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SCIENTIFIC AND TECHNOLOGICAL CONSTRAINTS TO ECONOMIC DEVELOPMENT:

An Analytic Cross-Country Framework

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by

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SCIENTIFIC AND TECHNOLOGICAL CONSTRAINTS TO ECONOMIC DEVELOPMENT: An Analytic Cross-Country Framework

I. Introduction and Background

A. Institutional Background

1. AID has recognized that science and technology is an essential element of development strategy, both for economic growth and for the reduction of poverty, hunger, disease and illiteracy. The capacity to manage science and technology is essential to industrial competitiveness in the world economy, a critical element of the modernization of Asia, which is one of AID's major themes in that region.

2. For this reason, AID is reviewing its approach to development assistance in the relatively advanced countries of the Asia and Near East (ANE) Region in order to define more precisely the role of science and technology in these programs. In support of this review, it has contracted with International Technology Management and Finance, Inc. (ITMAF), to produce a systematic framework of analysis that will (a) enable AID to assess whether a science and technology program is a good investment in a specific country; (b) provide baseline indicators to measure success if a program is undertaken; and (c) allow for cross-country comparisons to facilitate the evaluation of experience of the more advanced countries of Asia and its application to those countries that are less advanced.

3. Specifically, ITMAF is to sketch an overall model of pathways to technological development, and identify the key science and technology infrastructural variables critical to accelerated economic growth, analyzing the usefulness of both quantitative and qualitative indicators in cross-country comparisons, and outlining general methods to identify the constraints to scientific and technological development. ITMAF is then to apply this framework and methodology to examine selected countries in the ANE region, namely Sri Lanka, Tunisia, and Thailand, taking advantage of previous work by the members of the firm.

B. Scientific and Technological Development as a Critical Dimension of Overall Economic Development

1. Science and technology is an essential dimension of economic development. Scientific and technological capacity allows a country to make better choice of objectives, to foresee changes in markets and technology, to improve its allocation of investment funds, to take better advantage of existing market opportunities and create new ones, to use its resources more productively, to create new resources from materials hitherto thought useless, to improve its ability to avoid environmental and social harm, and to meet more effectively the needs of its poor and disadvantaged citizens. The success of the newly industrializing countries of the Pacific Rim of Asia in

harnessing science and technology for accelerated economic growth has aroused the interest of other developing countries -- and of the development assistance agencies -- in assessing their own progress in this critical dimension of development.

2. By scientific and technological development, we mean the capacity of a country, an agency or a firm to manage science and technology: to choose objectives to which science and technology may realistically be applied, to identify and assess existing technological alternatives and to choose among them, to adapt the technology chosen to local conditions, to implement and operate it, and to decide when innovations and research are needed and to carry them out.

3. Scientific and technological development is not an end in itself, but is rather a means to accelerated economic development and to a more equitable distribution of the fruits of that development. Indeed. much of the current preoccupation with scientific and technological development in AID and other development assistance agencies comes from the realization that science and technology is critical to the developing countries, both for its contribution to employment and to competitiveness in the international market place, and to the efficient allocation of resources for the solution of persistent problems of poverty, such as disease, malnutrition and overpopulation.

4. The development of this capacity does not come automatically with an increase in GNP per capita. On the contrary, India and China, two of the poorest developing countries, are among the most advanced in their capacity to manage technology. Conversely, some of the wealthiest of the capital exporting countries of the Middle East rely almost entirely on imported equipment operated for them by foreigners.

5. Nor does scientific and technological development flow automatically from the adoption of a given set of economic policies or from the operation of a given political system. To be sure, as we shall see, economic policies and political controls have a direct and important influence on scientific and technological development. Some economic environments stimulate scientific and technological development, whereas others can stifle it almost completely. But barring these extreme cases, the long-term success of virtually any set of economic policies can be made more probable if complementary measures are taken to promote scientific and technological development.

6. A balanced approach to scientific and technological development involves the capacity to manage both advanced and less advanced technology, according to the situation. Indeed, no technology or class of technologies is in and of itself "appropriate" to developing countries. Rather the

appropriateness of any technology is defined only in relation to a given situation and a given objective.

7. Scientific and technological development includes but is not limited to the installation of hardware, the transfer of foreign technology, the commercialization of innovation, and the carrying out of research. It involves people, money, and institutions, both in government and in the private sector. It involves both science and technology, a fact worth mentioning because of the common tendency to overlook the role of basic and applied science in underpinning the training of technologists and in laying the groundwork for technological advance. Finally, it involves not only the natural sciences and engineering, but the social sciences, especially economics and management, and even (in the consideration of objectives) the humanities as well.

8. Scientific and technological development is thus inextricably linked to the other aspects of development. Each affects the others, and is affected by them in return. This paper will be concerned mostly with the links between technology and economics, but the links of science and technology to social, cultural, and political factors are also of major importance. For example, a society may impose major obstacles on scientific and technological development by stressing authoritarian or bureaucratic control of information, by suppressing minority social groups inclined towards innovation, or by reflexively

distrusting or restricting the circulation of ideas of foreign origin.

9. Economic Impact of Science and Technology. Scientific and technological development has a critical impact on virtually all facets of economic growth and equity. The ability to manage technology is a critical determinant of total factor productivity, the efficiency with which resources are used throughout the economy. This in turn affects the terms of trade, as expressed (for example) in the number of hours of agricultural or industrial labor, or of managerial or professional time, that it takes to pay for a car or a tractor.

10. The choice of technology made throughout the economy also has a major impact on employment. Briefly stated, the use of labor-intensive technology in a labor-rich economy will result in a large number of jobs, each with relatively low productivity.[1] This should result in faster growth overall than the choice of relatively capital-intensive technology, because it makes better use of the country's factor endowments. The choice of technology also affects the structure of wages. If scarce

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1. This report uses the phrase "the use of labor-intensive technology" as a shorthand that refers both to (1) the choice of labor-intensive technology in preference to capital intensive technology when a choice exists for a particular production process; and to (2) the choice of economic activities that lend themselves to relatively labor-intensive technologies. The argument is a general one and applies to all sectors of the economy.

capital is used to finance capital-intensive undertakings which create a small number of privileged jobs of relatively high productivity, the remainder of the economy is likely to be starved for capital, and the jobs it creates will be of unnecessarily low productivity and hence will pay unnecessarily low wages.

11. Some labor-intensive technologies, such as those for assembly and confection, may be readily imported. But other seemingly simple technologies, such as technologies for labor-intensive road construction and for draft animal power in areas where these are not traditional, may have to be introduced through extensive programs of local research, adaptation and diffusion, and may require complementary changes in policy on the part of local planning, technical and financial institutions.

12. Science and technology has a role of special importance in the structural adjustments facing the many developing countries that have allowed systematic distortions to accumulate in their economies over the years: artificial exchange rates, high levels of protection and other barriers to competition and entry into industry, distorted prices for energy and other industrial and agricultural inputs and outputs, and excessive participation of the public sector in the economy. These countries face a bleak future if they do not restructure their economies so as to increase their rate of growth, increase

exports and (in many cases) reduce their level of debt. But it is not enough to rely on exposure to competitive market forces and liberal economic policies. These must be complemented by specific measures to assist the necessary building of technological capacity.

13. One of the major effects of this isolation from world markets is to remove the incentive of firms to manage technology effectively in order to meet foreign and domestic competition. It also encourages the choice of technology inappropriate to local conditions: typically, technology that is overly capital- and import-intensive, wasteful of energy and other scarce resources, neglectful of quality and quality control, and generally less efficient than technologies in use elsewhere.

14. To overcome this legacy requires not only the "standard economic prescription" of liberalization, privatization, and deregulation, but also specific efforts to promote improved management of technology and to provide scientific and technological services and technologically oriented risk financing for which there may hitherto have been little demand. The alternative is to accept the fact that many firms will be forced into unnecessary bankruptcies, or into selling out to foreign firms to become off-shore manufacturing

platforms, at a loss of the self-reliance and technological capacity built up during the years of protection.

15. Finally, science and technology has a critical role to play in enabling the fruits of economic growth to be equitably shared. We have already discussed the role of science and technology in providing productive employment. Such employment means market power for wage-earners, and this market power in and of itself attracts investment in the marketing of goods, such as modern medicine, that embody technology that enable people to address their own problems. Science and technology also makes possible innovative solutions to the special problems of the poor and disadvantaged: for example, improved methods of low-cost housing and low-cost sanitation, and new cures or immunizations for poverty-related diseases such as schistosomiasis and malaria.

16. Innovation as a Response to Market Demand.[2] In a market economy, technological innovation -- by which we mean the introduction and diffusion of a novel product or process-- occurs in response to profitable market opportunity. New products begin to be made, and new processes begin to be applied on a substantial scale, when an entrepreneur realizes that (s)he

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2. The discussion in this section and the next one is adapted from C. Weiss, "Government and Market Influences on Technological Innovation," Chapter 3 in M. Kamenetzky, R. Maybury and C. Weiss, Choice and Management of Technology in Developing Countries: A Training Program for Decision Makers, (World Bank, Washington, D.C., 1986).

can profit by matching consumer demand with a new product, or ar improved process for making an existing product.

17. To be sure, a relatively small number of innovations result from major improvements in technology that are driven, not by a recognition of market need, but by the internal development of a scientific or technological discipline. These include many of the major innovations that have transformed modern life: television, antibiotics, nuclear energy, lasers, and computers. The commercialization of such innovations is the culmination of a sequence of events, known as "technology push," that begins with basic research and proceeds to applied research, invention, development, engineering, demonstration and commercialization.

18. Most innovations, in contrast, are unspectacular and may not involve new technology at all. Rather they involve putting old technologies together in a new way, or making minor modifications in old technologies. These innovations result from the pull of market demand, and follow a "demand pull" sequence that is the reverse of the sequence of the previous paragraph. This sequence begins with the recognition of a market need, which may require engineering, applied research, or even basic research, before the new product or process can be generated to fill that need. Whether or not an innovation results from "technology push" or "market pull" (or some combination of the

two), innovators normally start by appealing to customers willing to pay a premium for the superior characteristics of the unique new product. This so-called economic rent compensates the innovator for the expense and risk involved in technological and market research and development.

19. In many cases, an innovation (in the sense of a product or process that is novel locally, although not necessarily world-wide) can be introduced without research because the needed technology is available elsewhere -- from a university, a government laboratory, or from another company, whether domestic or foreign. In developing countries, and even in many industrialized countries, such technology transfer is the normal way in which improved technology is introduced.

20. These three mechanisms of innovation -- by technology push, by market pull, and by technology transfer, are summarized in the simplified schematic diagram of Table I-1.[3] Each carries a different strategic implication for technology development. In brief, a country wishing to promote innovation via technology push will invest heavily in basic and applied research and the infrastructure that supports it. A country

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[3]. A more realistic diagram would show a much more complicated picture, with feedback loops showing how research problems may arise during the course of product development, technological advance may give rise to the possibility of new approaches to research, local invention may be integrated with transferred technology, and so on with nearly infinite variety.

wishing to facilitate technology transfer through market pull mechanisms will ensure a competitive environment that creates demand for improved technology, as well as sufficient local capability to master that new technology. And a country wishing to encourage technology transfer will ensure that its business and regulatory climate encourages the importation of technology, and that its institutions and policies facilitate the diffusion of technology within the country once it has been imported.

21. Innovation in the Absence of Market Demand. Left to themselves, businesses would have only a limited financial interest in improved technology to minimize pollution or to improve worker health and safety. Nor would they devote major resources to develop new medicines to cure diseases which are contracted predominantly by poor people who cannot pay premium prices for the products of the latest technology. Market pull for innovation in these fields would not exist but for the actions of government.

22. Government intervention is therefore required if technologies appropriate to local conditions are to be developed and applied to problems of environment and safety, or to problems specific to poor and otherwise disadvantaged people, such as those living in remote areas or belonging to minority ethnic groups. Explicit programs and policies, either by the governments of developing countries or by development assistance

agencies, are a main mechanism for assuring that science and technology contribute to the equitable distribution of the fruits of economic development.

23. In other sectors, the market for innovation is critically affected by government action simply because the government is the only or the major customer. Government procurement policy is critical in technologies for education, public health, public sector infrastructure (which in developing countries normally includes highways, public utilities, and telecommunications), and the military.

24. Broadly speaking, governments can stimulate innovation in the absence of market demand through four mechanisms. First, they can support research and development, either directly in government laboratories or by making grants to private researchers in the private sector or the universities. Second, they can adopt procurement policies that stimulate innovation in the private sector, for example by publicizing the need for a new product meeting defined specifications and guaranteeing to purchase a certain number at an agreed price if these specifications can be met.

25. Third, government can implement programs or adopt policies which have the effect of stimulating demand for a given set of technologies. These may be economic policies or programs

that transfer income to poor or disadvantaged people and thus increase market demand for the kind of goods that such people are likely to buy. Alternatively, they may be regulations that require private businesses or people to behave in a way that creates demand for a given kind of technology. Environmental and safety regulations fall into this category. Fourth, the government may intervene to influence the price of a key commodity, such as food or fertilizer, and thus influence the demand for technologies that use or produce that commodity.

26. If these explicit government interventions are to be effective in assuring the application of science and technology to the equitable distribution of the benefits of economic development in these sectors, it is critical that they apply the criterion of <u>replicability</u>. By this we refer to the need to design and implement projects that are built to relatively modest standards and hence can benefit a large number of people -- rather than to design an expensive show piece, perhaps using high technology, that benefits a relatively few people, often those with good political connections. (The other sense of the term replicability, namely that a project, once it works successfully in one place, can be readily adapted to use elsewhere, also applies.)

27. <u>Technological Capacity and Technological Effort</u>. In order to appreciate the rationale for these statements, we

must make a brief excursion into the economics of technology and technology transfer. In a hypothetical perfect market, technology would be readily available to the potential buyer from any of a number of possible sources, with little or no transaction cost. Both buyer and seller would be well informed regarding the nature and the market value of the technology, and competent to judge its value to themselves. Indeed, in pure neo-classical theory, technology is not a traded commodity at all. Instead, in this model, technological change is conceived as taking place automatically. When a price or a market changes, entrepreneurs adjust their technology without incurring any costs.

28. To compensate for this defect, we may now amend the model to include a hypothetical "perfect" market for technology. In such a market, technology would be available at a price that represents both the opportunity cost of the technology to the seller and the "customer value-added" to the buyer, taking into account all the relevant risks and uncertainties that affect each of them. The agreed price would also be equal to the value of the technology to the society at large.

29. The actual market for technology differs in important respects from even this amended model, because technology as an item of commerce differs in fundamental ways from the goods and services that are the usual subjects of

economic theory.[4] As a result, the benefits to society from investments in science and technology may exceed the rewards to the investor, especially given the risks and relatively long time horizons that inevitably attend such investments. It is these externalities and market imperfections that, together with the clear value of science and technology to economic development, provide the broad justification for government intervention to promote scientific and technological development.

