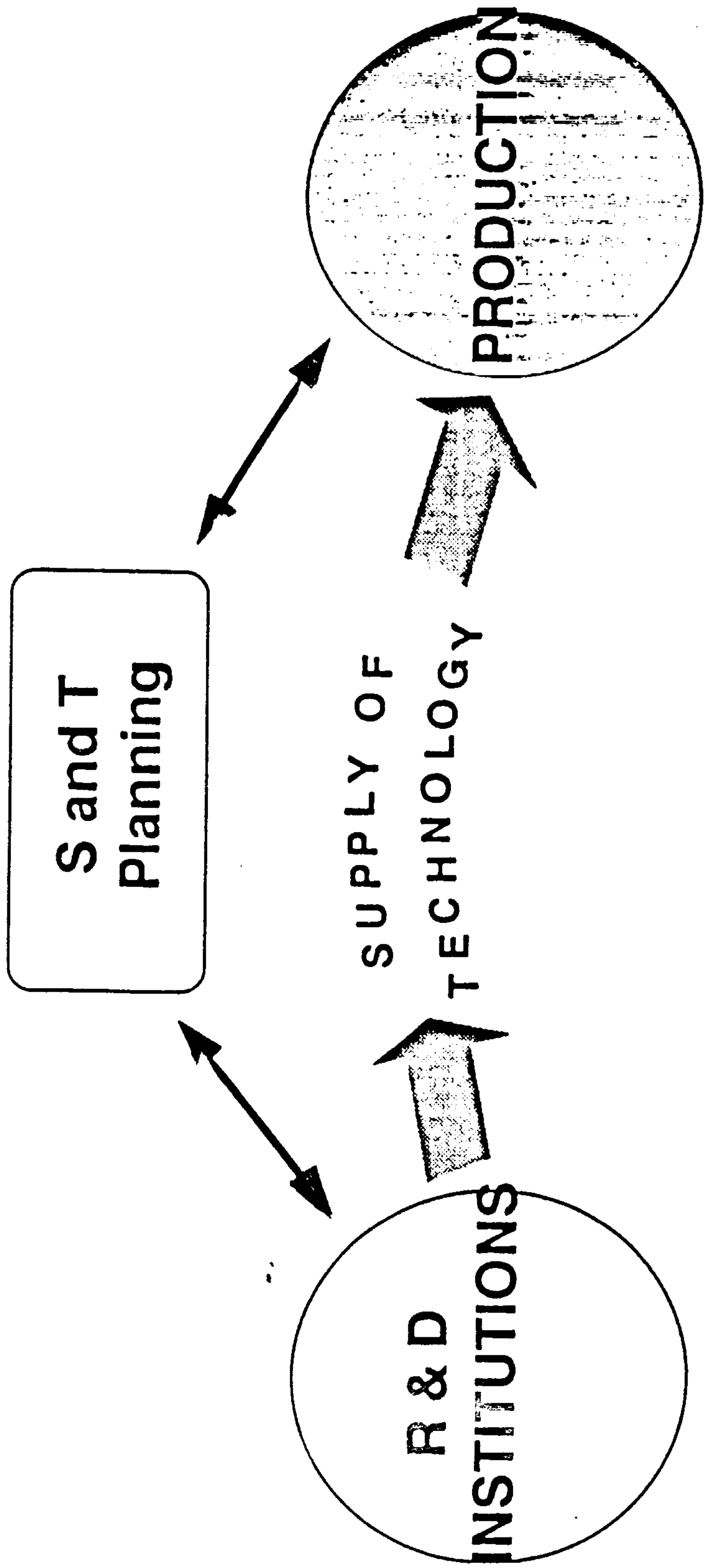
(d) Integration through bridge-building between institutes and firms.

### A. Integration through planning and improved resource allocation

This approach essentially presumes that there is little inherently "wrong" with either the R and D system or with the characteristics of industry and enterprises. Instead, the basic problem is seen in terms of the orientation of the R and D that is undertaken; essentially, R and D institutes do not allocate their resources to work on the kinds of technologies needed in production.

The proposed solution to the problem is fairly straightforward: an R and D "plan" should be constructed in order to guide the allocation of resources towards R and D in areas where the resulting supply of technology would match the apparent needs in industry (figure II). This might be done in a variety of ways. At one extreme, the problem is addressed at the macro level. The "needs" for R and D would be taken as latent (i.e., existing but not developed) in national social and economic development plans, and these could be analysed systematically through some form of

**FIGURE II.** __Integration through planning__



bureaucratic/academic process in order to make explicit the inherent "demands" for technology and/or R and D. Towards the other end of the spectrum, detailed surveys might be undertaken at the micro level to try and identify the "real" needs of firms -- as defined "objectively" by experts or "subjectively" by the firm managers themselves.[26] Somewhere in the middle, varying forms of the "expert committee system" might be set up to generate a picture of the apparent needs for R and D.[27]

Whatever the process used to clarify "needs" for R and D, it is presumed that the resulting picture could be used to guide the allocation of resources towards "more relevant" areas -- where the probability is high that the results would be used in industry. The reduction in supposedly "irrelevant" R and D being undertaken would correspondingly reduce the "gap" between R and D and production.

### B. Integration through organizational and managerial change on the R and D "supply side"

This second approach starts out by questioning one of the basic assumptions underlying the first -- that there is little inherently "wrong" with the R and D system itself. On the contrary, it is argued, while there might or might not be a problem with allocating resources to the "right" areas of R and D, there are distinct deficiencies in aspects of the organization, management and/or structure of R and D institutes. There are roughly two main variants of this perspective (see figure III).

#### 1. The micro variant

This focuses on various deficiencies within individual R and D institutes -- identifying weaknesses in certain aspects of their organization, management, structure, skill and competence, etc. The prescription, therefore, concentrates on the need for: better project selection and evaluation procedures; changes in the internal organization of sections and departments, often including the creation of additional sections concerned with disseminating or marketing the institutes' output; a different balance in resource allocation between staff costs and other items, such as investment in equipment or expenditure on the materials and journals required to do effective research; improvement in staff skills; and so forth.[28]

#### 2. The macro variant

This focuses not so much on the internal failings of individual institutes but on their immediate institutional environment. Indeed, from this perspective it is often

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26 For example, the industrial survey that was undertaken by the Battelle Institute at the time the Korean Institute for Science and Technology (KIST) was established in Korea.

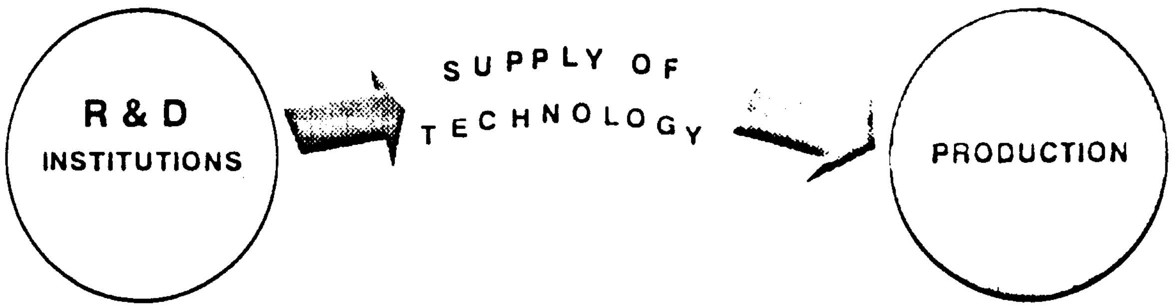
27 For example, the Indian science and technology planning process in the early and mid-1970s.

28 Many consultants' reports emphasized this approach, and the UNIDO/UNDP evaluation mentioned above also highlighted many of these issues as the means for improving the effectiveness of IRSIs.

**FIGURE III. Supply-side organizational/managerial change**

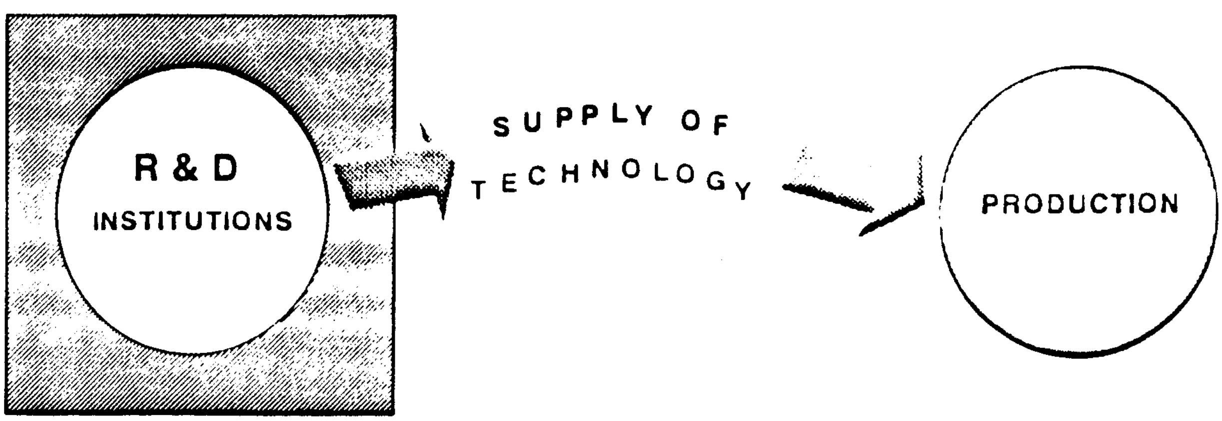
(A) MICRO VARIANT:

REFORM INTERNAL DEFICIENCIES OF INSTITUTIONS




(B) MACRO VARIANT:

REFORM IMMEDIATE ORGANISATIONAL ENVIRONMENT OF INSTITUTIONS



suggested that improvement in the organization and management of individual institutions (as described in subsection 1 above) would be impossible because of the constraints imposed by the immediate institutional contexts in which they work. Some perspectives emphasize the placement of individual R and D institutes within the overall institutional structure for R and D policy and administration -- suggesting, for example, that institutions should be under sectoral ministries (or not under sectoral ministries), or in new administrative structures right outside the framework of Government, where they would have greater independence from "bureaucratic control", and so forth. Other emphases concern such issues as the inadequacy of the government systems for funding institutes and the inadequacy of the permitted salary levels for staff.

### C. Integration through changes in policy affecting industrial demand for R and D

This approach locates the source of the basic problem in a completely different area. While recognizing that there might be deficiencies in the organization and management of individual institutes or in their immediate institutional contexts, it is argued that the "real" source of the problem of disconnection between institutes and industry lies in the behaviour of the industrial firms, which generate weak or non-existent demand for local R and D outputs. There are perhaps two variants of this approach (figure IV).

#### 1. The macro variant

This emphasizes that the environment in which firms operate represents a major constraint on the extent to which they will generate any significant demand for the output of local R and D. This perspective, in turn, takes two different forms:

(a) The structural/dependency perspective. Expressed in a wide variety of ways, the argument is essentially this: because of the "dependent" relationship between the domestic industrial economy and the international economic and political system (centred in the advanced economies), firms "externalize" their demand for technology, i.e., they seek the technology they need from foreign, not domestic, sources. Consequently, any possible linkage with the domestic R and D system is broken at the source of demand, and local institutes on the supply side are "marginalized" -- however well organized and managed they (or their wider S and T institutional context) may be. Policy prescription therefore emphasizes various forms of protection for local technology -- various types of measures to limit the inflow of foreign technology, thereby encouraging/forcing firms to turn to local sources for what they need;[29]

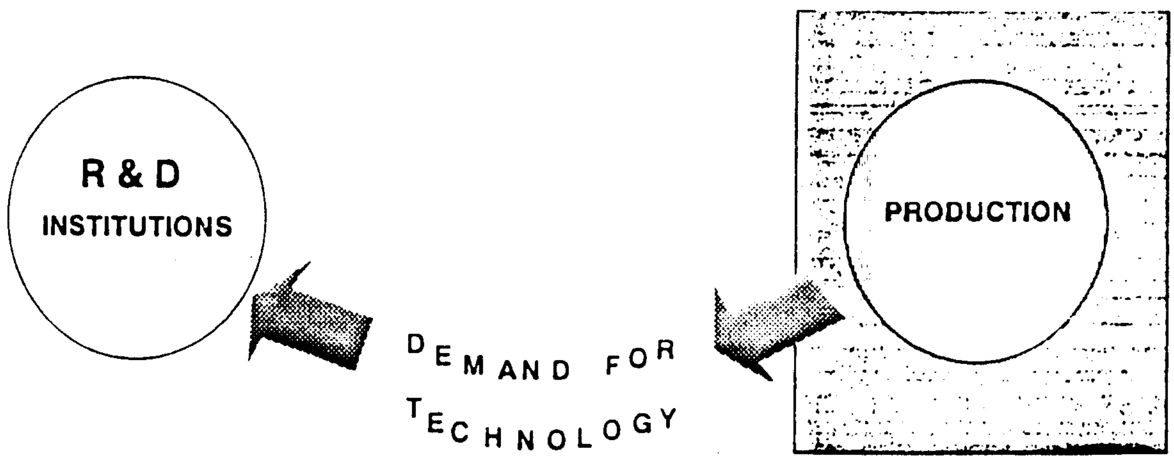
(b) The liberal trade policy perspective. This takes a totally different view. It argues that firms' demand for technology is determined by their demand for technical change, which in turn is influenced by the intensity of the competitive pressures they face. Consequently, with little competitive pressure (as in systems with "import substituting"

[29] This may take a variety of forms, including general technology import review mechanisms (as in India during the 1970s and early 1980s), or more focused restrictions on technology imports (as in the more recent Brazilian informatics policy).

**FIGURE IV.** **Integration through policy affecting the industrial demand for research and development**

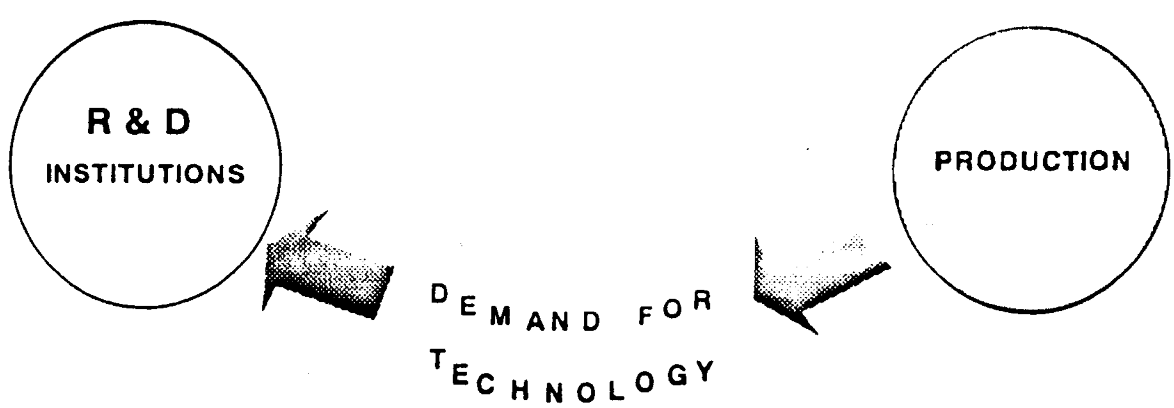
**(A) MACRO VARIANT:**

**CHANGE THE CONTEXT WITHIN WHICH FIRMS OPERATE**




**(B) MICRO VARIANT:**

**CHANGE THE BEHAVIOUR OF FIRMS THEMSELVES**



trade policy) firms have little demand for technical change, hence little demand for new technology apart from what they need in the form of equipment and other requirements for major investment projects, and hence little demand for the output of local R and D activities. Thus, the problem is not that firms externalize their demand for technology; it is that they have a very limited demand for technology in the first place. The net effect is the same as in the "dependency" perspective: however well organized the local R and D system, there will be little linkage with production because potential demand for the output of R and D is cut off at the source. The prescription, however, goes in the opposite direction from that emerging from "dependency" perspectives -- away from protectionist measures and towards greater liberalization.