30. First of all, the development of the capacity to make technological decisions requires significant specific investments of money and personnel. These investments are collectively known as <u>technological effort</u>. To a firm in a developing country, these investments represent very considerable transaction costs. They include the costs of gathering information on alternative technologies or on the technological requirements of different markets, carrying out pre-investment

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[4]. Some of these differences are as follows. First, the whole process of the creation of new technology is intended to create a monopoly which will enable the creator to earn profits over and above what he would earn in a perfectly competitive market. Second, unlike other goods and services, technology does not ordinarily lose its value to the seller when it is transferred. For this reason, the marginal cost to the seller may be much less than the value to the buyer, a circumstance that creates a great deal of room for negotiation regarding the price of the technology. Third, it is impossible for the buyer to have perfect knowledge of a technology until he has acquired and mastered it. Fourth, some technologies are of critical political and/or security value, so that governments may wish to promote their creation and commercialization, or to restrict their transfer to foreigners or to other unauthorized parties.

studies to make choices from among the alternatives, negotiating terms for acquisition of the technology, training local staff by involving them in the design and installation of imported equipment, improving the efficiency of the technology they have adopted and adapting it to local conditions in the course of day-today operations, as well as making formal investments in trouble-shooting, engineering, research, extension and technical assistance to suppliers.

31. Such technological effort, whether it involves creation of new technology or mastering of existing technology, may have great value to society, but may not offer a commensurate private profit, either to the creator or to the prospective purchaser of the technology. This so-called failure of "appropriability" may arise because the gains from the improvement in technology must be shared with the consumer in the form of higher quality or lower prices. What is more, key technical people, ranging from top engineer-managers to trained technicians, may leave the innovating enterprise and take its know-how with them. Another company with a stronger market position may imitate or steal the improved technology and appropriate most of the profits. Alternatively, other companies in other industries may profit by applying the technology to new situations, benefiting themselves and the larger society but not the innovators.

C. Economic Influences on Scientific and Technological Development

1. Influence of Economic Geography. The pattern of scientific and technological development is shaped first of all by the classical economic factors of land and labor: a country's size and geographic position, its natural resources, and its people. A country's size and population determine the ultimate limits of the size and diversity of its economy. Its geographic position affects its natural markets, its sources of investment and technology, and its relation to historical trade routes. Natural resources such as climate, agricultural and fisheries potential, reserves of petroleum and minerals, and natural harbors, provide potential products with which to generate surpluses and to attract investments in improved technology in other fields.

2. Influence of the General Economic Environment. The scientific and technological development of a country is inevitably affected by its overall development situation: its per capita income, the state of its physical and social infrastructure, its transport and communications facilities, and its energy infrastructure. While not specifically technological, the quality and reliability of such elements of classical infrastructure as roads, telephones, power and water, inevitably set the conditions for both the application of science and technology in the productive sector and the conduct of

specifically technological activities such as research and engineering. Beyond this, sophisticated technologies often place specific demands on physical infrastructure, such as the requirement of computers for regulated power and high-quality telecommunications.

3. The framework of scientific and technological development is also conditioned by the country's recent economic performance: its recent history of growth and inflation, its debt burden, its unemployment rate, and its terms of trade. These affect the willingness of governments and private investors to make money available for all aspects of technological activities. The demand for technology, and hence the pattern of scientific and technological development, is further shaped by the structure of the economy: the balance of production and employment among and within sectors, the balance between exports and production for the domestic market in the various sectors and subsectors, and the relative roles of the public and private sectors. These structural factors help determine the demand for technology and for trained technical and managerial personnel. Market demand for improved technology is further conditioned by the pattern of income distribution in a country, as well as the social services offered to poor and disadvantaged groups, as reflected in such indicators of quality of life such as life expectancy and infant mortality.

4. Influence of Economic Policy. Since the overwhelming majority of technical change in developing countries, flows from the demands of the market place, any policy that affects the marketplace will sooner or later affect the speed and direction of technical change. Indeed, some of the most important influences on a country's scientific and technological development come from broad economic policies which are normally set without much attention to their implications for science and technology.

5. Many of the most important determinants of the state of science and technology in any economy flow from macro-economic and trade policy variables. The first and most important of these is the exchange rate, which determines the relative profitability of importing technology, equipment and raw materials as opposed to developing and manufacturing them locally, and the relative profitability of domestic and export markets -- both of which are critical determinants of local technological effort. A second determinant of the state of science and technology in any economy is the degree of competition within the economy, as represented, for example, by the level of tariffs and other trade barriers that determine the inward or outward orientation of the economy, and by the licensing or other artificial barriers to entry faced by domestic firms. This determines the degree to which the discipline of foreign and domestic competition will impose

efficiency in management and in use of resources, and hence will increase demand for improved technology.

6. Technology choice in industry and agriculture is also conditioned by the prices of major inputs and outputs, most of which are heavily influenced by government policies in developing countries. These prices include wage and interest rates, which strongly influence labor/capital substitution and hence employment; energy and raw material costs, the major influence on conservation; the prices of steel, cement, fertilizer, and other key inputs; and the prices paid to farmers for staple crops, a major determinant of farmers' willingness to invest in improved production technology. Interest rates also affect the time preferences of investors: their willingness to incur costs in the present and to defer benefits into the future. This affects both their choice of technology (over and above the labor/capital substitution effects which were already mentioned) and their willingness to invest for the long pull in such fields as environment, training, and technology.

7. Market demand for improved technology is also conditioned by the existence, content and level of enforcement of regulations in such fields as environment, worker health and safety, and traffic safety. In these fields, only government

enforcement of appropriate regulations (combined, where this is politically possible, with pressure from organizations of those directly affected, such as labor unions and citizens' environmental groups) can give rise to demand for the needed technological effort.

D. Structure of This Report

1. Our first step in developing an analytic framework for identifying the scientific and technological constraints to economic development and the equitable sharing of its fruits, is to identify the key attributes which enable us to gauge the level of scientific and technological development in any given developing country, whether it be at a very early stage of development (such as Bhutan or Yemen) or at the threshold of full industrialization (such as Korea or Taiwan).

2. We use the characteristic changes in these attributes to establish a phenomenology, an empirical pattern that underlies scientific and technological development in a broad range of countries, so organized as to make it easier to identify cause-and-effect relationships and to make policy recommendations. We structure this phenomenology as a sequence of stages through which a country passes during the course of scientific and technological development, identify the milestones that mark the completion of each stage, and then trace a set of paths which a country can take through these stages, depending on

its geography, its resource base, and its general policies toward economic development.

3. To be sure, there is no single developmental sequence that is common to all countries. No matter how much it progresses, the Maldive Islands will never become Saudi Arabia, nor will China become an expanded version of Hong Kong. Nevertheless, it is important to understand the elements of scientific and technological development that are common to countries in different situations, and the differences among countries that matter the most to their development in this area.

4. In the next section, we shall describe these attributes, explain how they evolve during a defined developmental sequence, identify the major scientific and technological constraints to economic development that must be faced at each stage, and sketch the broad types of policy and programmatic intervention that are most useful in dealing with each of these problems. We also define those factors of eography, demographics and policy that have a decisive effect n technological development, and that may in extreme cases everely inhibit the effective contribution of science and echnology to economic development and to the more equitable istribution of the benefits of such development. An examination these factors may shed light on criteria that may allow AID to dge when its interventions in science and technology are likely

to contribute to these goals. This treatment is based on a broad review of the scientific and technological development of the 50-odd members of the World Bank with which the author is familiar.[5] It is intended as a first cut, to be refined by further research and exchange of experience by others working in the field.

5. A third section sets forth the constraints on the contribution of science and technology to economic growth and to the equitable distribution of the fruits of that growth, and discusses how intervention by AID might usefully promote the goals of economic growth and equity through the promotion of scientific and technological development in countries at each of these stages. A final section briefly sets forth three pilot country studies, in which the analytic framework is applied to three countries in the Asia and Near East Region: Sri Lanka, Tunisia, and Thailand. These pilot country studies are intended primarily as preliminary tests of the validity of the analytic framework. If they are useful also in stimulating thought regarding policy or programmatic interventions by government, perhaps with the assistance of AID, this is all to the good. Fuller accounts of these studies are found in annexes in a separate volume of this report.

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[5]. See C. Weiss, "Pathways of Technological Development," in M. Kamenetzky, R. Maybury and C. Weiss, Chapter 4 in Choice and Management of Technology: A Training Program for Decision Makers, (World Bank, Washington, D.C., 1986).

II. Pathways of Market-Oriented Scientific and Technological Development

A. Introduction to the Analytic Framework. This section of the report sets forth a model of the stages of market-oriented scientific and technological development in developing countries. The model is intended to apply to all developing countries, ranging in their state of development from Bhutan to Korea. It uses examples drawn primarily from industry, but could be readily adapted to agriculture, services, physical infrastructure, or virtually any other economic sector.

1. The model is based on a "comparative static" comparison of a large sample of developing countries. On the other hand, it is not deterministic, and indeed makes no attempt to determine causality. It does not posit inexorable progress towards modern technology. Rather it organizes a large collection of empirical observations into a verifiable framework or phenomenology, whose purpose is first, to facilitate the practical operational work of officials of developing countries and of development assistance agencies such as AID, and second to stimulate further research. In this way, it is more closely akin to the Periodic Table of the chemical elements than to past models of stages of economic development.

2. The model differs from models of the stages of development which based on growth of per capita income, on the one hand, in that it recognizes that scientific and technological development may correlate only weakly with per capita income, as the examples of India and Saudi Arabia make clear. For countries as for people, there are many roads to wealth, and fortunate location or control over resources may bring a relatively high per capita income despite a low state of scientific and technological development. On the other hand, the model differs from those based entirely on scientific and technological factors, in that it takes full account of the effects of economics and finance on scientific and technological development, and takes into account the fact that a technology that is appropriate in one country may be inappropriate in another, and that the use of "advanced" technology is not necessarily a sign of an advanced stage of technological development if that technology is inappropriately chosen or poorly operated.

3. The model distinguishes two main stages in scientific and technological development, each divided into three substages. In each stage, it identifies constraints to the contribution of science and technology to economic growth and equity, i.e., points at which investment in scientific and technological development will lead to increased growth and/or

equity. These points are identified as scientific and technological constraints to development.

4. In addition, the model identifies policy choices that hinder the progress of market-oriented scientific and technological development, and in extreme cases can make such development impossible despite the presence of an otherwise favorable climate for science and technology, and indeed despite major government efforts and investments to promote scientific and technological development. In this sense, the model is normative: it defines the stages of development toward a particular pattern of scientific and technological development, and dismisses major deviations from that pattern as the results of failure of policy and misallocation of economic resources.

B. Elements of Scientific and Technological Development

1. We distinguish six critical aspects of scientific and technological development which allow us to gauge a country's progress: the general state of economic development, scientific and technological capacity in the productive sector, technology policy, financing of science and technology, human resources, and scientific and technological infrastructure.

2. The general state of economic development sets the stage for scientific and technological development, and provides many basic inputs: general education, physical infrastructure,

communications facilities, health services, and the amenities and opportunities needed to attract trained people to remain and work in the country. What is more, the general economic environment determines a variety of parameters that exercise substantial influence on science and technology. For example, industrial structure dictates the balance between the demand for large- and small-scale technology, as well as the types of financial institutions needed for the financing of industrial technology. Labor costs and availability determine the level of labor productivity required for competitiveness, and hence the demand for labor-intensive technology.

3. On the other hand, economic development (as measured by GNP/capita or other common indices) is not the same as scientific and technological development. Indeed, Sri Lanka and Tunisia, which differ in their per capita GNP by a factor of three, are at comparable stages of scientific and technological development.

4. As in the earlier discussion, the elements of the general economic environment of greatest importance to scientific and technological development may be subdivided under the headings of <u>economic geography</u>, which includes size, natural resources and location, and the <u>broad economic policy environment</u>. The latter includes the level and structure of protection, the terms of trade among sectors, and the degree of

distortion in key prices, such as those of foreign exchange, interest rates, wages, major raw materials and agricultural inputs.

5. The scientific and technological capacity in the productive sector, the ability of the productive sector to manage technology, is the most direct measure of the ability of the productive sector to harness science and technology towards the objectives of economic growth and equitable distribution. In gauging the level of scientific and technological capacity in the productive sector, we consider both the level of the technology in use, the efficiency and effectiveness with which it is used, and the depth of the involvement of local people in the management of the technology.

6. In assessing the level of local technological involvement, we examine the level and quality of technological effort devoted to the choice of objectives, the identification and assessment of technological alternatives, and the "make or buy" decision to acquire technology from abroad or to generate it locally. In the case of the acquisition of foreign technology, we examine the level and quality of technological effort devoted to the acquisition of technology, its adaptation to local

conditions, the mastery of its operation, and the development of the capacity to reproduce and improve it.[6]

7. In the assessment of the level and quality of local technological involvement, we examine the level of technological effort devoted to the choice of objectives, to the identification and assessment of technological alternatives, and to the "make or buy" decision to acquire technology from abroad or to generate it locally. In the case of the acquisition of foreign technology (the more usual case in developing countries), we examine the level of technological effort devoted to the acquisition of technology, to its adaptation to local conditions, to the mastery of its operation, and to the development of the capability to reproduce and improve it.

8. We define technology policy as the sum of government policies that affect scientific and technological

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[6]In assessing the level of technology, we distinguish in this model only between "conventional" and "advanced" technology, the latter being limited for the most part to informatics and biotechnology. A more ambitious treatment might distinguish among various levels of specialization, automation and integration of the equipment in use, and increasing sophistication of organization and management. It would also make a more systematic distinction among the various aspects of technological capacity in the productive sector: pre-investment (including broad strategy), investment, project design, technology adaptation, project implementation/construction, operation of technology, innovation and research. (See for example, ESCAP Asian and Pacific Center for the Transfer of Technology, Technology Atlas: An Interim Report, Jakarta, 1987, and the work of Larry Westphal and Carl Dahlman.)

development. A description of the state of technology policy in a country must capture three separate phenomena: first, the policies that actually influence the pattern of scientific and technological development in the country; second, the capacity of the country to assess the effects of its overall economic and technological policies on its scientific and technological development, and to design and put into practice policies specifically intended to promote that aspect of development; and third, the level of explicit national commitment to science and technology as a critical element of national development.

9. These three aspects of technology policy are not the same, and may be startlingly divergent. For example, countries with few explicit laws devoted to science and technology, such as Hong Kong and Thailand, may achieve a relatively high stage of scientific and technological development. By contrast, a country such as pre-Rajiv India, may have a strong commitment to science and technology, research groups devoted to technology policy, and major public investments in scientific and technological institutions, Yet at the same time it may follow a set of policies which strongly <u>dis</u>courage market-oriented scientific and technological development. What is more, its academic and governmental experts may not be fully aware that these economic policies actually subvert the policy of official encouragement to science and technology and produce the effect opposite to the one

intended, and in this way constitute a significant barrier to needed change.

10. Of the policies that influence scientific and technological development, the easiest to recognize are those policies and programs which are specifically intended to promote science and technology, such as support to research and education, encouragement to industry to carry out training and research, and establishment of special programs and institutions for technical services and research. But as we have seen in our earlier discussion, economic policies can be comparable in importance to scientific and technological development as these explicit science and technology policies. Such policies may cover a wide range of issues, ranging from exchange rates to commodity prices to income distribution.

11. In the early stages, economic policies critical to scientific and technological development are typically made by officials with little understanding of their impact. As scientific and technological development proceeds, policy makers pay increasing attention to the links between science, technology and economic development, and the design and implementation of technology policy becomes an increasingly conscious process involving consultation with a broad range of interest groups.

12. The financing of science and technology is critical to scientific and technological development. First of all, investment decisions are key milestones in the process of choosing technology. Financial institutions and other sources of investment capital must develop the capability to assess technology of increasing sophistication, and to assess, accept and manage the risks attending the financing of innovative technology. Secondly, all aspects of technological effort, from identification of technology to engineering to research, require money. In the absence of suitable financial mechanisms, each of these processes will encounter severe obstacles.

13. Second, research requires special funding mechanisms different from those used to allocate other government resources. (Indeed, the quality of the evaluation mechanisms used has a critical influence on the quality of the research funded. While generalizations are risky, a typical developing country needs a balance between "block grants" to university and research institutions to assure a critical mass of researchers and equipment in science and engineering disciplines and research fields of special importance to the country, on the one hand, and grants awarded to individual researchers on the basis of their specific proposals as evaluated by a group of their professional peers, on the other.

14. Because of the broad range of issues and capabilities involved in technological decision making, the human resources aspects of scientific and technological development cover a very broad range. These include formal education in science, technology, engineering and management at all levels, including elementary, secondary, university, post-graduate, as well as specialized vocational, technical and teacher training. They also include popular exposure to modern science and technology in every day life, through the mass media and through specialized museums.

15. Since education in developing countries is usually free or at least heavily subsidized, and since good jobs are usually scarce, a peculiar cycle arises which can result in heavy demand for education despite the simultaneous presence of large numbers of educated unemployed. This anomaly may result in the production of a large number of highly qualified graduates of high school and university who have no choice but to emigrate because of a stagnant and technologically backward economy. The cycle works as follows: Competition for scarce jobs often drives up the qualifications for a particular job well beyond what the job actually requires. Parents and children, seeing that more education increases one's likelihood of getting a job, increase the political pressure to provide more places in the schools, resulting in still more educated unemployed.

16. For this reason, the presence of large numbers of highly qualified science and engineering graduates is not necessarily a sign of a high level of scientific and technological development. To be sure, an educational system capable of supporting scientific and technological development at an advanced level must have adequate training and research facilities. But these must be relevant and adaptable to the changing employment needs of the country.

17. Scientific and technological institutes and services, often collectively known as scientific and technological infrastructure, play a useful supporting role in assessing local resources, in developing indigenous technology, and in assisting the transfer and diffusion of technology from abroad and its diffusion among local firms.[7] Such institutions include natural resources surveys (oceanographic, geological, fisheries, etc.), service institutes that offer testing, troubleshooting, applied research and extension to specific subsectors of industry, standards institutes, technological information services, scientific documentation services, multi-disciplinary technological institutes, and institutes whose function is to serve as vehicles for the introduction of specific

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[7]. These institutes and services are listed last in this framework, not because they lack importance, but because their importance is sometimes overstressed, especially in countries (unfortunately too numerous) where publicly supported institutes are virtually the only loci of technological activity.

advanced technologies, such as electronics manufacture, remote sensing, telecommunications, educational technology, biotechnology, or informatics.

18. Such technological services are sometimes combined in the same institution with research, which is defined as the search for new scientific and technological knowledge. Research plays an important role in all developing countries, initially as an underpinning for university-level training, as a window on technological progress outside the country, and as the source of understanding of locally important phenomena and resources on which outside expertise is not available. Both basic and applied research are important to these processes. In later stages, research becomes a means to adapt technology to local circumstances (especially in agriculture, where such adaptation is essential to the introduction of improved technology) and to overcome dependence on foreign sources of technology, and eventually an essential element in competitiveness on world markets. At this point, the balance between basic and applied research become critical issues.

C. The Stages of Scientific and Technological Development[8]

1. In this section, we elaborate a framework of cross-country comparisons which enables us to better understand how scientific and technological development can contribute at various stages to the broader goals of economic development and the equitable distribution of its benefits, and to identify points at which interventions to promote scientific and technological development can overcome constraints to economic growth.

2. As we have already pointed out, in contrast with taxonomies developed for other purposes in development economics, scientific and technological development does not necessarily correlate with per capita income. On the contrary, some of the poorest countries in the world -- India and China are the most obvious examples -- are also among the most technologically developed. Conversely, some of the richest oil producers in the Persian Gulf rely almost entirely on turnkey projects, many which will be operated by foreigners for the foreseeable future.

3. The scientific and technological development of developing countries may be divided into two main stages: a

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8. This analytic framework is an elaboration of the analysis found in C. Weiss, "Pathways of Technological Development," in M. Kamenetzky, R. Maybury and C. Weiss, Chapter 4 in Choice and Management of Technology: A Training Program for Decision Makers, (World Bank, Washington, D.C., 1986).

first stage in which islands of modernization emerge in different parts of the economy; and a second stage, during which the country struggles for mobilization and mastery of technology throughout the economy. At the end of the second stage, the country has achieved the broad international technological competitiveness typical of the advanced industrialized countries. Yemen, Nepal, Kenya, Sri Lanka and Tunisia may be thought of as examples of countries in various substages of the first stage; Colombia, Thailand, India and Taiwan are at various stages of the second. Representative countries from each of these stages are listed in Table II-1.

4. From our preliminary empirical review, it seems likely that a given country at a given time will have the characteristics associated with a given substage in each aspect of its scientific and technological development. In other words, if a country is in substage 1c in one aspect, it will turn out to be in substage 1c in all the others. The characteristics of countries in each substage of scientific and technological development are laid out in some detail in Tables II-3 and II-4. These tables, which take up many typewritten pages, may be visualized as different representations of a large matrix with the different stages and substages of scientific and technological development defining one axis, and the different

aspects of that development defining the other axis. The skeleton of this matrix is shown in Table II-2.

5. Table II-3 is organized to read across the rows of this matrix. For each substage, it gives the typical status of each of the six aspects of scientific and technological development:

* General state of the economy
* Scientific and technological capacity in the productive sector
* Technology policy
* Financial institutions
* Human resources, and
* Scientific and technological infrastructure

These characteristics constitute the <u>typical profile</u> for that substage of scientific and technological development. Table II-4 shows how each aspect of scientific and technological development evolves from stage to stage. It gives the columns of the matrix described by Table II-2, and thus contains the same information as Table II-3.

6. The discussion in this section applies to a country which has a reasonably undistorted economy and whose scientific and technological development follows along more or less market driven lines. In such a country, the major imperfections in the market for science and technology are those intrinsic to the

process of scientific and technological development, as described in an earlier section. In a subsequent section, we shall treat the complications introduced into the model when the economy is substantially distorted by economic policy or other factors.

7. The hypothesis that the different characteristics tend to progress together, so that countries may be classified into typical substages of scientific and technological development, was tested in more detail in the pilot country studies summarized in the final section of this report. For each pilot country, we have established a profile by identifying the substage it has attained in each aspect of its scientific and technological development. Based on these judgments, we have assigned each pilot country to a substage of overall scientific and technological development. Our hypothesis that a country maintains more or less uniform rate of advance in the different aspects of scientific and technological development was in large part verified. On the other hand, it might be argued that this reasoning is circular, i.e., that we have simply adjusted our typical profiles to accommodate the findings in this rather limited sample. Only more extensive tests in many countries can verify this hypothesis properly.

8. <u>The First Stage of Scientific and Technological Development</u>. In the first stage of scientific and technological development, islands or enclaves of capacity to manage technology gradually develop in the midst of an essentially traditional economy, until they become quite numerous. The distinguishing feature of the first stage is that these "islands of modernization" remain largely isolated from each other. They do not fuse into a functioning scientific and technological system, but instead give rise to a dual economy, part of which uses traditional and part a modern approach to technology management.

9. The first stage of scientific and technological development is divided into three substages. The very earliest substage of national scientific and technological development, which we have called substage 1a, is now found in a few, relatively remote countries like Bhutan, Guinea-Bissau, and the Yemens. Literacy is low, people with even secondary education are relatively rare, there is very little industry or scientific infrastructure, and practically the entire economy uses traditional technology whose scientific basis is unknown to its user. Even patterns of thinking are pre-scientific in the great majority of people. Table II-1 encapsulates this stage with the phrase "economy based on traditional technology."

10. At the second substage of the first stage, denoted "first emergence" in Table II-3 and typified by such countries as

Ethiopia, Haiti, Nepal and Papua New Guinea, much of the population is still isolated from contact with modern technology, and much economic activity still takes place in small firms and farms in the "informal" or "unorganized" sector, using traditional technology. But pockets of modern technology management are beginning to emerge.

11. Even at this stage, these countries are able over a period of ten or fifteen years to develop some parastatal agencies or private industries that meet international standards for competence, especially if they are forced to compete on the international market or (in the case of a domestically oriented parastatal such as a power or telephone company) if they are run with a sustained commitment to efficiency in both economic and technological matters.

12. In the small modern sector of the economy, serious manpower shortages may remain at all levels of technology -- the more so since the government is the usual employer for new technical graduates. On the other hand, the government is now sufficiently effective that its macroeconomic policy does make its influence felt on the choice and diffusion of technology. For example, the technology chosen by small farmers depends on the prices they receive for their crops, the technology chosen by entrepreneurs depends on the prices they pay for raw materials and capital, and the quality of their products depends both on

the competitive pressures induced by domestic competition and by imports, and on the requirements of the export market. All of these strongly influenced by government policies.

13. By the third substage of the first stage of scientific and technological development, denoted "islands of modernization" in Table II-3, modern small industry has begun to develop, and there are many enclaves of capacity to choose, operate and manage modern technology. Modern technology is still imported, mainly as equipment or turnkey plants. Some of the larger private firms and parastatals, including public utilities, have substantial technological capacity to assess objectives, to choose, acquire and operate technology, and to negotiate with multinational corporations. In many countries at this stage of development, non-governmental organizations with few links to formal scientific and technological institutions are active in diffusing and sometimes in developing low-cost technology for use in urban and rural community development, including tiny enterprises.

14. By this substage, a country has established a reasonable base of human resources, basic scientific and technological infrastructure, a few well established universities, and the beginning of a basic research capability. It also will have applied research laboratories in a few critical areas, especially agriculture. Research projects are numerous

and sometimes of high quality -- although typically underfunded, poorly coordinated and carried out with limited attention to practical application.

15. On the policy side, macroeconomic and trade policies have a definite impact on scientific and technological development, but are rarely formulated with these effects in mind. Similarly, financial institutions are increasingly competent in their dealings with borrowers, although they are not generally competent to deal with specifically technological issues.

16. Scientific and technological development at the end of the first stage is thus patchy, with areas of high competence interspersed with sectors in which a much lower level of capacity has been attained. Economic policies are well established and affect the course of scientific and technological development for better or worse. The supply of technically trained manpower, while still a constraint, is no longer overwhelming. On the other hand, the educational system is still geared to the personnel needs of the government bureaucracy, and lacks the institutional flexibility and the contacts with the business community it needs to adjust to the changing demands of the labor market. This level of scientific and technological development is typified by such countries as Kenya, Sri Lanka, Tunisia and Guatemala.

17. The Second Stage of Scientific and Technological Development. During the second stage of scientific and technological development, the "islands of modernization" fuse to form a modern, integrated system whose production technology is capable of competing on world markets in price and quality across a broad range of products. By the end of the second stage, technology is a major factor in industrial competitiveness on world markets.

18. This second stage is divided into three substages. The first of these is denoted "mastery of conventional technology" in Table II-3, and is typified by Colombia, Malaysia and Turkey. (Thailand is between substages 2a and 2b.) At this point, industrial exports are growing rapidly, and quality and quality control, although still not optimal, are rapidly improving. Capacity to master the operation of imported technology is reasonably widespread in larger industry, many firms are beginning to make investments of their own resources in order to develop technological capacity, and there is some capacity to adapt technology and to innovate in order to maintain competitiveness. In this substage, the enclaves of technological capacity developed earlier have evolved stronger links with the rest of the economy through subcontracting, technical assistance to local suppliers, and movement of experienced personnel. Negotiating skills with multinational corporations are now

reasonably strong, and are beginning to focus on technology *per se* rather than purely on business arrangements. Scientific and technological manpower is in reasonable supply, and most scientific and engineering disciplines are well established. The educational system is making its first efforts to free itself of unnecessary restrictions and to become more responsive to the needs of the economy.

19. At this substage, a country begins to establish research associations and subsectoral product support centers to provide technical support services for firms too small to provide them for themselves, e.g. advice on productivity improvements, and testing and technical assistance services to promote improved quality and quality control. Local design and engineering capacity is fairly well developed in the larger firms and in independent public and private consulting and engineering organizations, especially for civil works and for power and other infrastructure projects. The quality of local research is reasonably good, as is coordination and research coordination, but links to the productive sector are still weak.

20. On the policy side, the government begins to pay serious attention to the impact of its economic policies on scientific and technological development -- and indeed, this is probably the first point at which it has the technical capability and the effectiveness to undertake to implement a coherent

policy in this area. Development banks are now competent to assess conventional technology in investment proposals.

21. The second substage of the second stage of scientific and technological development is the transition to newly industrialized country typified by India and Mexico. In these countries, many subsectors of industry are competitive on world markets, and exports are growing rapidly. At this stage, capacity to assess, choose and operate conventional imported technology becomes general throughout the economy. The local capital goods industries are well established, as are technical services and the consulting and engineering industries. Negotiating skills vis-a-vis multinational corporations are strong, and the overall business climate becomes more mature and stable.

22. More and more subsectors develop the capability to act as their own prime contractors, unpackaging the overall technology into components acquired from different sources and taking on themselves the responsibility for integrating the overall operation and ensuring its operating efficiency. Imported technologies are mastered to the point where they begin to be reexported, often at prices competitive with those offered by their original suppliers. Technological capacity extends beyond choice of technology to adaptation and innovation, occasionally even at world class. Private research and

development begins to be important, as do applications of advanced technology in agriculture and manufacturing. Financial institutions begin to change their procedures and policies to keep pace with these important changes.