### 2. The micro (or managerial) variant

This focuses on the behaviour of the firm itself, without giving very much attention to the influence of the environment in which it operates. In a variety of ways, this perspective rests on views about the imperfect knowledge, foresight, risk assessment and so forth of managers/engineers in firms. Consequently (for example), they do not invest adequately in technical change or in acquiring it from local R and D institutes. The prescription therefore centres on measures to directly (rather than indirectly through trade policy, etc.) alter these patterns of firm-level behaviour and management through, for example: (a) fiscal incentives for R and D undertaken in-house or contracted out to local institutions, or more broadly for implementing technical change that might draw on local R and D capacities;[30] or (b) exhortations to manage investment projects in ways that "unpackage" the sourcing of inputs, hence supposedly increasing the demand for local technology -- hopefully including technology derived from local R and D.

## D. Integration through bridge-building between institutes and industry

This approach places the source of the problem on neither the demand side nor the supply side. It focuses more on the interface between them, suggesting that, for a variety of reasons, measures are needed to build institutional bridges linking the two. It tends to start from the apparently common-sense notion that if there is a gap between two things, the obvious thing to do is to build something to connect them. The key terms used in discussing this approach are therefore not about either of the ends of the relationship but about the space between them -- terms such as interface, link, bridge, transfer and so forth. There have been several different emphases within this general approach (figure V).

One emphasis has focused on the need to create intermediary technology transfer institutions that will move available technology from sources that have created it to users who need it and can apply it. These intermediary institutions may be essentially information-dissemination institutions of one sort or another, or they may be more active as extension agencies, advisory services, consultancy organizations, etc.

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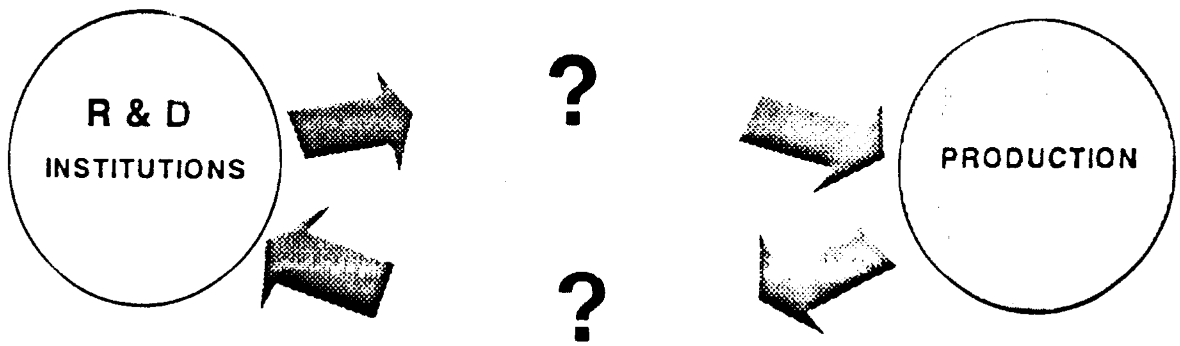
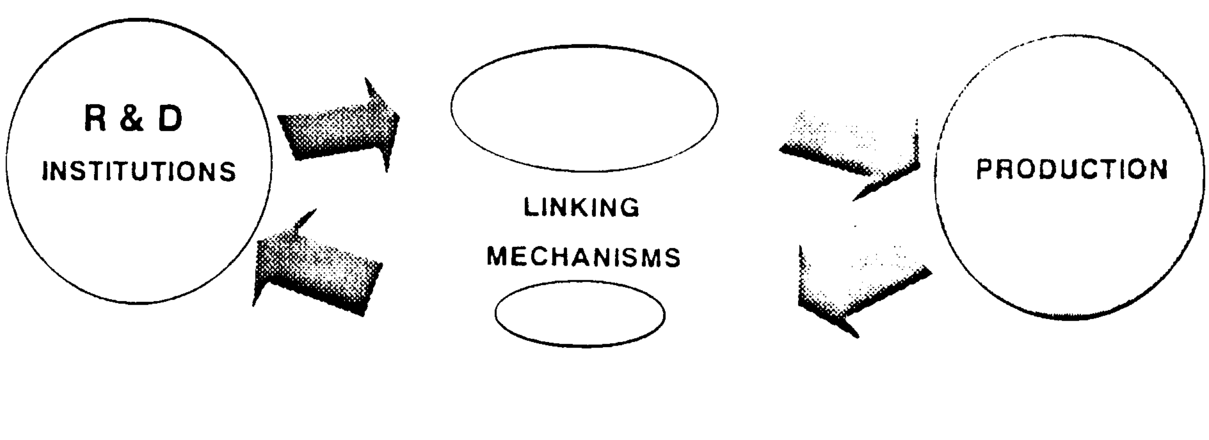
30 For example, as in the ITINTEC system in Peru (Sagasti, 1975).

**FIGURE V.** **Bridge-building: developing institutional linking mechanisms**




**DEVELOPING INTERMEDIARY ORGANISATIONS:**

**'Extension', Technical/Engineering, Financial, Locational (Science Parks), and 'Collaborative Associations'**



Another type of emphasis starts from more detailed views about the technology transfer process involved in linking R and D and production. It is stressed that this involves two quite different activities: not only moving "technology" from place X to place Y, but also transforming it on the way. The importance of the second of these activities lies in the fact that the output from R and D is very rarely "technology" in a form that can just be used by firms. Instead it often consists of "technology" in very disembodied forms -- outline specifications, formulae, information, test results, properties of materials, and so forth. In contrast, the demand from firms is often for "technology" in much more "embodied" forms -- detailed engineering designs, blueprints, proven operational systems, "ready-to-use" equipment, and complete turnkey plants. This type of perception has led to prescribing the creation of intermediary organizations that have the engineering capabilities needed to take R and D results and transform them into more "embodied" types of technology, while also moving them from source to application. Much of the discussion in the late 1970s and early 1980s about establishing consulting engineering and design organizations (CEDOs) involved the role they could play in linking R and D institutions and industrial enterprises.

Other emphases start from different perceptions of the main features of the interface problem. For example, some see it less in terms of a problem involving technology transfer, and more in terms of deficiencies in capital markets: the problem lies in financing the (sometimes risky) applications of the results of R and D. The prescription here leans towards ideas about financial intermediary institutions, venture capital organizations, and so forth. The same perspective has often been linked to another which sees geographical distance as making an important contribution to the gap. This leads to prescriptions that emphasize the importance of bringing industry and research institutes closer to each other through the creation of science parks, science cities, technopolises, and so forth.

## III. MORE RADICAL APPROACHES TO INTEGRATION: CHANGING STRUCTURE

### A. Some inherent limitations of dual institutional structures

All four approaches outlined in the previous section take as given the basic structural characteristics of the system. In particular, it is usually accepted that the existing R and D institutions, typically accounting for the major proportion of national R and D efforts, should continue to exist and operate outside the structure of organizations engaged in industrial production. The problem to be addressed is not about whether this disconnected structure is fundamentally flawed in its basic design in the first place. Instead, it is about finding ways to connect the two parts. As outlined, different perspectives may emphasize different reasons for the weakness of those connections, and they may correspondingly focus on different remedial prescriptions, but all of them concentrate on trying to connect the two components of the dual structure. In addition, the basic roles and capabilities of those two components are usually also taken as given. In particular, the primary technological role of the specialized institutions is usually accepted as being about undertaking R and D in order to generate new technology on behalf of industrial enterprises.

This section of the paper outlines more radical approaches to integration which do not consider those basic structural characteristics of the system as given; indeed, they may deliberately set out to change those characteristics. Underlying that perspective, although sometimes perhaps only implicitly, is a view about the temporary historical role of the existing dual structure: while it may have an important role to play in the relatively early phases of the industrialization process, it rapidly becomes less and less appropriate as industrialization proceeds. Consequently, from this perspective, the central problem is not about trying to "patch up" an inherently flawed system; it is about facilitating transition towards a fundamentally different structure for integrating R and D with production and technical change.

Also supporting this perspective is a growing body of information and understanding about the process of technological development. As emphasized above, the so-called "transfer" of technology from R and D to application in production usually also involves the transformation of the technology through various design and process/production engineering activities, along with the initial marketing of the products involved. In addition, however, these activities -- together with most of the "D" and much of the "R" of R and D -- usually have to be closely associated with the detailed specificities of particular firms' production systems, as well as the people and markets these products are made for. In other words, because much of it is highly specific to particular circumstances, large parts of the technology development process necessarily have to take place inside production enterprises if the overall process is to be effective. While individual component elements of knowledge and hardware contributing to innovation may be acquired from other firms and institutions, it seems to be extremely difficult to insert an inter-organizational break into the "core" of the innovation process and then to try and connect the various elements through the "transfer" of technology.

This has obvious implications for the probability of successful linkage between R and D institutes and industrial firms. If the former do "R and D" as it is usually understood, they stop before this transformation process (or at a very early stage in it), requiring firms themselves to undertake a large part of the R and D if technology is to be transferred. But if, as is frequently the case in industrializing countries, production enterprises are primarily engaged in production, with only limited intensity of activities that reach back through various kinds of engineering into "D"-type work and some of the related "R", they will not have the basis to undertake this transformation of technology.[31] So, if R and D institutions only do R and D, and production enterprises only do production, the probability of transfer between them is inherently low.[32] The importance of this issue has been recognized from at least two different angles through the experience of the more industrialized countries.

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[31] In addition, of course, they will have little of the in-house innovative activity that generates demands for inputs from external R and D in the first place.

[32] This is partially recognized by the perspective outlined above, which emphasized the importance of creating CEDO-type linking institutions between R and D and production. However, the focus on intermediary institutions neglects the importance of the tacit/specific nature of technology and the consequent difficulty of transferring it in semi-processed forms between different institutions unless the innovative/engineering activities and capabilities of those institutions overlap to a considerable extent.

On the one hand, the effectiveness of specialized R and D organizations has been limited when complementary technological capacities within industry have been absent. For example, in the 1950s the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia increased its research for the manufacturing industry, but had considerable difficulty linking it to technical change in industry. The difficulty apparently arose because:

> "One of the most serious obstacles that CSIRO has faced in dealing with Australia's manufacturing industries ... has been the lack of experience in industry in handling development work. ... Until Australian industry undertakes a significant proportion of its own development work, it will not be able to make fully effective use of CSIRO research. ... The application of this research depends in the long run on the ability of the firms concerned to take over the development from the stage beyond which it can be taken no further in the non-manufacturing environment of a government laboratory."

On the other hand, several studies have highlighted the complementary relationship between the in-house innovative activities of firms and the use of external R and D organizations. For example, Mowery's (1983) study of intra-firm and contracted R and D in the United States in the first half of the century suggested that firms without in-house research facilities were not the primary clients for independent research organizations; furthermore, the extent to which those specialized R and D institutes were able to act as substitutes for the R and D activities of firms was limited. That limitation reflected:

> "... difficulties of contracting, idiosyncratic knowledge, and the need for the involvement of many components of the firm in such activities as new product development. The firm undertaking particularly complex or risky projects ... therefore had little choice but to do so in-house. In addition, the ability of firms to exploit even the limited services that were available via contract was affected critically by the presence of an in-house laboratory. Firms lacking such in-house expertise were observed ... to utilize contract research primarily for simple analysis projects." (P. 366)

A similar complementary relationship was noted in a government-sponsored study of innovation and technology strategy in the Australian food industry in the late 1980s (Scott-Demmis and Darling, 1990). The general picture was one in which only a small number of firms had significant links with public-sector research institutes. However, there were important contrasts between different groups of firms. In particular, a much larger proportion of the "technologically active" firms (both large and small) considered collaboration with such institutes important; and the firms showing increased links with them over recent years were predominantly those which had themselves changed towards more active and innovative technological strategies. In contrast:

> "The low level of long term innovative activity in most firms limits the development of links with public sector research organizations as such links are clearly a complement to, not a substitute for, in-house R and D. The scarcity of

high-level research staff in most firms further opens the gap between industry and research organizations." (P. 28)

Finally, one should bear in mind that even in the context of competitive and technologically dynamic industries, specialized R and D institutes appear to play a very minor role as sources of technology for industrial innovation.[33] For example, a survey of more than 4,000 enterprises in Taiwan in 1987 showed that:

(a) About 63 per cent of them considered the firm's own R and D to be their major source of technology;

(b) About 31 per cent considered that their technology came mainly from abroad by way of purchasing formulas and authorization or physical plants, foreign technological cooperation, foreign consultants, improving the products of other countries, etc.;

(c) Only about 5 per cent reported joint research with local research institutes as a major source of their technology (Hou and Gee, 1993, p. 389).

Similarly, a recent study of wide-ranging innovative activities in more than 100 firms in the Veneto region of Italy indicated that technology for product and process innovations originated from the following sources:

(a) About 39 per cent from intra-firm sources;

(b) About 30 per cent through technology-centred interaction with supplier and customer firms;

(c) About 31 per cent from external sources.

Within the last category, only about 2 per cent originated from universities or government institutions (Belussi, 1992).

All this suggests that it may be unwise for policy efforts concerned with integrating R and D into industry in industrializing countries to conentrate exclusively on strengthening links within the existing dualist structures that so often characterize their industry-oriented R and D systems. Perhaps more precisely, after the centralized structure of specialized institutions has played its initial role in helping to facilitate the accumulation of R and D capabilities in the early stages of industrialization, it may be appropriate to shift the policy emphasis towards changing the fundamentally disconnected structure, rather than trying to maintain it and patch it up as its inherent weaknesses become increasingly evident. The following sections sketch several approaches that may be relevant in such a strategy.

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33 Although their role in contributing fairly directly to innovation seems limited, specialized technology-support institutions may make important contributions in other ways to production and technical change in industry -- an issue that is discussed in section C below.

B. Integration through strengthening the R and D and other technological capabilities of firms

In principle, fairly radical changes in key aspects of the structure of R and D activity can be achieved quite rapidly. It is striking, for example, that a fundamental transition was made in the Republic of Korea within only a decade (from the late 1970s to the late 1980s). Although they started with a structure in which about 80 per cent of R and D was undertaken in institutions outside industry (with firms undertaking about 20 per cent), the balance has been totally reversed so that more than 80 per cent of R and D is now undertaken by enterprises, and only about 20 per cent (but a much larger absolute amount) is undertaken within specialized institutions.

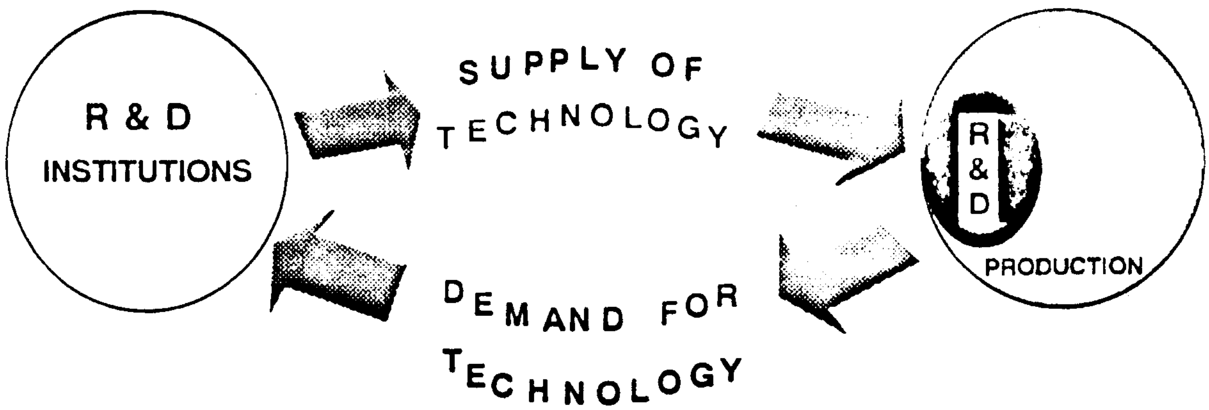
As suggested above, even much less dramatic transformations than this can achieve greater integration in two main respects. In addition to the obviously closer integration achieved by linking R and D and production within the organizational structure of enterprises, such changes in the institutional structure of R and D activity would be likely to increase the effective demand by firms for R and D undertaken in specialized institutions, and also to increase firms' capabilities to assimilate the outputs from such R and D (figure VI).