23. Scientific and technological infrastructure proliferates, and scientific and technological institutions begin to come to grips with the problem of improving their relations with the productive sector of the economy. Basic and applied research improves in quality and quantity and in some fields may gain international recognition. The management, administration and coordination of research also improve, and specific institutions are established for the financing of innovation. Science teaching in primary and secondary schools begins to improve, as does the awareness of science among the general public. On the policy side, there are systematic efforts to integrate technological considerations into economic policies and vice versa, to seek the opinion of the business community in decisions affecting scientific and technological development, and to make strategic investments in capability for managing advanced technology.

24. The third substage of the second stage of scientific and technological development is the culmination of newly industrialized country status typified by Korea, Singapore, and Taiwan. In these countries, technology is a

major factor in industrial competitiveness on world markets. Manufactured exports are competitive with developed countries across a wide range of products, although at the lower ranges of technology and labor productivity. Advanced technologies are well established in many fields, and expatriate scientists, engineers and technical managers are returning in response to the expanded professional opportunities they now perceive.

25. For the first time, the focus of scientific and technological development shifts from activities promoted or supported by government, to those financed and executed by the productive sector in the interests of protecting its own competitiveness for purely commercial motives. The major investments in research and in the building of local technological capacity are those of private industry. Business and government collaborate closely in technology strategy and policy. The stock market and other risk capital institutions are well developed. The country is technologically ready to take on a mature role in the world economy.

D. Scientific and Technological Development Outside the Market Framework.

1. A country may elect to institute economic policies that take scientific and technological development on a path different from the market-oriented path which we have outlined, In so doing, it imposes a major external constraint on scientific

and technological development. Such unfavorable economic policies -- high protection against foreign competition, high barriers to entry or exit, suppression of competition, grossly distorted prices and incentives -- may so suppress demand for improved technology and management as to make investment in science and technology virtually useless in promoting economic growth. Such policies control the scientific and technological development of the country: in effect, they become its de facto technology policy.

2. Economic policies affecting trade, exchange and interest rates, the prices of key inputs and outputs, and access of small businessmen and farmers to credit and services, also affect the choice of technology and hence the direction of scientific and technological development: the kinds of technology that are used, the types of technological capacity that are developed, the purposes to which technology is applied, and the beneficiaries of its use. The regulations that accompany an inward-directed regime tend to favor larger industry, and to divert investment capital and distort the choice of technology away from the small-scale, labor-intensive technology that would be more effective in creating productive employment. The same is true of economies in which the public sector controls a large part of the productive sector. The management of public sector enterprises are also frequently subject to heavy political pressures which adversely affect their efficiency.

3. The combination of overregulation, distorted prices and excessive state intervention in the economy creates over time an interlocking network of vested interests which is very difficult to dislodge. The result is a congealed economy in which enterprise managers have little incentive to absorb technology or to innovate. In economies in which prices are badly distorted, investments in science and technology may be a mixed blessing: they promote improved management of technology, but in the directions prescribed by the prevailing distorted factor prices. Such investments would promote international competitiveness, for example, but not employment (if capital is cheap and labor artificially dear) or conservation of energy and raw materials if the prices of these inputs were held artificially low.

4. If extreme inward-directed policies take effect at a relatively early stage of scientific and technological development, they may permanently stultify market-oriented scientific and technological development. This is especially true in small countries, such as Burma. If this happens at a slightly later stage, as in Sri Lanka or Tunisia, the "islands of modernization" do fuse into an integrated system, contrary to the description of the previous section. This system, however, will be focussed on profiting from the economic rents made possible by a closed economy, rather than from improvements in

competitiveness based on price and quality. In larger countries, such as Brazil, Mexico and India, market-oriented scientific and technological development may continue for some time despite an inward-looking economy, because of the competitive pressures generated by internal competition. Even so, such economies are likely to stall well short of full international competitiveness.

5. Non-market scientific and technological development goes through a series of substages similar to market-oriented development, but with important differences. It thus represents a path divergent from that of market-oriented development as described in the previous section, a fact which is shown diagrammatically by the divergent arrows in Figure 1. The task of structural adjustment is thus equivalent, at least in its scientific and technological aspects, to a return to the market oriented path of scientific and technological development, as represented by the diagonal crossing paths in Figure 1.

6. Post-war experience indicates that non-market scientific and technological development can succeed in making a only a limited contribution to economic growth or equity in the absence of substantial policy change. Such inward-oriented, over-regulated economies experience extreme difficulties in advancing from the transition to newly industrialized status (substage 2b) to the threshold of technological competitiveness (substage 2c), even in the presence of high direct investments in

science and technology. Indeed, the congealed civilian economies of the USSR and much of Eastern Europe may be regarded as the end-point of scientific and technological development which is not oriented to the market. On the other hand, the great success story of the post-war world, the Japanese economy, is far from an open, free market economy. This dramatic exception to the generalizations of this paragraph should give us pause before drawing too facile a conclusion.

7. Official Enclaves of Scientific and Technological Activity. Many developing countries, often those in which inward-directed policies have been in effect for a long time, have established official enclaves of technology based activity which enjoy a high degree of political support and which are kept deliberately isolated from the main body of economic activity of the country. These scientific and technological enclaves may be become objects of national pride, and may attract considerable attention in government policy and investment. They may be led by able statesmen of science, such as Minister Habibi in Indonesia and Professor Cyril Ponnamperuma in Sri Lanka: powerful, articulate and influential figures who are genuinely trying to build scientific and technological capability in an unpromising environment.

8. These enclaves are often designed to foster the development and application of a branch of high technology,

typically aerospace or atomic energy, often for military purposes.[9] In other cases, the special status of these enclaves is exploited in purely civilian efforts to demonstrate that modern technology can be successfully imported and managed even in a country which has otherwise achieved only a relatively low state of overall scientific and technological development. Even aside from the possible requirements of diplomatic and military secrecy, the technologies being promoted by these enclaves typically have special infrastructural and personnel requirements which are difficult to satisfy under the conditions of a developing country. A technologically oriented enclave will therefore be provided with special facilities and exempted from national regulations and policies which might otherwise inhibit its development.

9. In some developing countries, enclaves of this kind are the main loci of scientific and technological activity. They may be the only place in the country where substantial sums of money are available for scientific and technological activity, where serious research is carried out, where sophisticated equipment is available, where expensive technology can be easily

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9. In cases where the objective of the enclave is to acquire and develop military technology the export of which is forbidden by US law, such as chemical and nuclear weaponry, this special treatment may be augmented by clandestine efforts to import sophisticated technology and raw materials, in violation of Western export controls. This paper is concerrned only with the significance of scientific and technological enclaves to economic development, not to military or geopolitical considerations.

imported, and where highly trained scientists and engineers can carry out their work under reasonable conditions. In some cases, they have made their facilities available to a limited extent to industry outside the enclave, and in this way served as a gateway for the introduction of some aspects of modern civilian technology.

10. The technical achievements of this kind of non-market oriented scientific and technological development may be impressive. They may include any or all of the following: substantial accomplishments in basic and/or applied research, or in military or aerospace technology; international recognition as spokesmen for the scientific and technological problems and capabilities of the Third World; substantial production of secondary or university graduates, many of whom emigrate and achieve distinction in foreign countries; "high-tech" industries established by scientists with special access to resources; and major applied research laboratories.

11. The contribution of these enclaves to economic development begins when their products or their technological capacity is made available to the civilian economy outside the enclave, by sale of hardware or materials (e.g. in electronic circuits or nuclear isotopes), when sophisticated testing and research equipment is made available to civilian industry (this was an important function of the early "Atoms for Peace" nuclear

research installations) or when technologists trained in an enclave spin off to form manufacturing firms, as happened in the military in Israel and in the nuclear energy establishment of Argentina in the 1960s.

12. In this way, scientific and technological enclaves could, if they were to be effectively exploited, make a substantial contribution to economic growth and equity. In practice, unfortunately, this potential contribution is not generally realized, and the enclaves are not usually successful in "pushing" science and technology into the economy in the absence of substantial policy changes. The scientific and technological enclave struggles to remain relevant to its mission in the face of widespread lack of interest in its work on the part of its supposed clientele, but eventually loses the political support of the government and the ability to command financial resources and to recruit talented people, and thus becomes still further isolated from productive activity.

13. Other Factors Affecting the Contribution of Science and Technology. A variety of other external factors may enhance or limit the contribution of science and technology to growth and equity. Countries whose economy depends on the export of raw materials face the special problem of a boom-and-bust cycle which alternately starves the economy for foreign exchange and floods it with cash. This cycle places the government under extreme

pressure to invest the windfalls of the flush period quickly, to the detriment of proper choice and management of technology. It also tends to favor large-scale, capital intensive technology that is highly visible, can be implemented quickly, and is subject to government procurement and control. On the other hand, it provides ample capital for oft-times excellent educational and health facilities, as in Tunisia, which do form part of the general economic base for science and technology as for everything else.

14. Geographic location also affects the contribution of science and technology to development. Countries close to major markets, such as Tunisia, enjoy special access to investment capital, technology and markets by virtue of their location. This advantage is balanced by the disadvantage that their trained manpower is easily attracted to the superior economic opportunities, and the population distracted by the high level of technology, available nearby. The converse is true of countries distant from major markets, especially if their domestic market is small. Even so, experience has shown that the influence of geographic location is not decisive. Israel and Mauritius are small and remote, but nevertheless enjoy excellent access to world markets.

15. Science, Technology and Equity. The impact of science and technology on equity is determined both by the broad

policies of the country towards employment, income distribution and basic needs, and by specific technological interventions on scientific and technological problems and opportunities affecting poor people. Firstly, a broad range of economic policies affect the choice of technology and hence the ability of an economy to generate productive jobs at any given level of economic activity. These include primarily wage and interest rates, but secondarily, a broad range of macroeconomic and sectoral policies: exchange rates, tariff structures, and a myriad of policies concerning finance, economics and access to services that affect small-scale industry and farming.

16. Secondly, any policy that affects income distribution, whether or not it is intended to do so, affects the market power of the poor and hence the response of the market to the application of technology to their needs. Thirdly, the allocation of public investments to the satisfaction of the basic needs of poor people for health, education, nutrition, etc., is a prerequisite to the application of science and technology in these areas.

17. More generally, the application of technology to public health, environment, worker health and safety, and other areas outside the influence of markets, requires specific policy decisions, not only to devote resources to these problems, but also to make them the subject of technological effort as defined

earlier. The same is true of the application of technology to problems and production opportunities specific to poor and disadvantaged groups, as for example, the problems of rainfed farms on marginal soils.

E. Indicators of Scientific and Technological Development[10]

1. Background. There do not exist objectively verifiable measures of the overall state of scientific and technological development of a particular developing country, in the sense of reliable, widely collected statistics whose relation to scientific and technological development is widely accepted and well established. An example of such an index in another field of development studies is the "Quality of Life" index, consisting of life expectancy, infant mortality, and literacy, which has facilitated the characterization of the success of the different countries in meeting the basic needs of its population. Unfortunately, the design of quantitative indicators of scientific and technological development has proved difficult in the developed countries and virtually impossible in the developing countries. Long-term research will be required to overcome this difficulty.

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10. For a more complete discussion of the problem of indicators of scientific and technological development in the developing countries, see Annex E to this report, "Assessing Scientific and Technological Capacities in Developing Countries," by Kurt Hoffman.

2. The problem is three-fold: First, a proposed indicator must rest on widely accepted and extensively validated cause-and-effect relationships that express a relationship between the statistic being collected and the property one wishes to measure. Despite considerable progress in recent years in elucidating the relationship between science, technology and economic development, there is still no systematic and comprehensive picture that is clearly applicable to the wide range of circumstances that obtain in the 110-odd developing countries. Indeed, this report is an effort to establish a framework within which such a picture might be elaborated.

3. Second, if a proposed indicator is to be used for cross-country comparisons and hence for policy-making, it must be collected in a wide range of countries. This can happen only after standards and definitions have been agreed at the national and preferably the international level. Such agreement would in turn be possible only if there were a widespread consensus that the indicator does indeed provide a useful measure of an important dimension of development and thus justifies the trouble and expense of reliable collection.

4. Third, a useful set of indicators must provide, not only a measurement of the level of <u>in</u>puts into science and technology (expenditures on education, engineering, research, scientific and technological personnel, etc.), but at least as

importantly, a measurement of the outputs of scientific and technological effort. These are much more difficult to measure.

5. Nevertheless, there do exist a variety of partial statistical measures of scientific and technological development, which (when they are in fact available -- a condition that is not always satisfied) can be woven together in such a way as to support the judgments of an experienced observer. Extensive work by UNESCO and other parts of the UN system has resulted in the acceptance and widespread collection of statistics on research and development budgets, the supply of scientific and technological personnel, and the output of patents and scientific papers, as indicators of scientific and technological development. These are at present the only statistically reliable indicators of scientific and technological activity commonly available for the developing countries.

6. Unfortunately, these indicators, even if fully validated and in widespread use in the developed countries, would be of only limited use in the developing countries for two reasons. First, the relevant primary data are often not available. (For example, Tunisia publishes hardly any data at all.) Some of them (research budgets by subsector, for example) are often not collected in the developing countries. And standard sources in developed countries (for example, citation

indices, which are widely available in the natural sciences) often provide very limited coverage to research and journals in the developing countries.

7. Second, the relations between science, technology and the economy are very different in the developing countries from what they are in the developed countries. In developing countries, the critical task is the adaptation and diffusion of technology rather than research and innovation, and much of the most important technological effort takes the form of demonstration, production engineering, and the adaptation of existing techniques -- activities that are difficult to standardize and quantify for statistical purposes. We are therefore driven to seek indirect measures of the technology to industrial output, such as the data on the production or export of capital goods. Such data requires careful interpretation in the light of circumstances in a particular country.

8. Proposed Indicators. We have in this paper attempted to point the way toward a set of indicators of scientific and technological development which will assist in the classification of a given developing country into one of the substages defined in the previous section of this report, and hence will illuminate the relationship of science and technology to economic development and equitable distribution. For this purpose, we have reinterpreted the characteristic attributes of

the various stages of scientific and technological development as a set of statistics which could in principle be gathered and compared across countries.

9. Most of the indicators cited are intended to provide a measure of the level of scientific and technological development of a country. It is also important to have an indication of the direction of this development: for example, the balance between attention to competitiveness, to environment and to social needs. This may be gauged by the sectoral and geographical distribution of the various aspects of scientific and technological development discussed below, and their classification (if available) by social objective.

10. As might be expected, many of these desired statistics are not being gathered, either in developed or in developing countries, and many would require refinements in definition substantially beyond what can be attempted here. A more complete discussion of the definition, usefulness, and limitations of these and other indicators is found in Annex E to this report. These indicators are summarized in Table II-5, as they relate to each aspect of scientific and technological development.