Implementing such a strategy is likely to require concerted efforts on both the demand and supply sides. On the former, there is growing evidence that increasing the competitive pressures faced by firms does raise their incentive to generate technical change -- and therefore to invest in the necessary change-generating capabilities. However, firms face a range of costs, risks and uncertainties in making those investments, and a range of measures focused on the supply side of the technological accumulation process can help to reduce those obstacles. Some of these are well known (such as fiscal incentives), but their impact and administrative feasibility have been questioned. More positively, a variety of programmes can be developed to channel available public resources for R and D and related activities towards enterprises instead of, or in association with, specialized institutions. To support such approaches, and going beyond the obvious need for high-quality formal education and training, major initiatives can focus directly on subsidizing technology-related training activities undertaken by the firms themselves, as is well illustrated in the experience of the Republic of Korea and Singapore (see, for example, Hobday [forthcoming] on Singapore).

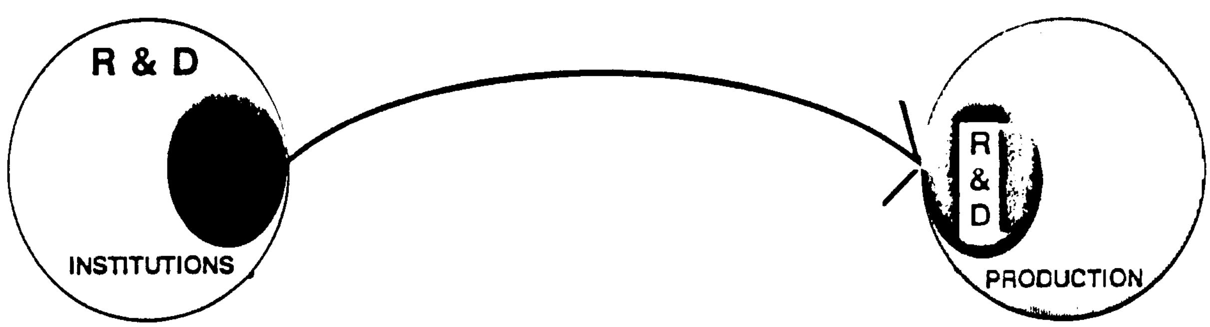
Another approach, described here as "spinning in", may involve R and D institutes more directly in helping to shift the balance between firm-executed and institute-executed R and D (figure VII). In contrast to "spinning off", where groups from R and D institutes set up their own independent enterprises, this involves groups from institutes (or perhaps even whole institutes) merging into existing enterprises. This constituted a major policy thrust in China in the late 1980s; however, the mode and scale of the initiative were inappropriate, and it encountered considerable problems (Conroy, 1992, pp. 110-112). In other situations, the approach seems to have been more successful. In the 1970s the Korean Institute for Electronics Technology (KIET) built up a substantial facility for and considerable competence in semiconductor technology; the facility was later sold to one of the large chaebol, which sought to develop its own in-house competence.

**FIGURE VI.** **Integration through structural change (I): strengthening the research and development and other technological capabilities of firms**

**(A) DEVELOPING 'IN-HOUSE' R & D**




**(B) 'SPINNING IN'**



## C. Integration through change in the roles and activities of institutions

Many industry-oriented R and D institutes appear to play limited roles in contributing directly to innovation, and there are inherent reasons why that role is likely to be limited; however, this does not mean that such institutions have no significant role to play in supporting industrial development. On the contrary, there are many important technological roles to play, but they are substantially different from the role of developing new technology for innovation in industry. Figure VII very roughly illustrates how these can be grouped into two categories:

(a) Acquiring and disseminating existing technology that is new for firms in local industries;

(b) Disseminating existing "best-practice" technology within local industry, and supporting its use and application.

Within both of these categories, a wide range of services may be provided. Some of these focus primarily on transferring technology via people-embodied knowledge skills -- not only through various types of training for existing employees in firms, but also by acting as sources of new employees with specialized skills and experience that may not be available in "mainstream" education and training institutes. Other activities are concerned with problem-solving, providing various kinds of technical advice and assistance for ongoing operations or for investment projects to create new facilities, and so forth. Other activities may relate to the use of specialized equipment and/or similar skills that are too costly for individual firms -- for example, various kinds of testing and analysis services. Finally, some may focus more on providing scientific or technical information to firms, although this type of activity often seems to be of limited value to firms unless it is closely tied to some of the others, and also closely linked to information about markets and other "non-technical" issues.

Compared with the effectiveness of the links that centre around the development of new technology and innovation, effectiveness in the provision of the types of services mentioned above usually depends much less on the prior accumulation of R and D and other technological capabilities in the firms themselves. It is thus perhaps not surprising that many R and D institutes in industrializing (and other) countries have found that industry's demand for these kinds of service significantly exceeds the demand for new, innovation-related technology.[34] It also seems likely that there is substantial scope in many countries to expand these roles further -- both by increasing their scale and by widening their scope. However, two issues are critical in considering such shifts in current emphasis.

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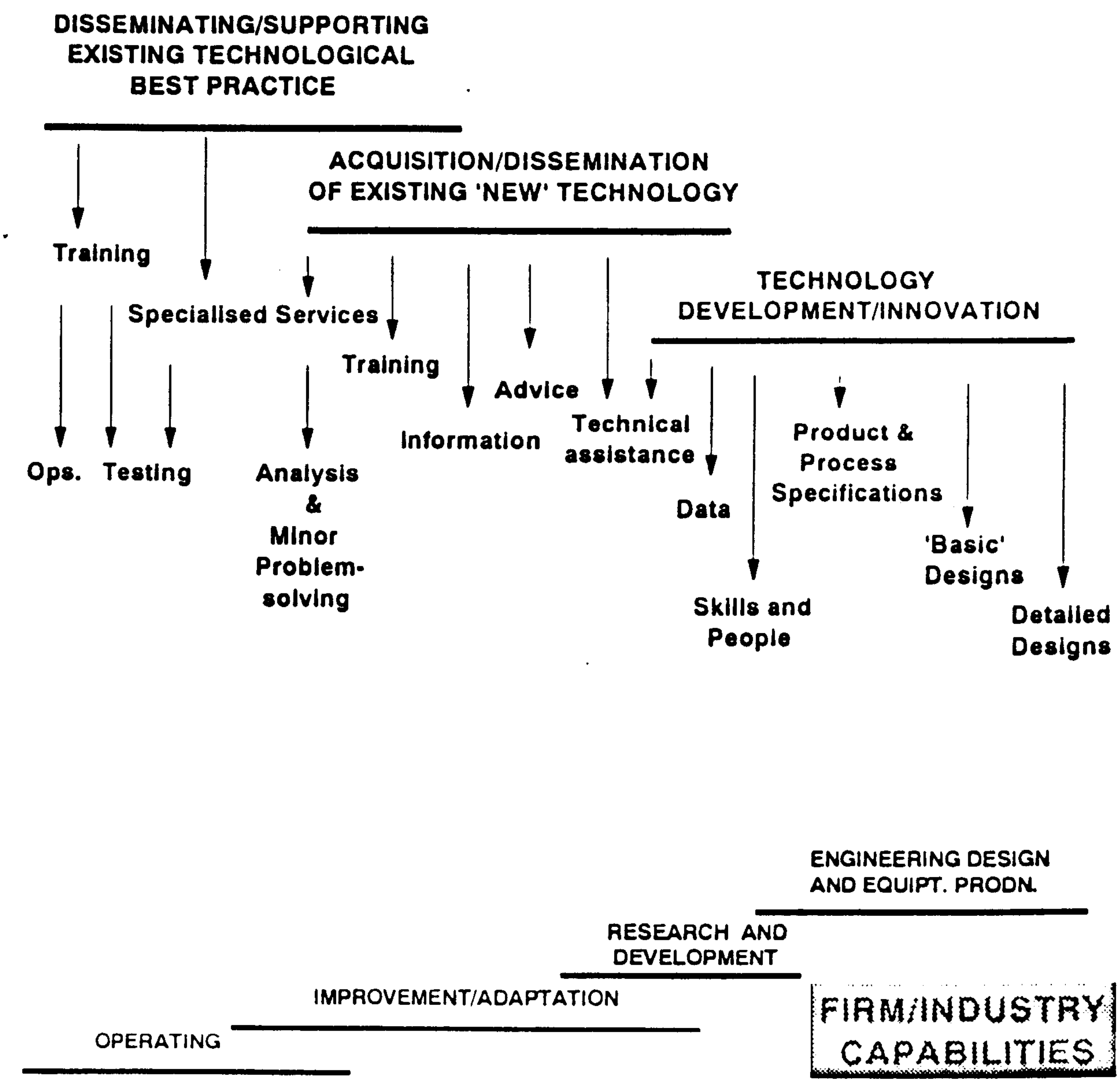
[34] This has been noted in several of the studies cited earlier. In particular, the 1987 ESCWA study "Strengthening research and development capacity....") indicated the existence of this pattern in several countries in the region: "Most of the industrial firms in Jordan were new and they were based on imported technology. This has created more of a need for services than a demand for R and D to develop new processes and products." (P. 93)

**FIGURE VII. Integration through structural change (II): changing the roles and activities of institutions**



First, much of the skill and experience required by institutes will often be very different from what is already available. In particular, much greater "hands-on" industrial experience will usually be a prerequisite. Indeed, in order to play many of these roles, what is needed in terms of knowledge, expertise and experience is not something fundamentally different from that which is available in industry; it is something that is just a little "better" and broader than what firms already have themselves.[35]

Second, and ultimately more important than "simply" shifting the available skill base, many of the goals, cultural characteristics and basic attitudes in institutes (and associated S and T policy organizations) will often have to change quite dramatically. On a general level, this will involve identifying service provision as an appropriate and valued primary goal of institutes, not as an inherently inferior activity that is reluctantly undertaken as a fall-back role when funding is unavailable for R and D activities.

More specifically, one particularly important attitude shift will often have to relate to the institute's resources, especially people-embodied resources such as skills, knowledge and experience. Human-resource flows out of the institute and into industry will have to be seen as an indicator of success, not as a problem and cost to be limited as much as possible. Indeed, it may be appropriate for some institutes to adopt the maximization, rather than minimization, of such flows of people-embodied technology as a primary objective.

### D. Integration through the creation of new firms: "spinning off" and "spinning out"

Instead of trying to transfer R and D to existing firms, or to provide them with other technology-related services, institutes may integrate their R and D activities with industrial production by creating new firms based on their accumulated knowledge and expertise. Some of these may be enterprises "spun off" to provide the kinds of services discussed above. Others may be associated more closely with R and D and its recent outputs. Such new enterprises may take two rather different forms.

The first is the conventional "spin-off" enterprise. This usually involves much more than the transfer of "technology". It also involves the transfer of part of the institutional structure in which the initial form of the technology was created -- some of the people, their relationships, their mutual understanding and mutually comprehensible communication "codes", their operating procedures, and so forth. This package of resources is moved out of the original institutional context into a different one -- the environment of production, markets, etc. In that new context, the process of transforming the technology continues, augmented by additional resources, skills and

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35 This issue was strikingly illustrated some years ago in aspects of the experience of the Central Leather Research Institute in India (Nayudamma, 1967).

competencies, and more open to the influences and requirements of the production and market environment.[36]

The second form involves a more comprehensive shift in institute resources. Instead of only parts of those resources being spun off to create new firms, whole institutes transform themselves into industrial enterprises. As they "spin out" of the system of R and D institutes, they acquire the necessary engineering, production, marketing and managerial resources, with the original R and D institute ending up integrated into the new production enterprise as its R and D department.[37]

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[36] Generating such spin-off enterprises has, for example, been a particularly important task of the electronics and information technology related institutes associated with the Industrial and Technological Research Institute (ITRI) in Taiwan (Hou and Gee, 1993).

[37] A number of research institutes in China appear to be following this route of fundamental institutional transformation as one type of response to a broad-ranging reform programme designed to increase the effectiveness of the large stock of scientific and technological resources accumulated within that country's structure of specialized R and D institutes.

# Part Four

# A FRAMEWORK FOR TECHNOLOGY-INTEGRATED DEVELOPMENT PLANNING

## A. INTRODUCTION

Over the past millenium and throughout the world, people -- at home, at work and at play -- have moved away from their sole dependence on only naturally available resources to increased reliance on many kinds of human-made technological resources. Consequently, at the enterprise level, technological resources have become as important to production as capital, labour and natural resources. At the national level, technology is now regarded as the engine of economic growth and a strategic variable for sustainable development. Furthermore, in a world where international trade is considered essential for economic progress, exposing domestic enterprises to the rigours of global competition is also found to promote technology-based efficiency. Hence, in an increasingly globalized and interdependent world economy, technology has clearly emerged as the driving force behind the following: the structure of domestic production; competitive advantages in the market; the opportunities for cross- border trade; and improvement in the standard of living of the people of a country. This vital power, however, rests with in the productive enterprises, and is derived primarily from their ability to introduce technological innovations faster than other competitors -- to make products and services better, cheaper and "greener". Thus, "management of technological innovations" is aptly described as the master key to sustainable socio-economic development in all parts of the world.

Recently, as a result of liberalized regulations for attracting foreign investments and the lifting of existing restrictions on foreign-exchange flows, productive enterprises in many developing countries are -- as a result of deliberate planning -- experiencing the importance and pervasiveness of technology in achieving global competitiveness. They have been forced to realize that the only way to compete globally is to possess an advantage in technology. The most important consideration for international market competition at present is thus the management of technological innovation. However, simple economic analysis is no longer sufficient to improve one's ability to manage technological change for international trade. One now needs a proper understanding of the technology-based development process and a suitable methodology for considering technology-related variables in an integrated way for decision-making at all levels.

In developing countries, enterprises have to introduce technological innovations through acquisition (technology transfer) and/or self-generation (technology development) to enhance their market competitiveness. Given this widespread recognition that the key competitive advantage in the international marketplace nowadays is the ability of a country to manage technological innovations through transfer and development, the need for endogenous technology management capability can hardly be overemphasized. Consequently, the development of technology management capabilities for effective "technology transfer" and "technology development" have become the two most important concerns. Technology transfer and technology development can be addressed: at the productive- enterprise level, where various technology components are employed to transform inputs to outputs and upgrade technological capability in the process; at the technology-infrastructure level, where the needed institutions are developed and the necessary linkages strengthened for innovation to take place; and at the national technology climate level, where a favourable techno- and socio-economic environment for technology transfer and technology development is provided.

The purpose of this paper is to present a rational framework which can be used for the management of technological change in developing countries. As conventional economic and financial indicators do not adequately describe the strengths and weaknesses of technology within a firm, an industry or a country, the approach taken in this paper is different in terms of its essential focus. It is proposed that a holistic approach to technology transfer and technology development, linked to the development strategy of a country, should be pursued as part of a multifaceted and dynamic process which interfaces with several elements. Using a systems approach, the framework presented in this paper attempts to integrate technological considerations in all levels of decision-making. Specifically, the framework attempts to establish technology-management methodologies in the context of public- and private-sector enterprises and the development of a technology support system at the sectoral and national levels. Starting with exposure to the unique characteristics of technology at the firm level, and using a systems view of the market structure, possible strategic mixes are determined by considering available business and technology strategies. Necessary considerations for the enhancement of technological capability and for a plausible technology strategy progression path are also discussed for different development conditions and circumstances. As most of the enterprises in developing countries operate on a small scale, they need a supportive infrastructure and a climate conducive to enhancing their technological capabilities. Technology infrastructure provides the mechanisms for endogenous capability enhancement; and technology climate determines the rules of the game for technology component/factor creation and capability advancement.

Besides discussing the unique characteristics of technology as a resource and outlining the elements of the technological system, the analyses presented in this paper focus on such important aspects as: the degree of technology component sophistication; the level of technology capability advancement; the status of technology infrastructure building and the dynamism of the technology climate. Some of these could be used by the managers of private- and public-sector enterprises, and others would be useful for investment project reviews and appraisals undertaken by national and international development planning institutions. These measures, taken together, provide an integrated framework for establishing a set of technology management methodologies designed to produce a much-desired synergy with respect to managing technology for the purpose of achieving global competitiveness and for sustainable socio-economic development.

## B. New world order of technological change

Recent technological and geopolitical changes have made all countries of the world increasingly "outward"-looking, and international trade has made them more interdependent. Much of this fast-growing and complex interdependence has come about as a result of unprecedented technological advancements in the past few decades, summarized as follows: modern transportation and communication technologies have made the world smaller (with respect to distance) and closer (with respect to time and space); modern production systems have made possible the simultaneous achievement of both "economies of scale" (through process standardization) and "economies of scope" (through product differentiation); and modern computer-aided activities have meant much quicker responses to customer preferences and market demands. This "interlocking" trend among all nations of the world is thus due to the widespread globalization of many production activities, to input sourcing, and to output marketing. Interdependence is also growing with the raised awareness of the global consequences of natural-resource depletion and what seems to be localized environmental degradation caused by various economic production activities in all parts of the world. Moreover, as a consequence of the failure of certain centrally planned economies in the world, there is also an observable trend (in most developing countries) towards full-scale deregulation, privatization, and international market competition; both public and private enterprises are under strong pressure to introduce technological change to improve productivity and to become internationally competitive.

At present, the world of industrial production is undergoing a thought and organization revolution. Recent technological advances are leading to changes in productivity and costs, radically influencing global and national structures of production as well as trade and employment. There is increasing concern with external, market, and customer-oriented goals, and efforts are also being stepped up to reduce uncertainly through the use of information "interventions". Microelectronics, informatics and biotechnology have all greatly affected the modes of production for all economic activities -- associated with greater diversity, more fragmented markets, more rigorous quality standards, more demanding customers, and the increasing number of environment-conscious societies. There is also evidence of profound changes in factory operations -- from the earlier mass production to the newer flexible production in competitive industrialization. New technologies help transnational companies to turn out new products much faster, while at the same time permitting them more flexibility in the manufacture of higher quality and more reliable products at a lower cost. Also, whenever economic considerations dictate, these companies move to developing countries with lower labour costs (lower wages, longer working hours, and less worker protection). Furthermore, compounded by the fact that international competition is increasingly intense and that there are new market economies (as a result of the recent failure of the centrally planned economies) with much lower wages, many newly industrializing countries are being squeezed out of the market-place and will have to engage in more technology-intensive production activities.

A comprehensive study on industrial productivity in the United States by a Massachusetts Institute of Technology (MIT) Commission clearly states that "for continued success in world trade, new ideas generated in the United States and elsewhere must be converted into products and processes that world-wide customers want, when they want them, and before competitors can provide them -- and those must be produced efficiently and well". This prescription is equally valid for developing countries, as they also now accept the free market concept and aspire to join the global economy. Therefore, in many developing countries which are now introducing trade liberalization policies, State-owned enterprises are under strong pressure to improve productivity and become internationally competitive. However, for the foreseeable future, those industries will have to attempt free-market business on the basis of upgrading their production facilities through imports. Their people have also realized that exporting raw materials and primary goods to pay for imported machinery and process know-how is a losing business, because the purchasing power of these commodities has steadily fallen while that of machinery has continuously risen over the last two decades. Furthermore, state-of-the-art machinery, which can provide a competitive edge in the international market, is normally not sold but can only be exchanged for something equally valuable. Therefore, consideration of building technological capabilities for transforming raw materials to high-value-added products is becoming extremely important for both private- and public-sector enterprises in developing countries ambitious to join the global market.

There is strong evidence to suggest that the industrialized world is now in a technological revolution of enormous proportions, entailing significant changes in many production activities and affecting almost all aspects of social and economic development. This would explain the many suggestions in contemporary writings that the most important consideration for market competition nowadays is the management of technological innovation. In industrialized countries, this quest for technological change in an enterprise is directed towards the acquisition and utilization of: the most advanced physical assets; the most competent human resources; the most valuable knowledge base; and the most effective management practices. Unique combinations of these four aspects (machinery, skill, knowledge and management) collectively contribute to the competitive edge of an enterprise. Many have also argued that comparative advantage based on differences in production factor costs (land, labour and capital) alone is no longer sufficient; now competitive advantage based on accumulated technological capability is most essential. However, acquiring technological competitiveness is progressive in nature, not a once-and-for-all event. Technological development takes place through costly and purposeful efforts resulting in the accumulation of technological capabilities; it is a continuous process of capacity enhancement and never-ending innovation. Without capability advancement, technological dependence increases. Furthermore, evidence is growing that access to advanced technologies is increasingly constrained by both the complexity and size of technology, as well as by the fact that it is increasingly under the control of transnational corporations which have invested heavily in specialized capability accumulation.

Understandably, every country is now interested in increasing value added (i.e., technology content added) by its productive enterprises as a strategic factor for global trade. In the industrialized economies' economic restructuring, there is an observable emphasis on innovation and specialization for the purpose of boosting international trade, as the value of a manufactured product is increasingly determined by the technology that goes into it, rather than by the raw materials that constitute it. Their recent successes show that, in the international market, the real competitive edge is derived from the efficiency of a production system in adding higher technology content to its outputs. Technology content added depends on the stock of physical resources, the quality of human resources, the usefulness of knowledge resources, and the effectiveness of management resources. Therefore, using higher technology content for international market competition requires that the production system expand and diversify the industrial base of a developing country by following a coherent technology strategy. Also, the technology strategies of enterprises in developing countries should change (a) over time, coinciding with different stages of industrialization, and (b) for different phases in the technology life cycle, as follows:

(a) First stage: imported and old-technology-based small- and medium-scale enterprises for the low-value local market;

(b) Second stage: selective importation of technology, mostly through joint ventures by medium-sized firms;

(c) Third stage: creative imitation based on licensed technology, enabling large-firms to enter the international market;

(d) Fourth stage: the introduction of self-developed technologies, giving rise to temporary monopolies in emerging areas.

Although the developing countries have long given high priority to the promotion and development of small and medium- sized industries, the technological aspects have often not received adequate attention. Proper management of technological change, particularly at the productive enterprise level, are important considerations for both private- and public-sector enterprises. Besides the private-sector companies, State-owned enterprises will also have to be internationally competitive if there is to be sustainable economic growth. Governments and corporations in the industrialized world are investing billions of dollars in creating the capabilities and institutions necessary to develop and deploy new technologies. Such changes in the industrialized world may undercut the comparative natural- resource and wage-rate advantages of many developing countries. Therefore, both for public- and private-sector production enterprises in developing countries, there is an urgent need to introduce technological changes to make their outputs competitive in the open market.

In developed countries, government policies are directed towards influencing the rate and direction of technological change, and they are justified because they correct market failures. Some of the common activities include: setting standards for interfaces and networks; flow-of-information penalties and restrictions on technological change that damages health, safety or the environment; and protection of intellectual property rights to reinforce the potential temporary monopoly rent afforded to would-be innovators by the natural time-lags and the cost of imitation. It may be important to note that though the transnational corporations do not need any support for technological innovation, they do need to be controlled. Small- scale enterprises in both developed and developing countries do not invest in technology factor creation. As developing countries do not have their own transnational corporations for international competition, catalytic and supportive institutions can help small enterprises in developing countries become global firms. One might note that in developed countries, universities, research institutions and the mass media actively support the growth and transformation of high-technology enterprises into global companies.

## C. Review of the existing situation in developing countries

Because of the diversity in the world, it is neither possible nor very useful to list the myriad of problems and issues faced by all developing countries in introducing technology-based development planning. Recognizing the uniqueness of each country situation, the following thus only attempts to highlight some of the most common and important aspects:

(a) All countries now recognize the importance of technology, but policy planners in developing countries do not appear to be taking advantage of the unique characteristics of technology. This is perhaps because technology is not well enough understood for its proper management, and hence, technology is still being treated as a black box or residual factor in models representing production functions. There is also a lack of understanding about the major distinctions between science and technology -- most fail to see that technology is the vital link (with both push and pull effects) between scientific knowledge and economic development. We find that technology is changing very rapidly and that the technological gap between developed and developing countries has widened; time-lags and discontinuities further complicate the matter. It can thus be observed that the planning situation appears hopeless due to a lack of appreciation of the presence of both the "dangers" and "opportunities" associated with the crises resulting from technological revolution;

(b) Policy makers often overlook the real fact that brainpower is the "ultimate source" of all kinds of production technologies. In many developing countries, natural resources have been exploited to a devastating degree, while human resources have not been fully developed. The reduction of natural resources due to inefficient use and over-exploitation for export is easily observed, but losses due to brain drain and the poor utilization of human resources are often not recognized. Nor is it understood that natural resources can be saved for future use, but technology resources become obsolete over time. It is thought that comparative advantages based on natural- resource endowments can be maintained for a long period. It is not known how technology can be used as a strategic variable, though it has been realized that the application of any technology may have some unwanted side-effects (which may be immediate and/or very long-term);

(c) Decision makers in developing countries still view technology as "a thing", or as machinery alone, and not as a composite resource for competition. There is a lack of appreciation that market value added by productive enterprises really means technology content added, which depends on the stock of physical resources, the quality of human resources, the usefulness of knowledge resources, and the effectiveness of management resources as criteria for selecting appropriate technologies. It is not understood that technology strategy is related to capability status and demand characteristics. Also sometimes overlooked is the fact that technology developed for one location is seldom equally well suited to others; investment in tailoring foreign technology to local circumstances is thus the rule, not the exception;

(d) Economic restructuring efforts in most developing countries reflect the belief that having production capacity is considered equal to having technological capability. Restructuring is mostly seen as progressing from basically agricultural to any or all kinds of industrial production -- without specialization. As can be observed, there is a mistaken expectation that any foreign investment in production capacity automatically results in technology capability. Also, investments are made in similar types of production capacities in most countries, without any consideration given to strategic specialization. Although it is apparent that economic growth results from technological capabilities localized in productive enterprises, it has not been learned that technological capabilities are not acquired when production capacity is built through "turnkey" projects and direct foreign investment. This illusion persists that production facility transfer by transnational companies means automatic transfer of technology capability to developing countries;

(e) For a long time, developing countries have followed many of the developed countries' science-and-technology-related models, but perhaps not those which could have ensured real success. There is an erroneous conclusion derived from the situation existing in developed countries that increasing research expenditure alone can enhance technological capability. It has now been noted that in developed countries the majority of research and development efforts are undertaken by private enterprises. Furthermore, compared to developed countries, total research and development efforts in most developing countries are insignificant and generally unproductive;

(f) Increased government funding and fiscal incentives for innovation are being given to universities and laboratories, but matching technological capabilities do not exist in the locally owned firms themselves. The research and development emphasis in government-funded institutions has failed to strike a balance between market pull and knowledge push. Minimum critical mass, continuity and proper linkages -- which are all essential for innovation -- are lacking. Most centres of academic and research excellence in the public sector have, for the most part, been isolated and disconnected from production, and have often proved unable to transform new knowledge into new and improved products or processes suitable for application in production units;

(g) In many countries, science and technology parks are being established as "incubators", but there are no matching requirements for universities to teach state-of-the-art subjects and practices. Due to over-protection and to the scarcity of funds, small-scale private enterprises in developing countries do not undertake in-house technological innovation efforts. Furthermore, most public-sector organizations suffer from outdated facilities and a rigid management style, both of which inhibit creativity. These organizations are often engaged in too many diversified activities, and operate with subcritical financial resources. Also, the mechanisms applied in funding, and the performance evaluation used (based on available indicators) give misleading signals. For innovation management -- as with other governmental administrative activities -- there is widespread emphasis on doing things right (efficiency) rather than doing the right things (effectiveness);

(h) The chronic balance-of-payments problem in developing countries reflects unbalanced international technology content in trade. This is primarily because developing countries have failed to give serious consideration to the problem of identifying technological needs. There are no procedures established for "needs planning" in the three technology domains, i.e., import/adapt, evolve/prosper, and produce/export. As actual technological needs relate directly to both self-reliance and sustainability, it is essential to consider world technological trends and situational realities in needs planning. Furthermore, the prioritization of needs and specialization decisions requires consensus-building, which is lacking. All countries are hopping on the bandwagon --

getting into the emerging technologies without adequate preparation or specialization. It is thus difficult (or even impossible) to deal with long-term considerations in planning decisions;

(i) For some reason or another, developing countries are still unable to integrate technological considerationsd into the socio-economic development planning process. Functions of the newly created ministries of science and technology and coordination councils for science and technology remain mostly peripheral. The development planning process has by and large remained fragmented and departmentalized, and also traditionally incremental. There is no distinction between the latent capacity of science-and-technology-related institutions and technology capability in productive enterprises. Instead of appreciating the problems of small-scale enterprises, which cannot invest in technology factor creation, most simply blame attitude and culture. No attention is paid to the fact that a strong commitment and active involvement by top leadership is the key factor;

(j) The sustainable-development aspect is generally seen only from the environmental conservation point of view, rather than from the technological self-reliance angle; what is often ignored is that technological self-reliance and sustainability are mutually reinforcing -- but it requires the accumulation of skills, knowledge and procedures. It has not been recognized that there is usually a lack of environmental standards, monitoring and impact assessment for development projects, and that the prevention is far better than the correction of environmental degradation. Environmental degradation is a result of poverty in developing countries and of affluence in the developed countries. Unfortunately, there is no mechanism for strategic policy formulation that can integrate shared technological visions. Policy contradictions and uncertainty in the policy-making environment discourage technological risk-taking. Although it is now recognized that a special focus on technology has become increasingly important for developing countries, the operational procedures needed to manage technology are still lacking.

A serious question requiring an urgent and careful answer is: Which policy systems, institutions and programmes should be put in place to enable countries to benefit from the new technological changes without falling too much deeper into technological dependence? The key issue here is the proper management of technology resources. It is imperative that an integrated approach to developing technology management procedures is developed, which should include considerations of: characteristics of technology resources; the technology structure of production systems; technology component sophistication; technology capability accumulation and advancement; technology strategy progression; technology infrastructure building and development; the creation of a dynamic national technological climate; and determining technology needs for risk reduction and sustainable development. The need becomes all the more critical given the current pace of rapid technological change. Discussed next are the rationale and a framework for developing a set of technology-assessment measures corresponding to the above requirements, specifically in the context of the prevailing deregulation and privatization trends (focusing on free enterprise) in most developing countries.

D. Technology resource characteristics

The resources for a productive enterprise are all those available supplies that can be used as needed. It is possible to categorize these resources into three broad types -- natural resources, human resources, and human-made resources. Natural- resource availability is widespread but varied: air is available everywhere, water in most places, food in many places, and minerals in some places. There are many natural-resource constraints: everything is not available everywhere; there is uncertainty regarding supply quantity and quality; concentration is inadequate in one place for long-term use; the regeneration cycle is generally very long; etc. Although there are problems in determining the true market price of State-owned natural resources (market mechanisms fail if prices are not realistic), endowments of raw materials reduce a country's imports, and natural resources, if saved, can be used later (perhaps in a better and more efficient way). Moreover, the most effective way to conserve natural resources is to give value to them; if people see their value, they will be more likely to conserve them. It may be worth noting that selling natural resources is a zero-sum game (one's loss is equal to another's gain).