(1) General Economic Environment. Standard economic indicators may be used to describe the general economic environment (GNP and its composition, recent economic performance, physical infrastructure, and equity and quality of life), economic geography (natural resources and location), and economic policy environment (inward vs. outward orientation, intersectoral terms of trade, price distortions, barriers to competition, business and investment climate). The definition of most of these indicators is well established, and many of them are readily available from standard statistical sources, such as the World Development Report published by the World Bank and the reports of UNIDO and UNESCO. The only innovation, a minor one, is to propose the establishment of a standard index to summarize the degree of distortion of a number of key prices, such as those of foreign exchange, interest, and key agricultural and industrial inputs and outputs.

(2) Technological Capacity in the Productive Sector. The indicators for the technological capacity of the productive sector are designed to answer the following questions: What are the country's major products, and what is its contribution of local value-added to them? What is the quality of the production in the country concerned, and what is the cost relative to that quality relative to international standards? What level of technology is in use in the country, and what is the level of local technological involvement? Finally, is the country

identifying its technological opportunities, and is it using its resources well? These are simple questions to state, but to embody them into indicators would require either detailed surveys of firms in order to determine their technological activities in detail, or else reliance on the market to provide objective measurements of performance.

11. The first approach, that of detailed micro survey, requires the expensive production of primary data and amounts to a fairly expensive research project. The alternative is to estimate these quantities indirectly from statistics on the composition and destination of manufactured products, imports and exports of technical services, research and development in the productive sector, and patents and trademarks of local origin, as well as from the results of firm-level surveys of technological capacity and of experiences of foreign customers and partners, and of total factor productivity. Such use of market indicators as proxies for technological performance -- for example, subsectoral classification and destination of manufactured exports -- requires careful expert interpretation and a good deal of country knowledge.

12. First of all, it is not straightforward to associate a given subsector, a given industrial structure (small, medium or large industry), a given end-use (consumer, intermediate or capital goods), or even a given STI code, with a

given level of technological performance. Such data must be interpreted with a good deal of care and country knowledge. Second of all, trade statistics can easily be distorted by trade and industrial policies, tie-in deals or politically motivated trade arrangements, and by temporary lulls in the domestic market, so that the fact that a sophisticated product is being exported to a demanding market does not necessarily indicate that it is being produced at international costs.

13. Fortunately, data does sometimes exist for other indirect indicators of technological performance, such as exports of engineering-intensive capital goods and of "disembodied" technological services. Interpretation of these data also requires some care, as it is important to distinguish the export of technological services related to construction and project supervision from those related to re-export of imported industrial technology, on the one hand, and those based on indigenous proprietary technology, on the other.

(3) Technology Policy. As has been previously discussed, indicators of the state of technology policy of a country must capture three separate attributes: first, the technology policies that actually influence the pattern of scientific and technological development in the country; second, the capacity of the country to assess the effects of its overall economic and technological policies on its scientific and technological

development, and to design and put into practice policies specifically intended to promote that aspect of development; and third, the level of explicit national commitment to science and technology as a critical element of a country's development.

14. The policies that actually influence the pattern of scientific and technological development may be roughly divided into economic and explicitly technological policies. The best indicators summarizing the economic policies that guide scientific and technological development are the indicators of the economic environment listed in Table II-5. The broad range of these indicators illustrates the pervasive influence of economic policy on scientific and technological development, and demonstrates the inseparability of economic and technology policy. The best indicators summarizing the results of policies explicitly designed to promote scientific and technological development are those shown in the portions of Table II-5 devoted to human resources and to scientific and technological institutions, services and research, respectively.

15. The best objective indicator of the capacity of the country to design and implement self-conscious policy for scientific and technological development, is the number and qualification of those officials and members of the academic, business and financial communities that identify themselves as dealing with technology policy during the course of their duties,

and the existence or non-existence of formally constituted governmental units and research and policy institutes devoted to science and technology policy, both serving individual economic sectors and cutting across them. Some evidence regarding the quality of this expertise can be gained from judgement of peers in other countries, and from the number and quality of their scholarly publications.

16. But it is more difficult to judge whether the studies undertaken by these units take into account the subtle interactions of economic and technology policies on market-oriented scientific and technological development. Such qualitative assessment inevitably depends on the judgement of the observer, which in turn may be colored by views regarding the wisdom of the policies and approaches being adopted.

17. Finally, indicators of the level of stated commitment to science and technology as an element of national development include the public statements of top government officials indicating their awareness of the importance of science and technology in national development, the existence or non-existence of a published official statement of national science and technology policy, explicit treatment of science and technology in national planning documents, and enactment of laws to implement the stated plan and to institutionalize the consideration of scientific and technological issues and to

provide appropriate, client-oriented services and other encouragements, in all aspects of the sectoral and cross-sectoral operations and policies of the government. Such pronouncements and legislation have by now been promulgated in many developing countries. But it is important to consider them in combination with the other indicators of the other aspects of technology policy discussed in this section.

(4) Financing of Science and Technology. The financing of research is perhaps the best established and most widely collected statistic regarding scientific and technological development in developing countries. Unfortunately, it is far from the most important, and the statistics which would be of greater significance both are harder to define and (once defined) would be more difficult to collect. The most important indicator needed would be a measure of technological effort in the productive sector, i.e., the expenditures of money and personnel made during the choice, acquisition, and mastery of technology. While in principle measurable, these sums are in practice difficult to distinguish from the normal expenses of operation and management of the firm without a detailed micro survey.

18. At the more advanced stages of scientific and technological development, it becomes important to measure the

amount of investment capital available for technologically innovative ventures, and the number of different sources of such capital. (The latter quantity indicates whether there are multiple sources of risk-oriented finance, or whether on the contrary, a few decision-makers have the power to stifle a new idea. Such ventures normally carry with them substantial risk, so that a key measure is the availability of risk-oriented venture capital. The problem here is that technologically oriented ventures are only one of the many classes of risky investments available in developing countries, so that it is a mistake to assume that any investment company labelled "venture capital" is necessarily oriented towards technology. Conversely, a country may express a need for "venture" capital when its main need is for any kind of risk-oriented capital, whether or not it is technologically oriented. (This is clearly the case in Tunisia.)

(5) Human Resources. Data on the stock of human resources for science and technology form part of the set of classical indicators of the level of a country's overall scientific and technological development, and are the most widely available and the most detailed of these indicators. At the highest levels of training, data are typically available on the population of scientists and engineers by degree level and general field of specialization (engineering science, agricultural science, natural science, medical science, social

science), by the sector in which they are employed, and by the proportion employed in "research and development."

19. Detailed statistics are also often available on the expenditure on higher education, and the qualification and age profiles of university faculty by field of specialization, as well as the number of degree granting institutions, their student-faculty ratio, and the availability of financial assistance for students in the various fields of study. Data are usually available on the number of technicians, the proportion of these employed in research and development, and hence the ratio of technicians to research and development scientists--this last being a measure of the efficiency with which research and development personnel are employed.

20. At the level of general education, detailed student enrollment profiles are typically available for the stock and geographic distribution of students in primary, secondary, general and vocational, and tertiary educational institutions, and the availability of teachers at various levels of preparation in various levels of the educational establishment, along with such basic indicators as student-teacher ratios and school size. These statistics are tabulated in the annual Unesco Statistical Yearbook,

21. Data on human resources stock can be a source of useful insights on the level of sophistication of the technical and managerial personnel in various sectors of the economy, the allocation of educational resources, and the availability of job opportunities for technical and managerial manpower in various sectors and geographic regions, and hence the extent to which the supply of human resources corresponds to the structure and sophistication of the economy and the efficiency with which available human resources are employed in the economy.

22. For example, the comparison between the human resources statistics of Sri Lanka and Thailand catalogued in the ESCAP interim technology atlas[11] shows clearly the difference in level of scientific and technological development between the two countries. Adjusting for differences in population, Thailand has a much larger stock of scientists, engineers, and technicians at all degree levels and in all fields. Of this smaller population, a higher proportion of Sri Lankan scientists and engineers work in the general service sector, as befits its earlier stage of development, whereas a higher proportion of Thai scientists and engineers work in the productive sector. A higher proportion of Sri Lankan scientists have doctor's degrees, but a higher proportion of Thai scientists and engineers have some post-graduate training.

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11. Asian and Pacific Center for Transfer of Technology, Economic and Social Commission for Asia and the Pacific, Technology Atlas: an Interim Report (Jakarta, 1988)

(6) Scientific and Technological Institutions, Services, and Research. Scientific and technological institutions and services are generally well documented. The first indicators of this kind of activity simply document the existence of the relevant institutions, their budgets and staff size, the balance among basic research, applied research, and technical services, and the scope of their coverage by discipline, natural resource, and subsector, and technology, and give the quantity and quality of their output (as measured by published papers, patents, etc.), and the willingness of clients inside and outside the government to pay for their services (as measured by the percentage of income covered by client fees). Beyond this, indicators describing the work of client-oriented institutions and services should also indicate the degree to which they are responsive to the needs of their clientele.

F. Constraints and Policy Objectives at Different Stages of Technological Development[12]

1. In the first stage of scientific and technological development, constraints appear which limit the contribution of science and technology to the larger goals of economic growth and the equitable distribution of the fruits of that growth. These

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12. An earlier version of this section appears in a chapter by C. Weiss, entitled "Pathways of Technological Development," in M. Kamenetzky, R. Maybury and C. Weiss, Chapter 4 in Choice and Management of Technology: A Training Program for Decision Makers, (World Bank, Washington, D.C., 1986), p.45-47.

constraints are intrinsic to the process of market-oriented scientific and technological development, and are over and above the external policy and geographical constraints discussed in the next section. Table II-6 lists these scientific and technological constraints, as well as some of the policy or programmatic interventions that can be used to overcome them.

2. These scientific and technological constraints are divided for convenience into six general categories: the general economic situation, scientific and technological capacity in the productive sector, technology policy, money, people, and institutional capacity, corresponding to the six aspects of scientific and technological development that were the basis of the analysis in the previous section of this paper. These categories are interrelated. For example, a shortage of people can affect institutional capacity, while a shortage of either people or institutional capacity can affect the ability of the country to overcome the lack of a specific technology. Moreover, some constraints that are apparently financial are actually matters of policy, since funds could presumably be reprogrammed from elsewhere if the priority assigned science and technology by policy makers were higher.

3. In the first stage of scientific and technological development, "emerging islands of modernization," the major scientific and technological constraints to economic growth lie

in the lack of manpower, basic institutional capability, and basic technological capacity in the private sector. These deficiencies often give rise to poor choice and management of technology in the larger industry and public sector infrastructural institutions, as well as high costs in foreign exchange for imported equipment and technical services. In small and medium industry, these constraints result in deficient quality and quality control, as well as low productivity. The major scientific and technological constraints to equitable distribution lie in the lack of institutional capacity to provide basic social services, such as education and health, and in particular a neglect of research and technical services in support of the problems of the poor and disadvantaged, and the small industry and agriculture that is likely to employ them.

4. In this first stage, the general aim of government strategy is to establish a pattern of effective use of science and technology in key areas of the economy. The major problems confronting policy makers are: to overcome the shortage of human and institutional resources; to raise the status and awareness of science and technology in the educational system and in the public at large; to increase the responsiveness of the educational system to the changing demands of the labor market and the changing needs of the economy; to start the process of building local technological capacity, especially for the selection and implementation of technology, in a few key sectors

of the economy; to build capability for research and innovation in key sectors (such as agriculture and environment) where imported technology and knowledge is insufficient to local needs; to ensure attention to the scientific and technological aspects of key social and environmental problems that are not adequately addressed by the market; and to establish an overall economic climate that encourages efficient management and resources use.

5. During this stage, one of the most important elements of technological strategy is simply to be careful <u>not</u> to <u>dis</u>courage investments in technology and the building of technological capacity (defined earlier as "technological effort") by policies, which are unfortunately very common, such as discriminating against small-scale production, distorting prices so as to encourage overuse of scarce factors of production, over-regulating, excessively protecting domestic production against foreign or domestic competition, and (especially in parastatals) tolerating political interference and excessive insulation from the realities of the market place. Such policies are in effect the de facto technology policies of the country, in that they guide the choice and management of technology in the productive sector.

6. In modern industry, commercial agriculture, and physical infrastructure, the most practical policy objective is to strive for the establishment of as many loci as is possible

within the limited supply of trained manpower, of competence in the assessment of objectives and the choice, management and operation of technology in the productive sector, plus a few centers of excellence in research and innovation, preferably in areas of direct relevance to national needs.

7. In the second stage of scientific and technological development, designated "struggle for mobilization and mastery" in Table II-3, a modern, technologically oriented economy is built up on the relatively isolated areas of effective use of science and technology established during the first stage. At this stage, science and technology becomes an increasingly important element of competitiveness on world markets for industrial and agricultural products. The keys to competitiveness -- market intelligence (which requires understanding and even forecasting of technological developments), quality, quality control, and low production costs through appropriate application of advanced manufacturing technology -- all involve the management of technology.

8. To facilitate this process, policy makers should set more ambitious objectives: to ensure systematic attention to developing an appropriate degree of technological capacity in all sectors of the economy; to extend this capacity to include adaptation, innovation, research, and evaluation of past results; to create a climate that will encourage industry to devote a

sufficient level of their own resources to technological effort, so as to reach international standards of efficiency and competitiveness; and to ensure adequate technological effort in addressing problems specific to the poor and disadvantaged parts of the population. Policy makers in government require an increasing understanding of the interaction between science, technology and economics.

9. In the more advanced substages of stage II, innovation and the ability to manage advanced technology in biotechnology, informatics, microelectronics, and advanced materials, becomes important to keeping up with intensifying competition -- the more so as technology suppliers in advanced countries become less willing to license technology that may be used to compete with them in their prime overseas markets. The ability to manage advanced technology, such as biotechnology, informatics, and advanced materials, becomes important to future (and in some cases, present) competitiveness.

10. The scientific and technological constraints to achieving an equitable distribution of the benefits of economic development lie mostly in the policy area, because they involve choices regarding the direction of the country's technological effort. At this point, for example, technological capacity in both public and private sector has reached the point where the constraints to the application of science and technology to

social services for the poor or otherwise disadvantaged, lies in the level of technological effort on these problems the government is willing to devote to them, through direct investment in research and technical services in these sectors, or through creating market incentives (as through the use of government procurement or other incentives) for private technological effort.

11. Achievement of these objectives requires attention to the areas of overlap between the economic and technological aspects of development policy, and continued efforts to remove the disincentives to technological effort, described in the next section, which by this time have often developed formidable vested interests in their support. Industries producing capital goods and other inputs critical to the use of improved technology (such as fertilizer and high quality raw materials) also require specific attention.