Technology is a human-made resource for competitive production, and it is being developed and upgraded at an accelerated pace. It is a resource for transforming inputs into desirable outputs, and it has different features from natural resources. It is produced by creative people in various places to amplify human capabilities with regard to both work and play. Technology exists not only to satisfy needs, but also -- much more importantly -- as a crucial factor for success in competition. An enterprise derives value from the use of technology; there is no intrinsic value without use. The price of outputs depends on technology content added by enterprises and/or market demand. It is now recognized that technology is the most important resource for development. Technology for productive purposes changes mostly through a process of successive "substitution of old by new" for better performance.

Human resources have a dual function: they are the consumers of natural resources; and they are also the producers of human-made technological resources. Over the millennia, the size of the world population has increased steadily and greatly. There is currently a strong emphasis on family planning, and there is much concern over the potentially catastrophic consequences of further growth; it is hoped that the world population will stabilize. When humans and enterprises consume natural resources, they normally produce wastes and cause pollution (environmental degradation). To produce technological resources, people need to be developed into productive human resources: well educated, trained and informed; with the right kinds of tools; and highly committed and motivated. Every human being and every enterprise have virtually limitless potential, and the conduciveness of the national technology climate determines the extent to which these latent forces can become a reality.

Human-made technological resources, as was mentioned earlier, are the most important resources for competition in business in the present world economy. However, since technology changes through a process of never-ending "substitution of old by new", any technological resource becomes obsolete when someone has produced a better one. Therefore, not only does technology by itself not produce results (it is only a means), but it cannot even be saved for later application, as it becomes non-competitive. The oft-made statement about technological resources -- use it or lose it -- is thus appropriate. However, a variety of risks (to life, environment, or business) pervade virtually all technology applications. And yet, over the years, the rate at which new technologies are generated throughout the world has grown exponentially. Each new generation of technology suffers from a progressively shorter life-span. Technology life cycles have become so short that a leading enterprise has to be willing to make its own products obsolete in order to maintain its competitive position.

All enterprises compete for scarce resources and attempt to ensure steady supply. Consumption of natural and human-made technology resources are very high in the developed countries; these countries normally do not export their scarce natural resources, and so poor countries generally find it expensive to import high-quality resources (both natural and human-made). Developing countries do, however, export their scarce, high-quality natural resources to earn hard currencies to pay for imports. Human-made technology resources on the other hand, as they are not location-specific and are also locally created, can be developed wherever and in whatever way one chooses. If an enterprise has to depend heavily on imported resources (natural and technological), its ability to continue to add to market value remains very vulnerable. There must thus be sufficient attention given to resource ownership and the balance or compatibility of local consumption with available resource endowments. An enterprise needs to consider the relative proportion of locally available versus imported resources, and ensure that it does not become the victim of over-reliance on its suppliers from abroad and on the foreign ownership of needed resources.

### E. The technology structure of production systems

Technology, as the human-made resource, is the best means by which available natural resources may be transformed into desirable products and services. Such a transformation process can simply be viewed as adding technology content to the inputs, which in turn gives market value to the outputs. One possible way to enhance the competitive edge in the marketplace is to increase productivity by increasing the amount of technology content added by enterprises. Increases in productivity arise from change, and in bringing about this change, technology is a crucial factor. Investment in new technologies is the major factor distinguishing enterprises that achieve consistently high productivity gains from those that do not. Enterprises specifically need to increase the sophistication of all forms of technology used for transforming inputs, and to steadily accumulate technology capabilities. While technology components make the necessary operations possible, the technological capability of the firm arises from and is developed through the performance of activities over time, acquiring resources from outside, and/or generating resources from within. However, acquiring technological competence is progressive in nature, and the prosperity of a nation is the result of continuous innovation; this is fraught with risk and uncertainty, and hence is more difficult for small-scale enterprises in capital-scarce developing countries.

At the beginning, a developing-country enterprise catering to the domestic market is almost exclusively dependent on imported and mature technologies to take advantage of relatively abundant endowments of either natural resources or unskilled labour, or both. During this period local technological capability is likely to involve principally the effective operation of simple imported technologies. These natural- resource-based or labour-intensive industries face difficulties over the years as a result of either depletion (and degradation) of natural resources or a decline in labour productivity. For open-market competition, an enterprise needs the capability to acquire better technologies and also the capability to maintain and adapt imported technologies for which highly skilled and motivated human resources are needed. The transition to international competitiveness requires a greater degree of local capability for the improvement of imported technologies. While all firms need not be able to engage in major product and process innovation, they must at least have the capacity to undertake incremental improvements in existing technologies, as competition is based on product differentiation and on response to the demand of customers. Successful entry into this market requires a large number of scientists and engineers and considerable investment in in-house research and development. Internationally competitive enterprises pursue innovations which lead to the commercialization of new products and processes. Thus, technology development capability becomes the most important prerequisite for emerging technology-based products and services, which are becoming the most fiercely competitive industries of the world -- some examples include biotechnology, new materials technology, computer-integrated manufacturing, and information technology. Some of these emerging technologies (being scale-neutral, flexible and situation-independent) are opening up new opportunities for developing countries to apply high-tech -- but low-cost -- solutions to basic-needs-related problems. Without utilizing advanced technologies and blends of the traditional and advanced, the surpluses needed for self-reliant economic growth cannot be generated. On the other hand, it is virtually impossible for any nation of the world to cover the entire spectrum of advances in technology. Some practical and strategic balance has to be struck between locally developed and imported technologies.

In a competitive market, the growth of a firm and the course of its technological restructuring are tightly interwoven. One can also find a direct link between business strategy and technology life-cycle characteristics. In the introduction phase, the performance requirements for new products and market needs are not well defined, which means that the source of innovation is often the users, and the business strategy is customer and environmental responsiveness. In the growth phase, the basis for competition is on performance and specific features. In the maturity phase, with achieved standardization, the basis for competition shifts from performance to diversification with respect to niche markets. In the decline phase, when a new technology replaces an old one, the continuation of older (mature) but still functional products and processes can give a competitive edge to companies with significant brand loyalty (due to image) or to small enterprises serving the price-sensitive market vacated by industry leaders (who have adopted new technologies for higher-value markets).

To integrate technological restructuring into the overall business strategies of an enterprise for successful competition in the international market, it is necessary to consider the dynamics of the overall system structure. The technology structure is determined by the interaction among the elements of the production system -- technology components, technology capabilities, technology infrastructure, and technology climate -- which influence the potential for technology content addition within an industrial enterprise. The influence of the technological transformation system on the production factor creation mechanism is determined by the dynamic interaction among the elements of the system. It is thus essential that an attempt is made to thoroughly understanding the interactions among the system elements.

### F. The sophistication of technology components

Technology is still most commonly perceived to be only a physical means (like a black box) used by an industrial enterprise (either the private or public sectors of a national economy) for all kinds of productive activities. Physical facilities can only enhance human capabilities (e.g., amplifying the powers of muscle, brain, sight and reach) and condition work surroundings (increasing comfort and improving health). By equating technology with machinery alone, the importance of many other associated elements such as skills, information and management techniques cannot be fully or explicitly recognized. Technology should be understood thoroughly to be managed properly. It should no longer be treated as just "a thing" or simply "a black box". One possible way to discern technology fully is to decompose the technologies needed by any productive enterprise into four specific embodiment forms (or components). The four components of technology and their unique characteristics are as follows:

(a) Technoware: object-embodied physical facilities such as tools, devices, equipment, machinery, and structures which enhance human physical powers to control all necessary transformation operations;

(b) Humanware: person-embodied human abilities such as skills, knowledge, expertise, and creativity which contribute to the actual utilization of available natural and technological resources for productive purposes;

(c) Inforware: record-embodied documented facts such as design parameters, specifications, blueprints, and operation, maintenance and service manuals which make quick learning possible and help in time and resource savings;

(d) Orgaware: institution-embodied organizational frameworks, including such factors as methods, techniques, linkages, networks, and practices which coordinate all of the productive activities of the enterprise to achieve purposeful results.

All four embodiment forms of technology (which can exist at different degrees of sophistication) interact dynamically, and all must exist simultaneously for an enterprise's successful performance. For any particular work within an enterprise, however, there is a wide range of possible choices between the required minimum level of sophistication and the available maximum level (represented by the best -- or state-of-the-art -- practice) for each component of technology. Obviously, the choice of technology depends upon the complexity of the work to be performed by the enterprise to meet any particular market demand, the interrelationships among the degrees of sophistication of the four components of technology, and the resources available to the enterprise. It may be noted here that some of the human actions or functions required for control and operation are often built into sophisticated physical facilities.

It is the unique combination of various components of the technology utilized that determines the market value of the outputs produced by an enterprise (which essentially performs a transformation activity that contributes to the technology content of the inputs). However, the relative importance of the four components of technology depends upon the type of transformation and on operational complexity. Also, there can be considerable variations in the efficiency with which a given combination of available technology components is used in terms of the intensity of adaptation and improvement, as well as the intensity of introducing new bases. Because there are many combinations of interactions and trade-offs among the components, similar outputs (in terms of technology content added) can be produced by different combinations of technology components. In other words, a number of technologies (that is, different combinations of technoware, humanware, inforware and orgaware) are available to perform most transformation operations, and the choice of technology is an extremely complex decision problem.

Technology has been changing since the dawn of human history. In this century the pace of change is accelerated, but the process has remained the same -- substitution of old by new. Nowadays, technology is evolving so fast that the shelf-life of most technologies now rarely exceeds ten years. Empirical studies show that there are two types of change: one involves the incorporation of new technology through investment in a new system or through substantial additions to an existing system; and the other is the incorporation of continuing upgrades of new technology into existing systems. Certain technology components (particularly technoware and orgaware) usually change through a process of non-linear step-jumps from one generation to the next. In practice, a new technology component substitutes for an older one because the newer one is better in some way -- in performance, cost, or user appeal. For another technology component (addition to existing stock), there is upgrading and updating. Although new knowledge can sometimes replace (or even negate) old knowledge, unlike a computer, human memory cannot be erased to "unlearn" something that is not useful anymore. In general, each new technology component is adopted by an enterprise through a process of diffusion conditioned by economic and political factors. Thus, over a period of time, technology changes through a process of successive substitution, though technology developed for one locale is seldom equally well suited to others; investment to tailor foreign technology to local circumstances is thus the rule, not the exception. A great deal of costly and purposeful effort must be expended to assimilate any newly acquired technology.

Technology content added depends on the stock of physical resources, the quality of human resources, the usefulness of knowledge resources, and the effectiveness of management resources. Improvement in the degree of sophistication of the four components of technology gradually enhances the potential for more technology content addition by an enterprise. Technoware changes through a process of continuous substitution of old by new. Humanware changes through a process of progressive learning of new things. Inforware changes through a process of the cumulative acquisition of knowledge. Orgaware changes through a process of evolving arrangements and networks. Generally, the degree of technoware sophistication corresponds to the increasing complexity of physical transformation operations; the degree of humanware sophistication indicates increasing levels of competence; the degree of inforware sophistication represents increasing utilization of available facts; and an increasing degree of orgaware sophistication results in improved overall performance in the market-place. It is important to note that under certain conditions technological "leapfrogging" is possible, and developing countries may be able to take advantage of their late-starter situation, provided they are very selective and it is clearly understood that leapfrogging in technoware requires considerable investment in humanware, inforware and orgaware. Thus, these four components of technology provide a dynamically interacting basis for the transformation of inputs into outputs. Of the four components, humanware is the most important. The ability to solve problems by applying new technoware, instead of performing rote tasks, is valued above all else nowadays.

A new technology replaces an older technology because the newer one is better than the older one in some way(s) -- e.g., performance, cost and/or appearance. Since most new technologies progress on the basis of a large number of continuous incremental changes and basically through the recombination of existing know-how, empirical studies show that the growth pattern of technology follows an S-shape. Major breakthroughs, however, come at irregular intervals. Thus, the technological change process over a considerable period of time represents a series of sequential substitutions, each following an S-curve.

There are two major implications of this technological change process:

(a) Late-starter countries can attempt leapfrogging in two ways: in the cases where the technological change process is rather slow, eventual catch-up is possible as long as there are no revolutionary breakthroughs in any specific technology; and in cases where technology is changing very rapidly, a careful skipping of intermediate stages may be possible under certain circumstances;

(b) Leapfrogging in the use and production of technoware is directly possible if humanware, inforware and orgaware are well developed. With humanware well developed, it is not too difficult to master acquired facilities through reverse engineering. That is why many countries impose restrictions on the international sale of "strategic" technoware. Leapfrogging in the development of humanware is only possible indirectly by compression of the learning period (through the use of modern communications technologies) and by taking advantage of the very large and inexpensive population base. Leapfrogging in inforware is not possible at all because the information that will provide a competitive edge in the technology market is unlikely to be available to late starters through documents in the public domain. New-technology reports involving developments in many of the latest commercially relevant fields are no longer being published in open literature, and many competitors have moved towards greater secrecy in order to protect new ideas and innovations. Leapfrogging in organizational frameworks may be relatively easy, but effectiveness requires adaptation.

There are many obstacles to the realization of leapfrogging opportunities. A whole range of technological capabilities and technology infrastructure needs to be developed within developing countries to apply and adapt state-of-the-art technologies.

## G. The advancement of technology capabilities

The availability of all four technology components in an enterprise is a necessary but insufficient condition for competition; technology capability is also essential. Capability is important because an enterprise must be able to react to and take advantage of new opportunities in the changing world. However, technology capability is often confused with the ability to carry out research and development only. While this is an important element of technological capability, the most critical aspect is the ability to manage technological change. Furthermore, the accumulation of technology capability occurs through a process of institutional learning which results in the increased productivity and economic efficiency of the enterprise. Even in developed countries research is almost never the core activity in technology capability accumulation. Major innovations require the design, construction, and testing of prototypes and pilot operations, and expenditures on these development activities far outweigh those made on research activities. An enterprise in a developing country may obtain the above-mentioned components of technology in two ways -- either by importing them or by developing them locally. However, in order to use imported technology or to develop indigenous technology components, the experience of "individual learning by doing" and the experience of "institutional learning" need to be accumulated.

It may be stressed that capability involves more than the possession of technology components. It also involves managing continuing (often incremental) technological change in two ways -- through the modification of technology components for specific situations and particular conditions; and through the development and first commercialization of new components. The most important aspect of technological capability is the capacity to manage technological change. This is neither automatic nor easy; it requires the accumulation of skills, knowledge and procedures. Furthermore, technology developed for one locale is seldom equally well suited to others, so (as mentioned before) investment to tailor foreign technology to local circumstances is the rule, not the exception. Technological development takes place when an enterprise accumulates technological capabilities by means of investment in all four technology components (physical facilities, human abilities, documented facts, and organizational frameworks). It is a continuous process of capacity enhancement and never-ending innovation. Progressive and continuous learning is required in the following four self-reinforcing areas:

(a) Technology utilization capability: the operation, monitoring and maintenance of technology components (technoware, humanware, inforware, and orgaware) for transformation and other supporting activities;

(b) Technology compilation capability: commissioning all required physical facilities, coordinating supply and demand, and mobilizing (handling and storing) all the resources necessary for transformation and support activities;

(c) Technology acquisition capability: upgrading all components of technology (technoware, humanware, inforware, and orgaware) through searching, selecting, negotiating and arranging timely procurement;

(d) Technology generation capability: defining market-driven needs; developing new products, processes and techniques; building prototype and scale-up models for testing; and arranging venture capital funds for the implementation of innovations.

The four types of capabilities mentioned above can also be approached through two kinds of learning processes -- learning by doing (utilization and compilation) and learning by changing (acquisition and generation). Advancement of the utilization capability generally refers to increasing the scale of the operation, monitoring and maintenance of all technology components; gradual progress is made towards the optimal use of all currently available technology components, resulting in increased productivity. Compilation capability advancement refers to the increased mobilization of all resources for optimum efficiency and economic benefit. It corresponds to increasing the scope of operations to respond to different market niche requirements. Acquisition capability advancement results in the enterprise's greater vitality in undertaking technological change management; it also results in better procurement. Technology generation capability advancement leads finally to the realization of crucial self-reliance and control in the supply of critical technology components for effective international market competition in the face of rapid technological innovation.