12. Beyond this, government action to encourage the second stage of scientific and technological development consists of support to various elements of scientific and technological infrastructure, including education, technical and information services, research, development and innovation, as well as specific attention to advanced technologies, to technology-intensive sectors, and to the scientific and

technological aspects of social, environmental and other problems not adequately addressed by the market.

III. External Constraints on the Contribution of Science and Technology to Economic Growth and Equitable Distribution[13]

A. Economic Constraints

1. We identify six "external" constraints which arise from factors outside of science and technology, as having a particularly important influence upon scientific and technological development. Some of these constraints derive from a country's broad economic environment, others from its economic geography, and still others from its economic policy. These constraints can operate at any stage of scientific and technological development and can lead to different pathways through the stages sketched in the previous section of this report.

(1) Constraints Arising from Broad Economic Development.

a. Retrogression. The economic and political events of the 1980s have led to scientific and technological retrogression in certain Asian countries and in large parts of Latin America and sub-Saharan Africa. In these countries, economic and/or political turmoil have led to disinvestment by

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13. This section is based on C. Weiss, "Pathways of Technological Development," in M. Kamenetzky, R. Maybury and C. Weiss, Chapter 4 in Choice and Management of Technology: A Training Program for Decision Makers (World Bank, Washington, D.C., 1986), p.47-50, 56-57.

business, pauperization of universities and technological institutions, and a massive brain drain. In these countries, emergency measures are needed to preserve what is left of the universities and the scientific community, while measures are being taken to revive the economy.

(2) Constraints Arising from Economic Geography.

b. Major Exporters of Raw Materials.[14] In these countries, the macroeconomic balance is dictated by the world demand for a primary commodity. When world demand is high, the country is flooded with money, much of it the hands of the government, which in a developing country usually controls the major export commodity. The currency appreciates, decreasing the competitiveness of locally produced goods and services.

2. Pressures to invest are high. Some of the new money goes for needed investments in health, education, and other social infrastructure. But much of the windfall is typically spent on the implementation of capital-intensive projects, which employ a relatively small number of people (often highly paid and strongly unionized) whose high wages put upward pressure on wage rates throughout the economy, further decreasing its competitiveness. These projects may be of dubious economic

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14. For an excellent treatment of the economic aspects of the "Dutch disease," see the paper by S. Lewis in I. Sirquin, ed., Economic Structure and Performance: Essays in Honor of Hollis Chenery.

justification. What is more, the country may exploit its new-found creditworthiness to borrow against future earnings projected into the future at their current high prices.

3. When world demand for the raw material falls, as it inevitably must, a demand-induced recession typically takes place. New investments naturally are cut, but it is politically impossible to retrench the workers on the high-visibility investment made in the boom years. What is cut are politically weak but often socially and economically valuable projects with high recurrent costs, among them undertakings in science and technology.

4. The major investment projects made possible by these export revenues in principle represent a substantial opportunity to build local capacity to all kinds. In practice, however, huge investment decisions are often made by public institutions which have limited technological capacity and are under extreme political and commercial pressure to make unwise choices. There is great pressure to install hardware and to provide social services so as to show apparent results quickly, even if this requires extensive use of foreign experts and technology.

5. In this atmosphere, the local scientific and technological community may be able to win approval for investments in enclaves of scientific and technological

infrastructure, typically research laboratories in universities or special-purpose or multidisciplinary institutes. Given the relatively long gestation period for scientific and technological projects, these may just be getting started at the peak of the boom and be just maturing when the bust hits. At this point, the pressures are great to cut expenditures that do not permit quick rewards and in which there are not already large sunk costs. Such scientific and technological expenditures as may have been authorized during the boom years are likely to be curtailed.

6. Ideally, planners in such a country should limit investments during the boom in anticipation of the bust. But given the universal difficulty in planning for the inevitable downturn, probably the best tactic for the scientific community is to attempt to influence decision-makers to designate selected investment projects as vehicles for the creation of local technological capacity and as models for other future activities. They should also continue to use the flush period to build enclaves of scientific and technological capacity in universities and institutes which can then begin to influence the productive sector. The requirements of these enclaves for recurrent expenditures should be sufficiently modest that they are likely to survive the lean years without too much damage.

7. A second objective, like the first easier to state than to implement, is to establish the principle even during boom times that it is better to use the foreign exchange earned by the export of natural resources to design and implement projects that are built to relatively modest standards and hence can benefit a large number of people -- rather than to design an expensive show piece, perhaps using high technology, that benefits a relatively few people, often those with good political connections. Thus replicability and sustainability should be key principles of technology policy even in countries with an apparent surfeit of resources.

b. Small and Isolated Countries. The scientific and technological development of small and isolated countries is shaped by inescapable facts of geography. No matter how much they develop, they will always have a small domestic market and a small population base from which to draw.

8. Nevertheless, the experience of Singapore, Israel and Mauritius shows clearly that small size and apparent isolation need not be a barrier to achieving a strong position in the world market. Since the local market is small, these countries have been forced to make a virtue of necessity and to seek to establish a place in the world market immediately. This has forced them to achieve world standards of quality and price, a difficult assignment but a rewarding one. As to isolation,

this is no longer determined by geographical location. Airlines are quick to establish routes that take people where they want to go, regardless of distance.

9. There are, however, inescapable limits to the resources which a small country will ever be able to invest in science and technology, even after it attains a relatively high level of scientific and technological development. Capability and infrastructure must therefore be fostered selectively in the areas of highest priority to the country. Specifically, capacity should be build up in the areas of greatest economic activity and in the areas in which foreign sources of technology are least likely to invest the resources needed to provide solutions to specifically local problems.

10. In a large country, exposure to broad issues of science and technology policy would typically wait until the policy maker or scientist has reached a senior level after a long career. In small countries, in contrast, a relatively few people in government and industry must inevitably make decisions requiring a very broad view of the problems of the country. There is therefore a need to provide broad gauge training at a relatively early stage of the formation of policy makers.

c. Countries Close to Major Markets and Sources of Technology. In these countries, foreign equipment, technical

services and marketing information are readily available and vigorously promoted. Dissatisfied local scientists and technologists can find jobs easily in the neighboring developed countries, creating a major draw for the brain drain. But this is less of a disadvantage than it might seem, since in an age of air travel, these pressures are universal.

11. Perhaps the most important influence of a powerful neighbor on scientific and technological development is more subtle. Ordinary people are familiar with the standards of living and the types of technology in use in the neighboring developed country and wish to see the same standards of living and the same type of technology applied at home, even well before the country is ready to use or pay for it. The same expectations exist among local scientists and technologists.

12. The best policy response to this situation is to maximize its advantages and minimize its disadvantages by building indigenous technological capacity. This means, first of all, an emphasis on exports and competitiveness. The proximity of markets provides a major source of market and technical information through exports. The very process of producing to international standards of quality provides feedback from customers who provide information and ideas regarding new uses, new designs and new processes that help to improve products and keep then up-to-date.

13. Secondly, it means designing local scientific and technological infrastructure in such a way to facilitate access to the market information and technological resources of the neighboring country, while at the same time maintaining sufficient information about alternative sources of technology so as to avoid excessive dependence on a single source. It is impossible and indeed undesirable to prevent the migration of trained personnel to an advanced neighbor that can offer superior working conditions and financial rewards. On the contrary, local citizens who have spent ten to fifteen years working in the environment of an advanced country represent a major human resource which can be reattracted back home if offered suitable professional challenges.

(3) Constraints Arising from Economic Policy.

a. Inward Directed and Over-Regulated Economies. As has already been extensively discussed, experience is universal in both socialist and capitalist countries, that an inwardly directed, excessively planned and administered economy inhibits and misdirects technological innovation by overregulation, overcentralization and suppression of competition. This inhibition of innovation occurs even though there may be at the same time substantial scientific and technological capability in publicly supported institutions,

which are, however, more or less separated from productive activity.

14. These investments and explicit policies for science and technology lead to a considerable degree of self-reliance, combined with a great deal of out-of-date and inefficient technology. This heavy role of government is frequently combined with a strongly distorted price structure, which guides both the choice of technology and the direction of technological effort into uneconomic directions. Local technological resources are often misdirected by economic policies that give misleading signals regarding resource scarcity or which otherwise encourage unrewarding technological effort. The scientific and technological infrastructure becomes a considerable vested interest in its own right. Attempts to reduce it or to improve its links to the productive sector may result in a storm of protests from prestigious technological figures.

15. From a policy point of view, there is little choice but to liberalize and deregulate insofar as possible, constructing reforms through a careful analysis of the relationship between science and technology and the economy, and transforming existing scientific and technological infrastructure or creating new services to ease the transition. Partial reform is easier to effect but produces limited results, and may even be counter-productive if a distortion or institutional inefficiency

in one area vitiates a reform in another. In a particularly far-reaching and dramatic example, Chinese policy-makers made the bold and risky decision simultaneously to radically increase the role of market incentives, to decentralize decision-making, and to eliminate many administered prices (some of which had hardly changed since the 1940s) -- in part because they realized that decentralized decision making would not produce desirable results if out-of-date prices sent the wrong signals to the newly responsible enterprise managers.

b. Countries with Severely Skewed Income Distribution. Countries which have seriously skewed income distribution, and in which the poor have neither market power nor political clout to press for satisfaction of their basic needs, devote few resources to poverty-oriented problems such as health, sanitation, malnutrition, illiteracy, and lack of shelter. Such countries are unlikely to devote resources to developing technological capacity for the design and operate programs in these areas and *a fortiori* to the development of technologies specially adapted to the local conditions.

B. Implications for AID

1. Limits on Science and Technology as a Leverage Point. Scientific and technological development is not an end in itself, but rather a means to accelerated economic development and to a more equitable distribution of the fruits of that

development. It is these larger considerations that stimulated the interest of AID in scientific and technological development in the first place. All the external influences identified in this section affect the policies and programs best suited to facilitating scientific and technological development in a particular developing country, and hence the design of possible interventions in this aspect of development by AID.

2. Of the six external constraints discussed in this section of the report, two have particular importance because they suggest limitations brought about by deliberate policy choice, on the effectiveness of interventions intended to promote scientific and technological development, in accelerating economic development and bringing about a more equitable distribution of its benefits. Specifically, countries where competition and innovation are severely inhibited by over-protection, over-regulation, and over-centralization are unlikely to achieve accelerated economic growth through science and technology, without substantial efforts to reform the macro-economic, industrial, trade and other policies that are inhibiting their overall economic performance. Similarly, countries with severely skewed income distribution, and no compensating efforts to focus on the specific needs of the poor and disadvantaged, are unlikely to achieve a reduction of poverty and its debilitating effects through the application of science of technology.

3. This is not to say that science and technology cannot be an important aspect of development in these countries as well. It does suggest that AID will have to take a great deal of care in designing a project that takes advantage of a particular niche where science and technology can in fact make a direct and reasonably foreseeable contribution to these policy goals, despite the unfavorable conditions that otherwise pervade the economy. This special niche might, for example, be the existence of an entrepreneurially and technology oriented business community in a particular section of the country (such as that of Bangalore in India and Sfax in Tunisia), a large private company (such as the Tata interests in India or Hayley's in Sri Lanka) or a government agency or parastatal (such as the Kenya Tea Development Authority) with a particular commitment to efficiency in technological innovation and to efficiency in both the economic and technological aspects of management.

4. Moreover, AID and other parts of the US government might well wish to collaborate with and assist these countries in science and technology for reasons other than their contribution to economic growth and equitable sharing of its benefits. For example, such collaboration is an excellent way to build bilateral goodwill, to establish contact with a politically influential scientific community, to stimulate discussion on policy issues of importance to both countries, to collaborate on

research of mutual interest, as for example on unique resources or environmental conditions unique to the area, or to take advantage of local expertise in science and technology.

5. In the end, however, science and technology cannot produce miracles by themselves. AID and the developing countries should not look to science and technology to effect dramatic improvements in economic growth and income distribution if its contribution will inevitably be swamped by overwhelming external constraints. On the other hand, once political will has been summoned to address these external constraints, support to scientific and technological development is an excellent way to encourage the government to continue to do so, and to stimulate highly visible activity that dramatizes the value of policies that stimulate competition and economic growth.

6. Possible Science and Technology Interventions by AID. Many of the policy objectives listed in Table II-6 are well suited to being furthered by interventions that are well suited to the capabilities and operating procedures of AID. Some suggested programmatic interventions available to AID to stimulate the scientific and technological development of developing countries at various stages of scientific and technological development are presented in Table IV-1.

7. In the earliest substages of scientific and technological development, AID's recommended interventions are focussed on assistance to science and technology education at all levels, the provision of information and technical assistance to small-scale entrepreneurs, the diffusion of low-cost technology, and the development of research capability in critical sectors like agriculture and environment.

8. By substage 1c, it is also useful to train policy makers in the broad concepts of technology policy, and to review the effects of tax, macroeconomic and trade policy on scientific and technological development, so as to take the first steps towards a coherent approach to technology policy. It is also useful to provide training in critical fields of engineering and management, and equipment and technical assistance in such fields as natural resources survey, primary and secondary science education, and industrial consultancy to improve quality and competitiveness. In line with AID's private sector emphasis, the last might be combined with a fund to assist industry to make the necessary investments in improved technology, especially in small and medium industry, and the establishment of bilateral services to facilitate the flow of technical assistance and of technological and market information from the US to small and medium industry. (These funds should be administered carefully so that they do not simply become a source of cheap capital for investments in ordinary production equipment.) All of these

interventions are well suited to AID's traditional format of development assistance projects, although they could probably be adapted to other formats as well.

9. By the beginning of the second stage, the country is ready for more nearly equal forms of partnership, such as scientific collaboration and the first research and development joint ventures. There is still, however, the need for equipment and training in key areas of scientific and technological infrastructure, training and technical assistance in research management, and (for the staff of financial institutions) in the management and assessment of technology.

10. By substages 2b and 2c, when the country is becoming a newly industrialized (NIC), there should be a strong emphasis on building links among the universities, banks, and government with the private sector in the country itself, and between the universities and the private sector in the United States and those of the newly industrializing country.

11. From the purely operational point of view, these arrangements are suited to being carried out under the provisions of a binational research foundation, a bilateral science agreement, or a bilateral industrial research and development foundation, and no doubt under other umbrella arrangements suited to the bilateral relations of the united States with these

relatively advanced countries. In general, and contrary to our expectations, we found that the programs suggested were indifferent to the umbrella arrangement; that is, that assuming appropriate administrative arrangements, a given programmatic intervention could function just as well under a bilateral agreement, a foundation, or a traditional bilateral aid program oriented around development projects.