With respect to acquisition capability, it may be noted that, internationally, financial and strategic imperatives rather than welfare motives dictate the direction of resource flows. For instance, technoware for production and services (other than state-of-the-art) can normally be bought on the international market for a price determined by the relative bargaining position of the buyer and the seller. However, high-quality humanware generally migrates from localities with poor standards of living (developing countries) to places with superior material and higher, professional standards of living (developed countries). Inforware that can provide a competitive edge is not sold on the open market; rather, restrictions are imposed on the flow of valuable (strategic and critical) inforware for reasons of commercial benefit. Imported orgaware needs adaptation to local conditions as it represents both an opportunity and a threat to the existing system. Although some advanced technoware can be transferred, maintaining a competitive edge requires technology generation. Moreover, decisions regarding which technology to transfer and which technology to develop require proper understanding of the unique nature of the technological change process (which is a series of never-ending, successive substitutions over time), so that advantage may be taken of possible leapfrogging. (As mentioned earlier, leapfrogging in the use of production of sophisticated technoware is often possible if humanware, inforware and orgaware are well developed.)

Accelerating the rate of industrial technology development requires steady improvements in the productivity of the learning process -- what is known as "learning to learn". This learning can be effected through the acquisition of better technologies -- either imported or locally developed. In most developing countries, there is (by necessity), heavy reliance on imported technology for industrial development. However, mere importation of technology is not a sufficient condition for sustainable development. Even though most non-state-of-the-art industrial technologies can be easily moved (transferred) from one place to another, they cannot be so easily mastered. Experience shows that one of the most critical elements for the success of technology transfer is its assimilation. Acquiring the ability to operate and maintain the imported technology is only a good beginning; however, unless it is assimilated, technology transfer is generally ineffective. Domestic capability must be developed to make possible the adaptation and improvement of imported technologies, and this may involve changes in the design, process and materials inputs.

Technological capabilities are acquired through learning in which practical experience plays a critical role, but in a far more complex way than is assumed in simple learning-by-doing models. In a dynamic context, technological necessities usually cause technological change to occur as a "cascade" of distinct but related changes. Experience gained in making the first change yields an important understanding of what is required to accomplish the next change. Experience and the intentional search for pertinent technology can lead to the necessary understanding that in turn leads to the introduction of technological change. It may be repeated here that two types of change are common: one involves the incorporation of new technology through investment in a new system or through substantial addition to an existing system; and the other involves the incorporation of continually upgraded new technology into existing systems.

There can be considerable variation in the efficiency with which a given combination of available technology components is used, in terms of the intensity of adaptation and improvement, and the intensity of introducing a new basis. The components of technology and technology capabilities are thus interrelated in a systematic way. They are mutually reinforcing, even though some of the interactions occur over vastly different time frames. There is also a definite relationship between capability and advancement -- starting with utilization capability and on up to generation capability. Initially, firms must accumulate operating experience for producing marketable outputs (utilization capability); the second stage involves accumulating "optimization" experience for the purpose of improving the performance of technology in use (compilation capability); the third stage involves the accumulation of "changing" experience, as technologies from other firms and economies are sought out and acquired (acquisitive capability); and the final stage is the building up of "adapting and innovating" experience by developing and being the first to commercialize new technologies (generating capability). This means "learning by doing" for operations and optimization capabilities and "learning by changing" for acquisition and generation capabilities advancement over time. Although efforts can be made to advance more than one capability at a time, they should still occur in the proper sequence.

However, for advancement in each capability, it is necessary to achieve an increasing degree of sophistication vis-à-vis the technology components relevant to the corresponding capabilities. Advancement in the level of capability accumulation means a better level of synergy; the combined actions of separate components make the total effect greater than the sum of the individual effects. Capabilities enable an enterprise to react to and to take advantage of new opportunities in the changing world. Capability enhancement is a process of institutional learning which results in both increased productivity and increased economic efficiency within an enterprise. A great many costly and purposeful efforts must be made to assimilate any newly acquired technology.

In a developing country context, the purpose of introducing technological change through the twin activities -- technology transfer from abroad and/or indigenous technology development -- is to enhance the international market competitiveness of the productive enterprises (both in the private and public sectors). The enhancement of any enterprise's competitive edge in the marketplace can be accomplished by increasing the quantum of the technology content added by the enterprise operations, which in effect is achieved through enhancing both the degree of sophistication of the technology components utilized and the level of accumulation of technology capabilities with respect to the specific functions involved in managing technological change. Generally, improvement in the degree of sophistication of the components of technology gradually enhances the accumulated technology capability of an enterprise. The status of the technology infrastructure and the development of the technology climate are very much linked with both market conditions and these government policies which set the rules of the game. A cascade of infrastructure and climate factors determine the ability of a firm to manage technological change effectively. Therefore, specific measures with respect to the technology infrastructure and technology climate should also be undertaken to ensure that the national setting is conducive to technology-based industrial development.

## H. The progression of technology strategies

These days, for competition to flourish under free-market conditions, technological considerations must be properly integrated into the overall business strategies of an enterprise. Many practitioners have found it useful to begin the desired integration process by considering those currently practised business strategies which give rise to comparative advantage in the market-place. These business strategies can be categorized as striving for price leadership through producer cost minimization, quality leadership through user value maximization, niche leadership through segment feature specialization, and image leadership through customer prestige (status/appeal) creation. Most business enterprises use some combination of these strategies for different outputs and different markets. Nowadays, the factors of production can be moved from one country to another almost at will. What's more, everything is on sale, everywhere, at cut-throat prices. Low-wage countries can exploit their comparative advantage using extender strategies until sophisticated customers (demand) put a higher premium on reliability, quality and performance than on price.

Although price competition (for growing markets) and feature competition (for mature markets) have been meaningful strategies for a long period, it is increasingly observed nowadays that retaining comparative advantage will depend on the ability of enterprises to compete -- beyond quality and feature -- on the basis of environmental soundness. Image strategy is currently placing a special focus on "green leadership". Most Governments (both in developed and developing countries) have now recognized their special responsibilities for the conservation of the natural environment, and are thus introducing the legislation necessary for strict enforcement. Some say that companies which ignore "green" pressure will be part of a tide of casualties that will sweep the global market-place. To avoid being branded as black sheep, the business community has also accepted a proactive responsibility and is voluntarily introducing a green strategy to achieve image leadership. The green strategy involves directly preventing or reducing the adverse effects of industry on the environment (as opposed to applying corrective measures after the fact). Environment- related business is expected to be the driving force behind the future economy and the source of most of the new competitive advantages in international markets. Developing new technology for sustainable development will naturally link environmental management with the innovation management of firms.

The growth of a firm and the trajectory of its technology are interwoven. The latter is a major factor in determining cost, quality, features, and environmental impact, which may be observed to be directly linked to product life-cycle characteristics. In the introduction phase, performance requirements for new products and market needs are not well defined, which means that the source of innovation is often the users, and the business strategy hinges upon customer and environmental responsiveness. In the growth phase, the bases for competition are performance and specific features. In the maturity phase, when standardization has been achieved, the basis for competition shifts from performance to diversification with respect to niche markets. In the decline phase, when new technology is substituting for an older one, the continuation of older but still functional products and processes can give a competitive edge to small enterprises serving the price-sensitive market vacated by industry leaders (who adopt new technologies for higher-value markets).

Technological innovations contribute to the economic welfare and progress of an enterprise through market gains based on segmentation. First, a new product or innovation is introduced in a market niche where the unique properties of that product or innovation are highly valued (valued highly enough to compensate for any negative attributes or its less reliable initial performance). As experience is gained, and the product and processes are improved, it can be introduced in still other niches where its special properties and better qualities are also valued. With the increase in sales volume -- due to the learning effect, the economy of scale and higher competition -- product price diminishes. If improvements in product design, manufacturing and distributing efficiencies continue, then the differentiated products eventually gain large market shares. During this process, it is known that the product attributes must be approximately equivalent to competing offerings in order for cost to influence the customer. Similarly, costs must have near parity if a price premium for unique features is to yield advantage. As different segments of the market have different needs, differentiation allows a firm to command a premium price by providing unique and superior value to the customer in terms of product quality, specialized features, and/or after-sales services. However, firms have to be innovative to find new niches in the market if they are to cope successfully with the saturated markets for existing mature products, because the benefits of comparative advantage soon level off as other firms introduce similar changes.

Technology capability advancement (accompanied by technology component sophistication) is expected to contribute to better market performance by the enterprise through strategic restructuring. As different segments of a market have different needs, enterprises attempt differentiation (providing unique and superior value to customers in terms of quality, feature and image) to command a premium price. The ramifications of technology are implicit and pervasive in each of these business strategies. However, to consider technology aspects more explicitly, it is desirable to pay attention to the possible technology strategies for securing competitive advantage. In the context of developing countries, the dynamism of the strategic choices can generally be derived through gradual but determined advancement from price, quality or niche leadership to image leadership on the basis of the following technology strategies:

(a) Technology extender strategy. Small-scale start-up enterprises based on imported and old technology use this strategy of "salvaging or extending the life of obsolete technologies" to cater to a low-value local market. Some of the general characteristics are: price- and service-sensitive markets; filling market niches vacated by industry giants/leaders (as they have shifted to emerging areas); utilizing time and production factor cost advantages; price leadership; acquiring easily available technology components; using mostly elementary technology capability; and practically no local research and development efforts. This strategy has a very short life in a competitive business environment;

(b) Technology exploiter strategy. Technologies are selectively imported (mostly through joint ventures) by medium-sized firms, which use the strategy of "exploiting mature and standardized technologies" for quality leadership in the medium-value national markets. Some of the general characteristics are: attempts by firms to become international companies, basically using advantages of production factor costs and market differentiation; reliance on uniform quality; some efforts towards method-package innovation; generally, price leadership in medium-quality market; cost savings through cheap labour and cheap input substitutes; the purchase of available technology components; the possession of secondary technology capabilities; the need for adequate technology infrastructure support; and often, the reflection of foreign market needs in product design;

(c) Technology follower strategy. Creative imitation based on licenced technology enables large firms to use this strategy of "joining the league by adapting advances and latest technologies" to enter the international market. It is generally characterized by: companies that allocate resources for mastering and using advanced technologies for expanding regional and global markets; reliance on adaptive research and reverse engineering; emphasis on skill-knowledge innovation; sufficient efforts related to skill-knowledge innovation; economies of scale; subcontracting approach; emphasis on market promotion; niche and quality leadership; high-value markets; both the transfer and development of technology components; and the need for advanced technology capability for quick learning through reverse engineering;

(d) Technology leader strategy. The introduction of locally developed technologies gives rise to temporary monopoly, allowing very large companies or new-technology-based start-up companies to follow the strategy of "being first to commercialize state-of-the-art technologies" in emerging areas. This is usually seen among pioneering companies using state-of-the-art technologies to venture into emerging global markets. It is characterized by: heavy reliance on internal research and development; emphasis on product-process innovation through basic research; niche and image leadership; flexible production systems; very-high-value markets; the control of segment markets; economy of scale as well as economy of scope; "demand" sophistication, which accelerates quality improvement; and the need for superior technology capability and a conducive technology climate.

Any firm needs to progressively develop its technological capability for gradual progression with respect to the above- mentioned technology strategies if it is to achieve sustained growth. For instance, a firm which starts with a technology extender strategy should achieve outputs of desired quantity and quality very efficiently; thus, the firm needs (at least) technology utilization capability. But, to move on from the extender strategy to the exploiter strategy, it will need (in addition to utilization capability) the capability to acquire and maintain new technologies (acquisition and compilation capabilities). The need for support and acquisition capabilities becomes even stronger as the firm develops further and starts pursuing a technology follower strategy. Ultimately, to become a world leader, the capability to generate new technologies on its own (generation capability) is most critical. It may also be noted here that the relative importance of the four components of technology are quite different for different capabilities. For example: facts and abilities are more important for acquisition; facilities and abilities are more important for utilization; facilities and facts are more important for compilation; and abilities, facts and frameworks are all very important for generation.

The technological progression pattern from extender to exploiter to follower to leader reflects a process of industrial restructuring which is broadly determined by competitive market forces. At the beginning, a developing country industry is almost exclusively dependent on imported mature technologies to take advantage of relatively abundant endowments of either natural resources or unskilled labour, or both. During this period, local technological capability is likely to involve principally the effective operation of simple imported technologies. These resource- or labour-intensive industries face difficulties over the years due to either depletion of the natural resources or decline in labour productivity. For quality competition, industry needs the capability to acquire better technologies and also the capability to maintain imported technologies (highly skilled human resources are needed), and thus it must move into the exploiter situation. The transition to the next level requires a greater degree of local capability for the adaptation of imported technologies. While all firms need not be able to engage in major product and process innovation, they must at least have the capacity to undertake incremental improvements in existing technologies, as competition is increasingly based on product differentiation and value addition. Successful entry into this follower strategy requires a large number of scientists and engineers. To move into the leader category, innovative capability becomes most important; the lack of entrepreneurship is the critical constraint.

Being technology leader requires that firms are fast, fearless, fluid, facilitative and flexible with respect to technological innovation. They become industry leaders, cater to a very-high-value market, spend heavily on research and development, and determine to a large extent the technology trajectory of the industry. Technology followers can reap benefits if they can buy state-of-the-art facilities or modify products and processes through reverse engineering. They need to be very good at quickly adapting advanced technologies to join the high-value market in the beginning of the growth phase of the product life cycle. Technology followers neither have the first-mover advantage (supernormal profit) nor their disadvantages (high cost and risk). When the market is growing, the exploitation of standardized technologies may give rise to rapid growth (a strategy successfully implemented by newly industrialized countries such as the Republic of Korea, Singapore and Taiwan). They cater to the medium-value market, with advantages in production factor costs (cheap labour and raw materials). However, the exploiter strategy cannot be sustained unless the infrastructure is built to move into the follower and then leader strategies in selected areas. Technology extenders cater to the low-value, price-sensitive markets which have been vacated by the industry leaders. Production technologies that are suitable for the extender strategy are readily transferred to the developing countries.

It is apparent that, unless there is a world-class research institution producing state-of-the-art information, it is virtually impossible for a small-scale enterprise in a developing country to start with a technology leader strategy. The likely path for strategic progression in the developing country context is from technology extender to technology exploiter to technology follower, and then to technology leader. Step by step, the ladder is ascended in very carefully selected areas of specialization. This progression pattern in developing countries reflects a process of industrial restructuring which is broadly determined by competitive market forces. There are significant technological implications in the above restructuring process in developing countries. The relative importance of technological capabilities changes as an enterprise attempts to move from the extender strategy to the leader strategy. For higher positions of technology strategy, advanced-level technology capabilities are required. For example, an extender needs to emphasize mostly utilization capability; an exploiter needs both utilization and compilation capabilities; a follower must have adequate utilization, good compilation, and fair acquisition capabilities; and a leader must have a very high level of all capabilities. Furthermore, this process of accumulating higher-level capabilities should be coupled with a progressively higher degree of sophistication in each component. It may also be noted that the critical role of technology transfer and technology development changes along the technology strategy progression path -- with more emphasis on technology transfer initially, and eventually more emphasis on technology development.

## I. The development of technology infrastructure

Due to the scarcity of capital resources, small- and medium-scale enterprises in both developed and developing countries are likely to under-invest in technological capability advancement. Also, there is an increased degree of specialization in technology generation today compared to earlier days, due to the high cost and risks of research and development. Existing evidence suggests that most of the fast-moving fields are centred in large firms in knowledge- and skill-intensive sectors; these firms generally carry out highly professionalized and specialized activities in their research laboratories. Some of the common incentive mechanisms for such factor creation are: alleviating a relative factor scarcity; exploiting abundant natural resources; achieving a mastery of some science-based technology; and exploiting widely used core technologies on a global scale. It is obvious that small- and medium-scale enterprises need help from the Government -- more so in developing countries.

Since almost all enterprises in developing countries are on a small- or medium-scale, their capability to introduce technological change depends upon the support provided by the national technology infrastructure. What can be bought and what can be locally developed depends upon the state of this infrastructure, which is supposed to promote technological innovation through strong triangular linkages among: the academic institutions engaged in science and technology education and research (academia); a wide range of science-and-technology- related research and development organizations (R and D units); and the engineering and industrial production enterprises (industry). Three major types of technology innovation expected to result from the triangular linkages are: product-process innovation; knowledge-skill innovation; and method-package innovation. A large number of promotion agents (public and private institutions) are necessary to support any or all of these innovations. The totality of these institutions can be called the "advanced factor creation mechanism" or simply the technology infrastructure. Infrastructure status can be understood by specifically considering the following:

(a) The strength of "triangular linkages" among the three types of institutions -- academia, R and D units, and industries. Linkage here refers to the elements of the connection (the institutions) and the flow between them. Major criteria for assessing the strength of the innovation triangle may include: the presence of all links above the minimum critical level; the magnitude of their interactions; and the extent of utilization of the facilities. The magnitude of interactions may be considered in terms of the flow of money, technoware, humanware, inforware and orgaware;

(b) The continuity of technology "innovation chains", which cover three prominent development aspects: product-process development; knowledge-skill development; and method-package development. The major phases of the product-process development chain are: searching, designing, generating and modifying. Phases of the knowledge-skill development chain are: exposing, training, educating and upgrading. Phases of the method-package development chain are: conceiving, formulating, preparing and evolving. The most important consideration is to ascertain the presence and adequacy of performance of the promotion agents corresponding to each phase of the three development chains;

(c) The catalytic effect of "technology mentors", which are generally of two types: financial institutions (investment promotion corporations and venture capital banks); and technical institutions (certification, testing, quality assurance and standardization organizations). These institutions contribute significantly to screening and determining the appropriateness of imported technologies, and also to promoting the commercialization of indigenous technologies. Major criteria for assessing the impact of these institutions could include the extent of equity participation and the direct involvement of these institutions with the local productive enterprises;

(d) The supportive role of "technology guiders", which are categorized into two broad groups: all those institutions involved in science and technology information services; and other institutions engaged in advisory and consultancy services (including technology transfer boards). These institutions provide the direction as well as the opportunity for self-reliance. Major criteria for assessing their contribution could be the value of the services provided and the extent of independence from external (foreign) services.

A major factor contributing to the low level of technological capability in many developing countries may be the poor science and technology infrastructure. For a developing country to gradually move from an agricultural to an industrial economy, it is necessary to ensure the continuity of the technology capability and component development chains and the availability of minimum critical mass with respect to all promotion agents. It is important not only to recognize that each promotion agent must have the minimum critical mass, but also to note that the relative importance of the distinctive phases in each of the development chains is not equal. Some of the phases are much more critical and require considerably more resources than others. For self-reliance, it is essential to attain sufficient strength in each phase of the development chain by adequately supporting the promotion agents. A complete absence of any particular phase in the development chain makes an industry vulnerable to foreign competition. A major contribution Governments make to technological capability is their investment in education and training.

All institutions need a minimum level of critical mass for satisfactory performance. Therefore, a missing link in the technology innovation process exists not only if one of the promotion agents is missing, but also if any of the institutions (or promotion agents) lack this minimum critical mass. Furthermore, most of the linkages are non-reliant. Incentive mechanisms for factor creation -- alleviating a relative factor scarcity; exploiting abundant natural resources; achieving mastery in some science-based technology; and exploiting widely (and increasingly) used core technologies.

## J. The dynamism of the technology climate

The success of an enterprise in achieving technology-based development depends to a large extent upon the national technology climate within which the enterprise has to operate. Many factors determine the contribution of threats and opportunities to the technology climate. Technology climate refers to the intensity of national commitment to and socio-cultural acceptance of the use of technology for development, as well as the effectiveness of national mechanisms for integrating science and technology policy aspects with development planning. Besides government policies, there are other factors -- market forces and cultural aspects -- which set the rules of the game for any productive enterprise and also influence the dynamism of the national technology climate. The development of technology infrastructure is also very much linked with market conditions and government policies. In many developing countries, government controls are currently being replaced by deregulation, privatization, competition and other market features. Government officials are defining and fulfilling a new role as facilitator in which they bring key parties together to encourage collaborative new ventures and resolve disputes. The incentive and regulatory system affecting industrial development must put pressure on enterprises to enhance their technological capabilities and thereby increase productivity and/or competitiveness. Dynamism in the national technology climate -- which determines the technology potentials of an enterprise -- can be viewed in terms of the following "stimulating" factors:

(a) The intensity of "competition from open market rivals". Competition puts pressure on firms for continuous technological innovation. Some possible factors to assess to determine the fierceness of competition could be the ratio of the export of outputs to total production, the difference between the largest and the smallest producer, and the number of similar enterprises in the local and international markets. As one competitive industry helps to create related industries in a mutually reinforcing manner, this process of industry evolution in a place often breeds new competitive industries;

(b) The extent of "cooperation from a related industry cluster". Cooperation magnifies and accelerates the process of factor creation. A developed cluster of related industries can pool private resources for the creation of technology factors such as human-resource development, information services and consultancy services. Clusters also provide mobility for skilled manpower. The strength of the cluster may be assessed indirectly by determining the ratio of imported inputs to total inputs consumed and the local cluster market's share of the world cluster market;

(c) Pressure due to "preferences of the customers". Customer preferences make technological innovation essential. Whether the customers are price, quality, feature or image sensitive largely determines the business strategy of an enterprise, which in turn influences efforts in technology component and capability development. Preferences for quality products and services are related to factors like economic pressure, culture and education. One key factor for successful innovation is location; the enterprise must be located in an area which has a reputation for evaluating and using outputs in a very demanding way (seeking better than what is available);

(d) The general "conduciveness of culture" to creativity. This depends on many factors, such as a knowledge-seeking and future-oriented human-resource base, an open reward system that encourages innovation and risk-taking, a strong leadership and commitment through direct involvement, and an interest-coordination and consensus-building mechanism for adequate resource mobilization. The leadership (at every level -- firm, industry, and nation) should be a catalyst with respect not only to the technological challenges and opportunities of today, but also for the preparedness of the future. Commitment is essential to translate needs into appropriate actions.

A large concentration of rivals, customers and suppliers promotes efficiency and specialization, which, in turn, influence the innovation process. The incentive and regulatory systems affecting economic development have to put pressure on enterprises to enhance their technological capabilities, thereby increasing productivity and competitiveness. Earlier, laws and rules concerning entry into industry, competition, and restrictions on trade were adopted to offset the natural tendency of a mass-production-based system to grow to the largest possible scale. Nowadays, it is necessary to encourage resource accumulation and joint research for the development of widely used and generic technologies.

## K. The identification of technology needs for sustainable development

National development agencies currently consider technology needs from two points of view: funding and promotion. The first involves fund allocation for research and development activities, and the other involves the promotion of foreign investment (which includes technology transfer). Actual technological needs are determined through a process of incremental planning. However, without any deliberate attempts to take advantage of the unique characteristics of the technological change process (e.g., leapfrogging), the technological dependence of these countries is expected to grow continuously. Problems also arise due to the lack of clear differentiation between technological self-sufficiency and self-reliance. Technological self-sufficiency means the ability to produce all necessary technologies (which is neither economically efficient nor even possible), while technological self-reliance involves the ability to make autonomous decisions, the possession of the critical technologies needed for economic growth, and the accumulation of capabilities to manage technological change on a continuous basis.

The same way an enterprise attempts sustainable development, a nation also needs to consider the principle of a "make some and buy some" technology strategy for self-reliance. There are basically three approaches that can be taken to increase the level of sophistication of technology components: buy the entire gamut of available technologies; generate all technologies from within; and buy some and make some. The buy-all option's greatest advantage is that it gives instant results with minimum risk. The make-all option, on the other hand, has the wonderful advantage of total self-reliance. However, one must avoid being blindly engaged in such noble but certainly financially unrewarding exercises as reinventing the wheel. Also, make-all is a very slow and painful process. The approach which is most practical is "buy some and make some", a two-pronged combined strategy for sustainable development. Unless systematic and comprehensive efforts are begun in developing countries to develop the needed technologies using the make-and-buy strategy, it will be impossible to build a technological foundation, and the risk of becoming more dependent on imported technologies will grow. One of the critical needs is to identify the appropriate mix, at each stage of development, of the imported and indigenous technologies needed.

Both technology transfer and technology development are important for identifying those technological needs which will make meaningful industry restructuring possible. Overall industrial restructuring refers to the continuous change in the industry mix within the industrial sector of the economy -- from heavy concentration on "agro-nature" to "raw-materials" to "capital-energy" to "new-science" based industries. But what needs to be transferred and what can be locally developed depends upon the strength of endogenous capabilities (including infrastructure and climate) and global trends. Monitoring world technological trends and trade opportunities are important to ensure proper future orientation and long-term considerations in all "make and buy" technology decisions.

Major steps necessary for the identification of national technology needs are as follows: analysing development objectives to prioritize technological areas of relevance; forecasting world market and technological trends; formulating an acceptable set of criteria for assessment; evaluating necessary technology inputs for desired national outputs; prioritizing technological needs as basic, generic, unique or strategic; and classifying these needs by technology domains (importing, evolving and exporting) for transfer and development. Importing domain represents areas chosen where there is dependence on others -- because technologies have very long gestation periods and require enormous expenditure. Evolving domain represents areas which are unique from the point of view of local endowments and heritage. Exporting domain represents areas for future competition and other specific strategic benefits.

The type and nature of the outputs (both desirable outputs and by-products) produced by an enterprise generally determine its competitiveness and profitability in the free market. As can be observed from current international market competition trends, the most important attributes (in addition to price) are: the technology content of the outputs; the environmental friendliness of the outputs, and the transformation operations of the enterprise. While the degree of sophistication of the technology components, the level of advancement of technology capabilities, and the characteristics of the natural resource inputs do, to a large extent, determine the technology content of the outputs, all transformation activities invariably produce wastes, cause some pollution and often involve environmental hazards and degradation. Given the potential severity of the possible environmental impact, all productive enterprises are morally bound to minimize potential risks (not only to their businesses but also to human beings and their living conditions in general) while introducing new technologies.

Attempting technology component sophistication (for strategic progression) through technology transfer also requires careful consideration of environmental soundness. Even in developing countries one must pay attention to environmental sustainability considerations in addition to economic and technological considerations. For this reason, the appropriateness of transferred technology must be assessed. However, technological appropriateness is a complex and dynamic concept, involving value-based evaluation on the basis of many factors, including economic feasibility resource availability, technology progression, and environmental sustainability. Besides abiding by government regulations on pollution control and waste disposal, decisions regarding technoware sophistication should include considerations related to replacing non-renewable resources; reducing the use of scarce resources; reusing all resources; and whenever possible recycling all resources to conserve nature. Technology management for sustainable development calls for the importation of technologies that are economically efficient, commercially attractive, and at the same time environmentally acceptable.

Technology should be used as a strategic variable, but it should be very well understood that application of any technology may have some unwanted side effects (immediate or long-term). It is known, however, that technology by itself is not responsible for environmental problems. Environmental degradation is a result of poverty in developing countries and of affluence in developed countries; in other words, environmental problems are due to the mismanagement of technology. Proper management calls for environmental protection without the compromising of economic development. Therefore, even though there are both financial and environmental risks inherent in all use of technology, both businesses and Governments can and should work together to minimize these risks. In developing countries, one generally finds that overuse, waste and inefficiency coexist with resource scarcity. Keeping all of these in mind, environmental acceptability needs to be assessed in terms of the short-term effects of enterprise activities in terms of air, water, land and atmospheric pollution, and also in terms of all kinds of long-term threats to human life.

In addition, business risks can also be considered in terms of international trade resistance (e.g., non-tariff barriers using environmental pollution and allegations of human-rights violations) to the outputs and the associated processes involved. High trade barriers for transformed goods constitute a constraint for the economic restructuring of many developing countries. Trade restrictions imposed by national standards and technical regulations often centre on packaging, marketing and labelling requirements. It may be noted here that at present, protectionism is being used by the world's major economic markets to slow their unemployment growth. It is also known that established systems give power to the already powerful. Therefore, consideration must be given to the distinctive nature of the risks inherent in failing to pay enough attention to technological capability accumulation and strategic progression. One of the critical requirements is to identify the appropriate mix, at each stage of development, of the imported and indigenous technologies needed by the production system and the need for supportive infrastructure building.

## L. Required technology assessment procedures

In the previous sections, relevant factors for technology management were identified using the basic premise that, even in developing countries, the selective generation of new technology and the application and blending of both new and old technologies are important for self-sustained economic growth. However, the infrastructure required to support innovations is often the determining factor for such technology-based competitive economic development. It was stressed that more attention must be paid to the linkages among various institutions involved in the innovation processes and to the effective functioning of the innovation triangle. The fragmentation that currently exists is seriously undermining the effectiveness of the innovation system. Besides the support of the technology infrastructure and the conduciveness of the national technology climate in developing countries, the most important considerations for an enterprise in identifying a strategic progression path involve a thorough assessment of the status of available technology components and its accumulated technology capabilities. Although all four components of technology are necessary for each type of capability, the specific combination and the relative importance of the four components of technology are different. Moreover, the relative importance of technological capabilities also changes as an enterprise attempts to move from the extender strategy to the leader strategy. For an enterprise to develop competitively from the initial (start-up) technology extender stage to the technology exploiter (expansion) stage to the technology follower (consolidation) stage and then to the technology leader (mature) stage, technological capabilities need to be upgraded through institutional learning and through the progressive addition of sophisticated technology components. While introducing technological sophistication, the enterprise should also ensure that the chosen option minimizes business and environmental risks. It is now possible to summarize the most important indicators for technology management as follows:

(a) The resource-mobilization situation -- Alarming-Disturbing-Tolerable-Reasonable -- representing constraints due to foreign ownership with respect to natural resources, human resources and human-made resources. An assessment of vulnerability and of the critical dependence on foreign inputs would ensure recognition of the supplier's power with respect to technology and would identify importation constraints in its use as a strategic variable for competitive growth. Potential indicators are: the content of important human-made resources; the share of foreign ownership of resources; the constraints caused by automatic technology obsolescence; and the failure to use human resources for technological leapfrogging. The general interest of enterprise owners in technology factor creation and technology capability enhancement should also be considered. Four kinds of situations may be considered: foreign direct investment; joint venture; licensing; and fully local. For each of these arrangements, the interests and aspirations of owners and technology suppliers in generating the four components of technology locally (technoware, humanware, inforware and orgaware) and acquiring the four aspects of capability (utilization, compilation, acquisition and generation) may be assessed, using such criteria as the relative amount of resources allocated;

(b) The degree of sophistication of technology components -- Low-Medium-High-Top -- indicating the status of available technoware, humanware, inforware and orgaware in relation to the best practice elsewhere. An assessment of the relative distance from the state-of-the-art (or best practice) can help in the evaluation of technological strengths and weaknesses for the proper allocation of additional investment funds for achieving increased productivity. Potential indicators relate to the sophistication of: physical facilities, human abilities, documented facts and organizational frameworks. Major criteria for assessing the technoware position vis-à-vis state-of-the-art may include the scale of operations, the scope of outputs, the quality of outputs, and the safety or environmental soundness of operations. Major criteria for assessing the humanware position relative to the best practice elsewhere may include the level of general education, the appropriateness of training, relevant experiences, and the motivation of the personnel. Major criteria for assessing the inforware position may include the relevance, timeliness, and reliability of acquired facts. Major criteria for assessing the orgaware position may include the market competitiveness and self-reliance (in technology capability) of the enterprise;