IV. Pilot Country Profiles and Their Programmatic Implications

A. Sri Lanka[15]

1. According to the analytical framework presented in this paper, Sri Lanka is at stage 1c in its overall scientific and technological development, i.e., it is at the stage of "islands of modernization," as evidenced by the following profile:

General State of the Economy	1c
Technological Capacity in the Productive Sector	1c
Science and Technology Policy	1c
Financing of Science and Technology	1c
Human Resources	1c
Scientific and Technological Institutions, Services and Research	1c

2. The scientific and technological development of Sri Lanka has been inhibited by a combination of economic and security factors. On the economic side, the country is emerging only slowly from the legacy of heavy protection and state direction of the economy: inefficient state-owned industry and plantation agriculture, private industry habituated to look to the government for direction, and a government bureaucracy which

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15. The full version of the pilot country study on Sri Lanka is found in Appendix B of this report.

is still oriented to government control of the economy. On the security side, long-term investment of the kind needed for scientific and technological development is severely inhibited by the activities of two separate groups of guerrilla revolutionaries. Except for the level of effective protection (about 80%), the economy is relatively free of gross price or other policy distortions, at least compared to its South Asian neighbors. Wage rates compare favorably to those of other South Asian countries, making Sri Lanka an attractive place for footloose investments, such as garment manufacture, which is expanding rapidly.

3. Unemployment (officially at 20%) is a pressing problem, and helps create support for guerrilla opposition. New investment has not taken the place of the low-technology industries displaced by freeing of imports, while job creation is constrained by overly complicated and generous labor legislation, as well as by fiscal incentives that favor large scale capital-intensive investments.

4. The universities are now out of operation for a third year because of guerrilla activity on campus. This deprives Sri Lanka of trained manpower, and creates a large number of idle and frustrated students inside the country, who are ripe for recruitment into one or another radical force. This aside, universities are well established as institutions,

but their rigid structure hampers efforts to create links with the business community and to adjust their programs and curricula so as to meet the country's changing manpower requirements. The government's requirements for technical manpower are largely satisfied, so that technical graduates are forced to consider employment opportunities in the private sector. The output of technical graduates from secondary schools and universities suffices to meet present demand, but would be insufficient to meet the needs of a rapidly expanding economy. There are, however, serious shortages of personnel in fields where global demand is high, such as computers and electronics. There are serious shortages of experienced technical personnel at all levels, from skilled machinist to engineering professor, due to the brain drain.

5. There are many enclaves of capacity for choice, operation, and in larger production units in agriculture, in industries connected with natural resources, and in parastatal authorities concerned with infrastructure (telecommunications, highways, power). Likewise, there are many small and tiny enterprises ingeniously managed in the face of difficult external conditions. Even so, quality and quality control is a serious problem throughout the industrial sector. So is the inefficiency of the larger industry in operating conventional technology, and there is little diffusion of technology by

subcontracting or by the movement of technical personnel. There is little capacity to adapt technology and product design, and to innovate to meet local needs or maintain competitiveness in changing circumstances.

6. Sri Lanka still lacks any formal cross-sectoral science and technology policy, a major exercise to that end in 1985 having ended inconclusively. Government officials (at least in the previous government) now recognize the importance of science and technology, and the need for policies to encourage that aspect of the country's economic development. But there is no locus in the government of expertise or responsibility for such policies (other than operational responsibility for the publicly owned research and technological institutes). The recently adopted Industrial Policy Statement includes a chapter on industrial technology. A proposed action plan and policy for industrial technology were prepared by consultants just before the recent elections, but have not yet been formally considered.

7. The staffs of Sri Lankan development banks are reasonably competent in reviewing business plans and in the economic and financial aspects of project analysis. The Sri Lankan stock exchange is in its earliest stages of operation, and trading is thin in a few listings of large companies. There is little private risk-oriented capital available, and few well-formulated ventures seeking financing.

B. Thailand [16]

1. According to the analytical framework, Thailand is at a stage between 2a and 2b in its overall scientific and technological development, i.e., it is poised to enter into a transition stage of a newly industrializing country, as evidenced by the following profile:

General State of the Economy	2b
Human Resources	2b
Technological Capacity in the Productive Sector	2a - some in 2b
Scientific and Technological Institutions, Services and Research	2a - some in 2b
Science and Technology Policy	2a - some in 2b
Financing of Science and Technology	2a - some in 2b

2. With the exception of some distortions caused by tariffs on capital goods and raw materials and the absence of rebates of tariffs on imported goods used by intermediary suppliers to exporting firms, Thailand has created a relatively level and competitive environment in support of manufacturing exports as an important part of its industrial strategy. Thailand was poised to take advantage of a growth in world trade and, from 1986 onward, she did.

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16. The full version of the pilot country study on Thailand is found in Appendix C of this report.

3. Thailand is on the right track in terms of her macro economic policy, and she should continue her liberalization efforts. Competitiveness will increase, as will the role of technology in private and public investment decisions.

4. Manpower projections point to a widening gap between supply and demand for scientists and engineers in specialty fields and for qualified production-oriented technicians. Labor mobility is relatively high among engineers and among highly trained people in expanding industrial fields, such as electronic and information services. Thailand must expand its science and engineering disciplines in specialty areas, increase exchanges between the universities and private firms, expand its output of scientists and engineers in response to a rapidly changing industrial structure, and restructure some of its vocational training programs to include apprenticeships and on-the-job training.

5. The technology capacity in Thailand's productive sector is generally good, as demonstrated by the rapid expansion of new industries such as electronics and electrical equipment. Investment in human capital development are relatively limited; there are no special fiscal incentives either for these investments or for those in research, development and engineering by private firms. These are areas of increasing importance if

Thai firms are to remain competitive in world markets. Thailand's capital goods industries must also be strengthened.

6. Technical services to firms, on the whole, are underdeveloped in Thailand. Government groups established to assess and access technologies or to provide services to small and medium-sized companies are generally understaffed and lack experience in private firms. There are a host of government research laboratories and industry-specific research organizations associated with universities. The links between these research organizations and the private sector is generally weak. Those that are industry-specific and are financed in part by the private sector have been the most successful.

7. Consulting services and general engineering development organizations exist, but the demand for their services on technology acquisition, adaptation and development is not widespread. In some areas, such as electronics, private consulting firms did not exist until very recently. Research and research coordination are improving, and the Thais recognize this as a problem that needs further attention, including more involvement in the private sector. Both public and private services for testing and calibration of equipment and for quality control assistance and assurance to industries must be strengthened.

8. There is strong support throughout the Thai body politic for private sector led development, and for increased emphasis on science and technology as an integral part of Thailand's industrial strategy. Debate will continue, as will experimentation about the relevant roles of government, the universities and the private sector in formulating and implementing science and technology programs, but education is universally supported as an important private and public investment and such fields as agriculture, medical sciences and engineering are considered prestigious.

9. Thailand has not enacted laws as a major instrument of government policy for promoting science and technology for industrial development. Thai business is represented and consulted by the government on developing science and technology policy, but this is not widespread and the effort generally is not considered serious. Seminars abound where these issues are discussed and business associations take the initiative to work with government agencies. There is a need for more private sector participation in the formulation of science and technology policy, greater integration of science and technology as a component of economic policy and strategy, and better coordination among the various government ministries and agencies.

10. Thailand's financial markets are relatively broad and innovative retail banking services. Merchant banking and venture capital are surfacing. The Thai financial system is fairly broad, although institutional small business lending, merchant banking and venture capital are relatively limited.

11. Most financing of technologies in the private sector is done through internal cash flow of the firm and for entrepreneurs by family and friends. Thai banks have the capability and the experience to assess the technology of proposed investments, although to date they have not financed technology development. The government finances research in government laboratories within the ministries and at the universities, but the amounts are relatively small (except for agriculture) and most of it is late in the product development cycle.

12. Unlike all its major competitors for markets for manufactures in the more industrialized countries, Thailand does not have any institutional financing for technology adaptation and development by the private sector, except for one small program. This is a gap in Thailand's financial market that needs immediate attention.

C. Tunisia[17]

1. According to the analytical framework, Tunisia is at stage 1c in its overall scientific and technological development, i.e., it is at the stage of "islands of modernization," as evidenced by the following profile:

General State of the Economy	1c
Human Resources	1c
Technological Capacity in the Productive Sector	1c
Scientific and Technological Institutions, Services and Research	1b
Science and Technology Policy	1c
Financing of Science and Technology	1c

2. Tunisia has a relatively high per capita income, but is by no means an advanced country from the point of view of science and technology. Its economy was until recently sustained by exports of oil and phosphates, tourism, and workers' remittances. Of these, only tourism continues strong.

3. Tunisia is only just emerging from a long period during which its industry was heavily regulated and almost totally protected from competition, and hence had little reason to improve its technology. Its systems of banking and education

17. The full version of the pilot country study on Tunisia is found in Appendix D of this report.

are inflexible and poorly suited to the demands of an internationally competitive economy.

4. But the ice is now breaking. Top leaders of the Tunisian government and business community realize that the country cannot sustain its standard of living without far-reaching economic reform and without substantial improvement in the country's ability to manage science and technology. They have begun to give explicit attention to science and technology and are receptive to new ideas in this area. They regard the U.S. as an important source of science and technology and also as an institutional model for the some of the institutional reforms they need to undertake.

5. Investments in science and technology are useful oints of leverage for AID in Tunisia, even though they are nlikely to lead to a rapid economic breakthrough. AID should elp Tunisia to effect needed changes in institutions and ttitudes and to build capabilities in fields of science and echnology that will be needed in the long run. It should seek rogram opportunities in supporting reform in science and echnology education, should assist small industry to improve its arketing and technological intelligence, and should explore the ervices sector for leverage points in which the private sector perhaps in collaboration with U.S. business) can provide needed echnology-based business services, e.g. in informatics and

management consulting. It should assist the Tunisian government to develop an overall strategy for scientific and technological development, and should support the efforts of the World Bank to promote the liberalization of the economy and the rationalization of the tax system.

Scope of Work

6. AID has contracted with International Technology Management and Finance, Inc. (ITMAF), to produce a systematic framework of analysis that will (a) enable AID to assess whether a science and technology program is a good investment in a specific country; (b) provide baseline indicators to measure success if a program is undertaken; and (c) allow for cross-country comparisons to facilitate the evaluation of experience of the more advanced countries of Asia and its application to those countries that are less advanced.

7. Specifically, ITMAF is to sketch an overall model of pathways to technological development, and identify the key S&T infrastructural variables critical to accelerated economic growth, analyzing the usefulness of both quantitative and qualitative indicators in cross-country comparisons of the state of science and technology, and outlining general methods to identify the constraints to scientific and technological development.

8. ITMAF is then to apply this framework and methodology to examine selected countries in the ANE region, namely Sri Lanka, Tunisia, Thailand and either Indonesia or Jordan. The analysis will proceed along the following lines:

Supply Side

a. Capabilities of local firms to select, acquire and absorb foreign technology, adapt it to local conditions, to do research, development and engineering and to commercialize innovations;

b. Capabilities, management and responsiveness to user needs of scientific and technological services: engineering firms, standards institutes, contract research and development laboratories, research associations, etc.;

c. Budgets, priorities, and management of more fundamental research in academic and government institutions;

d. Human resources: quality and quantity of the supply of technical and managerial manpower, including patterns of professional training, output and curricula o relevant local degree programs, patterns of career development of technically trained professionals, and support to professional careers (professional and disciplinary organizations, etc.);

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e. Availability of finance at various stages of the innovation cycle (research, inventions, development, commercialization).

Demand Side

f. Effects of macroeconomic and sectoral policies on the demand for improved techn ogy and innovation;

g. Effectiveness of implicit technology programs and policies (technology transfer regulations,tax write-offs for research, etc.

h. Effect of government procurement policies on innovation and the development of local technological capacity;

i. Effect of pricing and other economic policies on the choice of technology and the direction of technological development.

9. From this analysis and baseline data, one can measure program success by identifying and monitoring measurable indicators of change which result from modifications of policy and program interventions.

10. ITMAF is then to identify and assess options for program investments in science and technology program investments and technology commercialization with the selected countries by AID, including a brief examination of various institutional arrangements, e.g. the foundation approach. Criteria for assessing alternative approaches will be identified, such as costs, manageability, and acceptability of various approaches to bilateral partners.

11. ITMAF will test the framework and develop the comparative indicators and measures in one country, and will conduct similar assessments for one or two additional countries, to be selected from the ANE region by ANE/TR in consultation and agreement with ANE/PD and ANE/DP and the relevant USAIDs.