(c) The level of technology capability accumulation -- Elementary-Secondary-Advanced-Superior -- indicating the degree of institutional learning through the utilization, compilation, acquisition and generation of technology components. This analysis can also help in identifying current institutional strengths and weaknesses so that a solid foundation can be built upon which capabilities for managing technological change (both technology transfer and technology development) can develop and grow. Potential indicators include the current status of: utilization capability, compilation capability, acquisition capability, and generation capability. The extent to which the enterprise is capable of carrying out all of these functions vis-à-vis the world leader could indicate the level of accumulation of individual capabilities (utilization, compilation, acquisition, and generation);

(d) The prospects for technology-based strategic restructuring -- Bleak-Difficult-Promising-Shining -- showing the degree of strategic progression through an assessment of sophistication and capability advancement conditions. Persistent efforts and step-by-step progression (with adequate allocation of resources) in highly selective and high-potential areas are essential for strategic restructuring and competitiveness building. Potential indicators are: restructuring from the extender to the exploiter strategy; restructuring from the exploiter to the follower strategy; restructuring from the follower to the leader strategy; and the prospect of sustaining the technology leader strategy. As income increases, people start substituting quality for quantity, and they also become more concerned with the environment. In developed countries, environmentally superior products, processes and services now represent the biggest new market in the history of world business. Developing countries can perhaps take advantage of this new opportunity;

(e) The status of the development of the technology infrastructure -- Poor-Average-Good-Excellent -- describing performance relating to triangular linkages, innovation chains, mentors and guiders. Adequate attention is necessary to ensure the presence of linkages and minimum critical mass, resulting in institutions (promotion agents) achieving both relevance and excellence. Potential indicators include the strength of triangular linkages, the continuity of innovation chains, the catalytic effect of mentor institutions, and the supportive role of guider institutions. The actual positions of the innovation triangle, development chains, technology mentors and technology guiders can be assessed by comparing the existing status of each with that of the best practice elsewhere;

(f) The degree of stimulation produced by the technology climate -- Negligible-Weak-Moderate-Exceptional -- recognizing the degree of dynamism provided by market competition, levels of industrial cooperation, customer preferences and cultural conduciveness. Increased funding for research and development is not enough; policy measures have to encourage technological innovation by the private sector. The ability to make effective use of technology is critical to the achievement of self-sustained development. Potential indicators are the intensity of competition from rivals, the nature of cooperation within clusters, pressure from customer preferences, and the conduciveness of culture to innovation as a result of policy interventions. The local technology climate can then be assessed by comparing the aspirations of the owners and technology suppliers, the influence of the cluster, and the policy environment with the best practice elsewhere;

(g) Severity of technology-choice mistakes and risks -- Extreme-Large-Some-Little -- negative consequences in terms of the impact on air, water and land and the threat to life, and other factors that constitute resistance to international market entry. Ensuring the proper use of technology as the key resource for sustainable development requires keeping in mind economic efficiency, commercial attractiveness, and environmental soundness -- without sacrificing the realization of self-reliance. One purpose is also to promote the generation and use of environmentally sound technologies to safeguard the natural environment for future generations. Potential indicators include an emphasis on quick and short-term benefits; inadequacy in needs balancing and specialization; the likely impact of environmental degradation; and the extent of prevailing international pressure.

For each of the technology management indicators mentioned above, qualitative assessment is possible if one identifies situation-specific criteria (generic examples were given in previous sections) for relative scoring between the worst and the best positions. Scoring methods of varying complexity can be used. Scores can be determined by applying a set of criteria (which are preferably quantitative technical parameters) to each assessment aspect. Once the individual positions are assigned to the attributes (with pre-defined scores), a simple weighted average can indicate the overall situation. The above assessments can be presented as a score-sheet (using the four broad gradings between the worst and best cases) depicting overall status at any particular time. These measurements can provide the basis for strategic decisions, and they may strengthen foresight and prudence in identifying proper business strategies along with the technology strategies. Such measurements invariably involve enterprise-specific information perceived to be confidential (not released to outside investigators); hence, these indicators are meant to be used by the enterprises themselves.

Due to the absence of absolute measures -- and because the technological change process is very dynamic -- the assessment of technological aspects has to be undertaken on a relative and regular basis. Moreover, since markets in most developing countries have a high degree of imperfection, conventional financial indicators do not adequately describe the technological capabilities of a firm or an industry. Technology assessments which focus explicitly on measuring the technological strengths and weaknesses (relative to state-of-the-art or best practice elsewhere), could therefore provide valuable insight for management decision-making. Since a "technology gap" is generally self-reinforcing, deliberate investment is needed to get out of this trap. It is possible to use a relative scoring method in terms of selected qualitative attributes. Given the limitations of theory and data, relative assessments are usually more valuable to decision markers than attempts at absolute assessments. Although individual aspects of technology can often be assessed quantitatively, when they are aggregated (and exist in a larger dimension), the measurements must generally be qualitative in nature and are expected to be complementary to conventional economic and financial indicators for management decision-making.

Everyone is aware of the difficulties encountered in operationalizing the concept of technology-based development and developing indicators for it. Currently, technology assessments are severely limited by the lack of good data. Instead of using only comparative and superlative words, it may be more useful to express oneself in terms of numbers, weights and measures. Several quantitative and qualitative indicators are needed to measure progress. Qualitative scoring against some quantitative benchmark is very easy and intuitively appealing. There are many reasons for measurement: to know where one stands relative to a certain benchmark; to monitor and control performance; to identify strengths and weaknesses; to focus efforts; and to quantify achievements for motivational purposes. It can also be used as a barometer for management actions and as an effective tool in target-setting dialogue and for communication. Furthermore, numbers bring the real world home to the reader in a way that even eloquent writing cannot.

## M. Imperatives for technology integration

It is obvious that the integration of science and technology in the development planning and management process has to be undertaken at all levels. At the enterprise level, it means the integration of technological considerations into business strategies, which results in successful technology transfer and technology development by the productive enterprises. At the industry or sectoral level, it involves the development of a self-sustaining mechanism for technology factor creation -- providing the infrastructure necessary for the three types of innovation chain (product-process; skill-knowledge; and method-package). At the national level, the purpose is to create a culture which is conducive to technological innovation and which influences the orientation of the decision-making system. Earlier sections of part four presented a detailed description of technology management measures suitable for developing countries. Enterprise-level measures involve technology components, technology capabilities and technology strategies. Industry- or sectoral-level measures cover technology resources and technology infrastructure. At the national level, the measures are related to the technology climate and technology needs. These measures provide a practical framework for integrating technological considerations at every level of development-related decision-making, and serve four major purposes: assessing current standing against international benchmarks; evaluating strengths and weaknesses to focus investment efforts; quantifying achievements for setting targets and for motivating; and the planning, implementation, monitoring and control of performance. In using these measures, it is very important to remember some of the critical issues which were discussed in earlier sections. A few of the issues are presented here just to stress the fact that the measures will have to be adjusted with changing situations.

The nature and success of technology transfer depend to a large extent on the existing technological capabilities of an enterprise. The transfer of technology between two enterprises (a developed country transnational corporation and a developing country firm) separated by a large gap (in component sophistication and capability accumulation) tends to be one-sided, with little scope for technology assimilation. On the other hand, when the gap is too small, technology transfer may not take place at all due to market competition. Any transfer between partners with a large gap should include specific steps for strengthening all components of technology -- physical facilities, human abilities, documented facts and organizational frameworks -- if the transfer is to be successful. It may be noted here that, internationally, technology is moved either for economic benefit and/or to take advantage of environmental regulations. It can be observed from international market trends that technology transfer to developing countries encounters the following limitations: the latest physical facilities cannot be bought in the open market; human abilities (provided as foreign assistance) are generally of poor quality; documented facts, particularly those that are critical, are protected; and organizational frameworks need adaptation for transplantation. However, in terms of the sequential substitution process of technological change, it may also be noted that leapfrogging (by skipping intermediate stages) is possible by late-starter developing countries with respect to physical facilities, provided one is very selective and considerable investment is made in developing human abilities, documented facts and organizational frameworks. Therefore, the degree of technology component sophistication, the level of technology capability accumulation, the status of technology infrastructure building and the dynamism of the technology climate would all have a direct bearing upon the possible strategic options of an enterprise.

Due to a lack of financial and technical resources, enterprises in developing countries are initially dependent on imports for obtaining sophisticated technology. For the advancement of technological capabilities, they are also very dependent on the transnational corporations and/or national technology infrastructure and technology climate. Technology infrastructure and climate can be either a constraint to or a catalyst for an enterprise's fulfilment of its full technological potential. Without a proper diagnosis of technological needs or a clear understanding of the value of technological innovations, enterprises cannot effectively acquire or introduce new technologies. The current environmental situation is troubling; in introducing technological innovations, this aspect should be considered. At present, when environmental concern is high on the global agenda, it is important to incorporate environmentalism (including the "pollution prevention" and "polluters must pay" approaches) into technology-management decisions. Even in developing countries, environmentally sound technological resources can contribute to the wealth of a nation through competitive advantage in international trade; it is the foundation upon which the competitive world market of tomorrow is being built. It is appropriate to repeat here that environmentally superior products, processes and services now represent the biggest new market in the history of world business, and advantage should taken of them.

**Part Five**

# CONCLUSIONS

The present study draws attention to the Arab experience in integrating science and technology with development planning. It also underlines the special importance of science and technology policy to sound development planning and demonstrates the necessity of acquiring and maintaining a dynamic science and technology system. The strategic roles of consulting and contracting firms and the necessity of externalizing industry-related services are also discussed.

The first part of the study concludes that, having made an important strategic investment in manpower development, the Arab countries could profitably direct their attention towards integrating this investment with the operational requirements of economic and social development.

Subsequent sections of the study also seek to highlight a number of basic characteristics of the process of industrial technical change that became, or were perceived as, increasingly important during the 1980s. They are summarized in the following paragraphs:

(a) In competitive, technologically dynamic industries, technical change is a continuous process, not something which occurs only intermittently in conjunction with the introduction of major innovations or with investment in new production facilities. Moreover, in the international context of the 1990s, the rates of technical change that are needed to sustain competitiveness appear to be greater than in earlier decades, while the directions of change are more complex;

(b) Technological dynamism is mainly generated and managed in industrial enterprises. Even in those cases where enterprises appear to be "users" of technology generated elsewhere, they play active and creative roles in generating change in the technologies they use. Moreover, when they acquire technology from elsewhere, they acquire much of it embodied in goods and services that are supplied by other enterprises. Thus, structures (or networks) of interacting firms constitute the heart of the institutional base for generating the technological dynamism of industries;

(c) The core technological capabilities that firms draw upon in this process consist of various kinds of engineering competence, and the effectiveness of any R and D capabilities depends heavily on the strength of engineering activities within interacting networks of enterprises;

(d) In technologically dynamic industries, firms play key roles as creators, and not just employers, of the human capital they need to generate their trajectories of technological dynamism;

(e) The technological behaviour of firms -- in particular, the extent to which they generate those paths of technological dynamism -- is heavily influenced by key features of their economic environment, and hence by wide-ranging aspects of economic policy.

These patterns seem to call for at least two important sets of perceptions that are different from those that commonly underlay the development of the S and T policy-making system in the 1960s and 1970s:

(a) First, policy-making needs to be imbued with a pervasive perception of the costs of failing to match the intensified rates of technical change that seem to characterize most industries in the more dynamic economies in the 1990s. Those costs often involve declining, not just slowly rising, economic welfare -- in effect, moves "backwards" in an active process of underdevelopment. For example, in most cases, export industries that fail to match the rates of productivity change elsewhere can only survive if there is a corresponding drop in the real incomes of those involved; and even that is unlikely if product designs, specifications and quality standards do not keep pace with competitor industries in other countries. Similarly, if domestic industries are shielded from experiencing competition from industries in other countries which generate more rapid rates of continuously improving product and process performance, the welfare of domestic consumers steadily falls in both relative and absolute terms if rising tariffs (and consequently domestic prices) are used to compensate for the relatively slow domestic rates of technical progress. Moreover, in these situations the process tends to be socially skewed: it is usually those with lower incomes and the least access to resources that suffer most. Indeed, those with higher incomes and the greatest access to resources (including power) are usually able to manipulate the policy structure that is used to compensate for slow rates of technical progress so that they benefit, rather than suffer -- inevitably shifting a yet larger share of the burden to those least able to bear it.

(b) Second, policy-making also needs to be pervasively imbued with a perception that one cannot achieve internationally competitive rates of technical change simply by "buying" technical change ready-made in the form of imported technology. Only partial contributions to the overall technological trajectories of firms and industries can be obtained that way -- mainly contributions to only the relatively large intermittent steps of change that are implemented through investment in new production facilities, and even these must often be bought through imperfect markets and frequently at very high cost. Other contributions, especially those that generate large parts of the continuous stream of incremental change, can often not be purchased. They have to be generated by the technology-using firms themselves, often through interaction with networks of local suppliers of specialized goods and services.

The issues summarized above seem to call next for changes in the common emphases of approaches to industry-oriented technology policy.

(a) Institutions and firms

Policies shouldn't focus or rely quite so strongly on activities undertaken in specialized institutions (supposedly) on behalf of industrial enterprises. Instead, they should concentrate on (a) the technological activities undertaken in enterprises, and (b) strengthening the firms' capabilities to perform those activities. While various kinds of scientific and technological institutions are obviously needed to support industrial firms, their relative importance (vis-à-vis the technological activities of the firms themselves) appears to decline sharply with the development of increasingly dynamic industries. It may be the case that such a decline is overdue in many industries and countries in the region;

(b) R and D and "engineering"

Policies should not concentrate so heavily on R and D activities and capabilities. Much greater emphasis must be given to the wider range of "engineering" capabilities and activities. Again, this is obviously a matter of radically shifting the balance of emphasis, not one about mutually exclusive alternatives;

(c) Centralized and dispersed policy-making

The dominant approach must shift away from the centralization of technology policy responsibility in specialized "S and T policy" agencies in Government. Such centralized responsibility is often highly appropriate for the small part of technology policy that deals with R and D -- or the smaller part that deals with publicly funded/executed R and D. However, a much more dispersed responsibility is necessary to ensure that wider areas of economic policy are aligned with objectives focused on the longer-term dynamism of industry.

Other sections of the study suggest that the integration of R and D with industrial production in industrializing countries may require quite radical changes in the institutional structure, rather than just the types of efforts -- to link disconnected components of the existing structure -- that were outlined earlier. Several countries are moving in this direction -- often within broader policy-reform programmes that also involve radical changes in government funding for R and D. However, there appears to be very little information about shifts in these directions in the ESCWA countries.

The final part of the study concludes that technology, as a human-made resource, is inextricably linked with the welfare of productive enterprises: it is an instrument for achieving higher productivity and competitive growth in market share. At the national level, it is considered a valuable means for improving the standard of living and a vehicle of emancipation and greater democracy. However, at the same time, technology has also been assailed for social disintegration and sometimes condemned as the cause of environmental decay. And it cannot be helped but to worship technology as the supreme expression of military, economic and political power. Whatever position one takes, the management of technology is indispensable for both survival and the prosperity of productive enterprises in developing countries under the current trends of deregulation and trade liberalization, and in these countries' attempts to attract direct foreign investment. But to manage technology properly, measurable and effective indicators are needed. The study, in its final part, thus presents an integrated set of technology management measures for developing countries. The simple framework presented in this section can help enterprises, industrial- and national-level development planners, and managers to meaningfully integrate technological considerations into their strategy-formulation calculus for becoming competitors in the global market. Senior managers should take a strategic view of technology -- identifying vulnerability in terms of their success in sourcing technology, and focusing improvement efforts on technology capabilities to produce better quality outputs at lower costs for the market-place, and to do so faster than others. Investment promotion agencies can also use the framework for project formulation and evaluation. Government departments engaged in the development of technology infrastructure and the national leader responsible for the creation of a conducive technology climate may find some of the indicators useful for their decision-making.

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