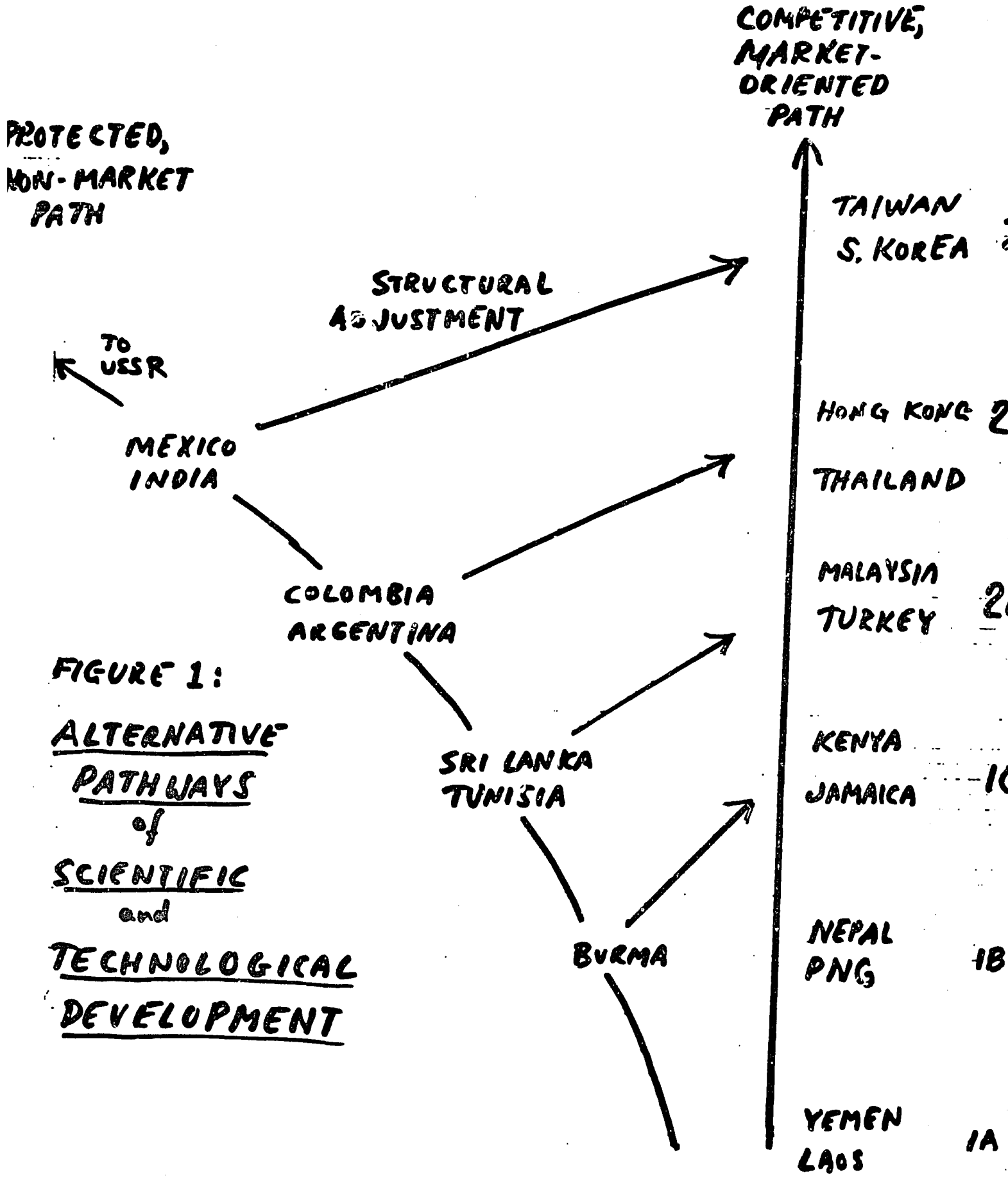
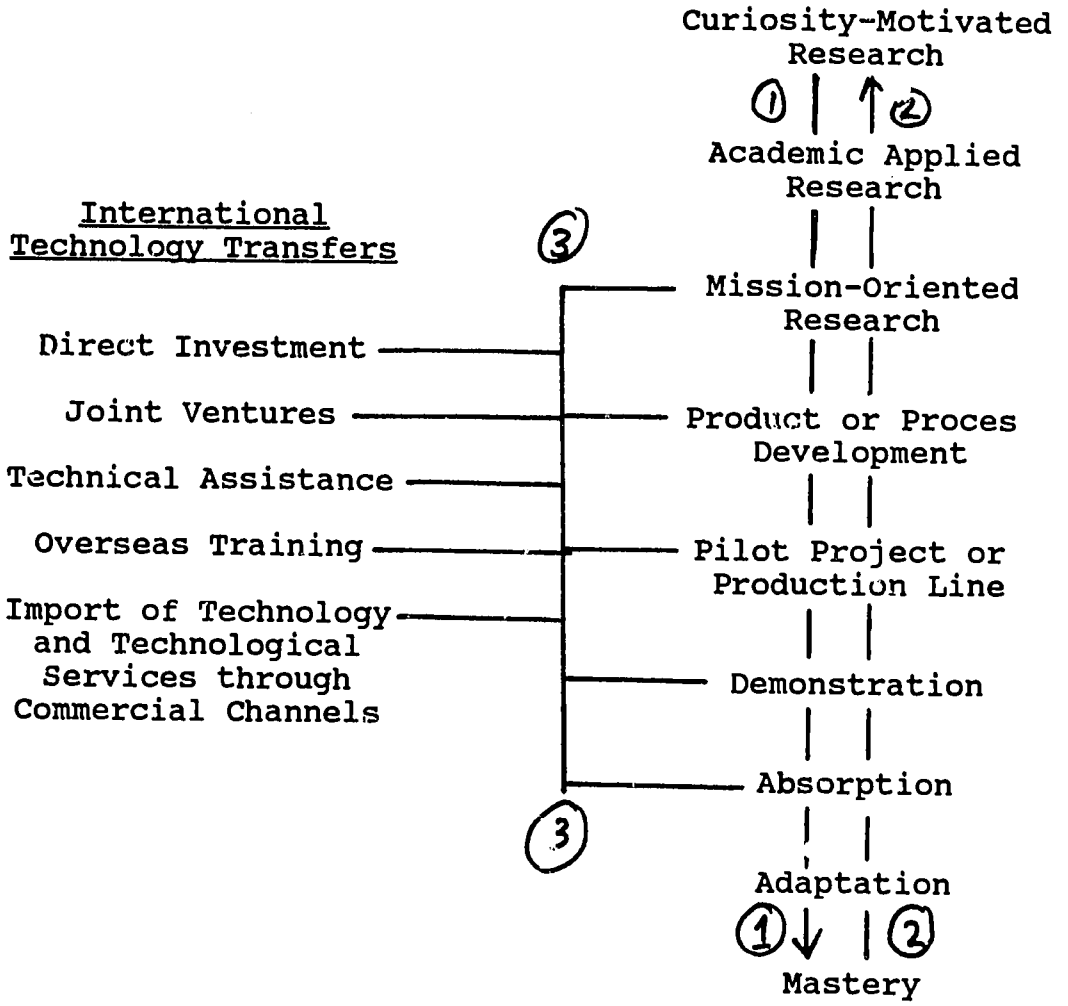


FIGURE 1:

ALTERNATIVE PATHWAYS of SCIENTIFIC and TECHNOLOGICAL DEVELOPMENT

Table I-1

PATHWAYS OF TECHNOLOGICAL INNOVATION[1]



1. "Technology push"

2. "Market pull"

3. Technology Transfer

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[1]. Adapted from R. E. Hughes, Saswinadi S., P. Delp and J. Rice, "Science and Technology and the National Academy of Science Efforts in Indonesia," USAID, September, 1988, mimeo, p 16.

TABLE II-1: Representative Countries at Various Stages of Scientific and Technological Development

	Asia and Near East	Latin America and Caribbean	Sub-Saharan Africa
Stage 1:			
Emerging Islands of Modernization			
1a Traditional Technology-based Economy	Yemen Laos	Surinam	Equatorial Guinea
1b First Emergence	Nepal Papua N.G.	Haiti Guyana	Ethiopia Burkina Fasso
1c Islands of Modernization	Sri Lanka Tunisia Indonesia	Jamaica Peru	Kenya Ivory Coast Zimbabwe
Stage 2:			
Struggle for Mobilization and Mastery			
2a Mastery of Conventional Technology	Iran Malaysia Turkey	Colombia Argentina	
2b Transition to Newly Industrialized Country	India Thailand Hong Kong	Mexico	Republic of S. Africa
2c Threshold of Technological Competitiveness	Singapore Taiwan S. Korea	Brazil	

Table II-2: STRUCTURE OF MATRIX REPRESENTATION OF PATTERNS OF SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT

STAGES OF DEVELOPMENT	ASPECTS OF SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT				
	Technological Capacity in the Productive Sector	Technology Policy	Financial Institutions	Human Resources	Scientific and Technological Infrastructure
Emerging Islands of Modernization					
1a Traditional Technology-Based Economy					
1b First Emergence					
1c Islands of Modernization					
Struggle for Mobilization and Mastery					
2a Mastery of Conventional Technology					
2b Transition of Newly Industrialized Country					
2c Threshold of Technological Competitiveness					

Table II-3. TYPICAL COUNTRY PROFILES AT VARIOUS STAGES OF SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT

STAGE 1: EMERGING ISLANDS OF MODERNIZATION

SALIENT FEATURES

Establish pattern of efficient management and resources use in infrastructure, in key areas of the productive sector, in delivery of basic social services to the poor, and in the protection of the environment.

Develop human and institutional resources.

Substage 1a: Economy Based on Traditional Technology

(Bhutan, Laos)

General State of the Economy

Basic infrastructure largely lacking.
Effective government influence on economy still minimal.

Technological Capacity in Productive Sector[1]

Little technological capacity in productive sector.
The economy is dominated by traditional technology whose rational basis is poorly understood by the user and is sometimes unknown to science.

Technology Policy

Policy concerns focussed on basic education and services.

Financing of Science and Technology

First development banks established.

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1. The productive sector is defined here to include both industry and agriculture, whether publicly or privately owned.

Table II-3 (continued)

Substage 1a (continued)

Human Resources

Low literacy rates, few highly trained manpower.
Little experience with modern production technology.
Pre-scientific world-view in most of the population.
No higher education or research in-country.

Scientific and Technological Infrastructure

Little or no formal scientific and technological infrastructure.

Substage 1b: First Emergence

(Nepal, Papua New Guinea)

General State of the Economy

Basic infrastructure under construction.
A few well-established parastatals in mining or basic services.

Technological Capacity in Productive Sector

A few enclaves of capacity for choice, operation, and management of technology exist in larger production units in agriculture, in industries connected with natural resources, and in parastatal authorities concerned with infrastructure (telecommunications, highways, power).
Many small and tiny enterprises ingeniously managed in the face of difficult external conditions.
Modern technology for public sector and larger private sector plants is usually operated by foreigners under management contract.

Technology Policy

Macro-economic and trade policy begins to affect scientific and technological development.
Policy focus on vocational training, establishment of universities and basic scientific and technological infrastructure.

Table II-3 (continued)

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Table II-3 (continued)

Substage 1b (continued)

Financing of Science and Technology

Staffs of development banks gaining in experience and competence.
First mechanisms for support to university scientific research.

Human Resources

Basic industrial discipline being established.
Large areas still without contact with modern technology.
Serious manpower shortages at all levels of science and technology: skilled workers, supervisors, managers, engineers (especially civil and agricultural), scientists, primary and secondary school teachers, university faculty.
Universities established, chiefly for training undergraduates.
A few professional disciplines in engineering and agriculture well established.
Most technical graduates work in the government bureaucracy.

Scientific and Technological Infrastructure

Beginnings of research and of scientific and technological infrastructure.

Substage 1c: Islands of Modernization

(Sri Lanka, Tunisia, Jordan, Indonesia)

General State of the Economy

Commercial agriculture well established.
Modern small industry developing.
Industrial exports based on labor-intensive technology growing rapidly from a small base.

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Table II-3 (continued)

Substage 1c (continued)

Technological Capacity in the Productive Sector

Modern technology for public sector and larger private sector plants is imported, mainly as equipment or turnkey plants.
Local civil works construction capability well established.
Reasonable local operating and trouble-shooting skills.
Improved negotiating skills in larger enterprises for extracting concessions from multinational corporations.
Limited export marketing capability. Product specifications and production technology specified by buyers.
Limited information on technological alternatives and overseas market opportunities.

Technology Policy

Economic policy clearly affecting scientific and technological development, but these effects receive little explicit attention.
First laws regarding patents, standards, and technology transfer.

Financing of Science and Technology

Staffs of development banks reasonably competent in reviewing business plans and in economic and financial aspects of project analysis.
Stock exchange begins to operate, but lists only large companies.
No private venture (risk-oriented) capital.
First attempts at coordination of scientific research. Budget still very small.

Table II-3 (continued)

Substage 1c (continued)

Human Resources

Substantial majority of at least the younger male population is literate.
Basic industrial discipline is well established.
Increasing contact with modern technology throughout the country.
Spot shortages of personnel in fields where global demand is high, such as computers and electronics.
Universities well established and their graduates may be of excellent quality.
Rigid institutional structure of universities hampers their efforts to meet the country's changing manpower requirements. Few links with business community.
Shortages or gluts of human resources in other fields, depending on the state of the economy, due to mismatches between the educational system and the labor market. Problems of educated unemployed and brain drain may be severe.
Government requirements for technical manpower are largely satisfied. Technical graduates are open to alternative employment opportunities.

Scientific and Technological Infrastructure

Basic scientific and technological infrastructure is in place, but quality and links to productive sector are usually inadequate.
Non-governmental organizations diffuse low-cost technology with little relation to formal scientific and technological infrastructure.
University-based "small science" is well established although poorly funded. Pockets of excellence exist, usually with international support.
Limited national funding and coordination of research. Few links to the economy.

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Table II-3 (continued)

STAGE 2: STRUGGLE FOR MOBILIZATION AND MASTERY

SALIENT FEATURES

International standards of efficiency, competitiveness.

Technological effort at socially optimum levels in market and non-market sectors.

Technological capacity well-launched for adaptation, innovation, research, and evaluation of past experience.

Technological capacity for selected advanced technologies and technology-intensive industries well established.

Systematic attention to scientific and technological aspects in all sectors in the economy.

Substage 2a: Mastery of Conventional Technology

(Malaysia, Turkey)

General State of the Economy

Manufactured exports continue rapid growth and increase in technological sophistication.

Technological Capacity in Productive Sector

Quality and quality control improving throughout the industrial sector.

Larger industry operates conventional technology competently. Its competence spreads through technical assistance to subcontractors and through movement of technical personnel.

Negotiations with multinational corporations begin to focus on absorption of technology.

Some capacity to adapt technology and product design, and to innovate to meet local needs or maintain competitiveness in changing circumstances.

Improving local capacity to identify export markets and to match product specifications and production technology to them, and to control marketing.

Some limited investment in developing firm-level technological capacity.

Applications of advanced technology beginning, especially in agriculture and manufacturing.

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Table II-3 (continued)

Substage 2a (continued)

Technology Policy

First serious understanding of the impact of economic policy on technological development.
First serious attention to basic policy framework for science and technology.

Financing of Science and Technology

Staffs of development banks reasonably competent at assessing conventional technology.
Stock market assumes larger importance. Beginnings of private risk financing.
Strengthened coordination of funding of scientific research.

Human Resources

Last isolated pockets are linked to the modern economy.
Demand for scientific and technological manpower increases rapidly. Supply may have difficulty in keeping up.
Most science and engineering disciplines well established.
Educational system making first efforts to shake off institutional rigidities and to become more responsive to the needs of the labor market and the business community.

Scientific and Technological Infrastructure

Sectorally specific associations, technical service facilities, and applied research centers established, with varying success.
Consulting and engineering development organizations fairly well developed for design and construction tasks.
Research and research coordination and management improving. Links to productive sector still weak.

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Table II-3 (continued)

Substage 2b: Transition to Newly Industrializing Country

(India, Thailand, Hong Kong)

General State of the Economy

Many manufactured products competitive on world markets. Exports continue to grow.
Transition from family-based to professionally managed companies.
Locally based multinational corporations beginning to form.

Technological Capacity in Productive Sector

Capacity to choose and operate conventional technology fairly general throughout economy.
Capital goods industries, technical services, consulting and engineering development organizations well established.
Local manufactures beginning to be exported under their own brand names.
Some reexport of imported technology.
Reverse engineering well developed. Piracy is a major activity and a source of friction with developed country trade partners.
Substantial local innovation. Occasional world-class innovations.
Negotiating capacity improves, more mature relations with multinationals. "Unpackaging" of foreign technology common.
More extensive applications of advanced technology.
Beginnings of technology transfer from enclaves of offshore manufacture to indigenous industry.
Some research and development within firms. Research and development joint ventures beginning.
Substantial technology transferred to smaller firms through subcontracting, but usually at the end of the product cycle.

Technology Policy

Efforts to integrate technology into economic policies and strategies.
Business well represented in technology policy making.
First attempts at strategic investments in advanced technology.

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Table II-3 (continued)

Financing of Science and Technology

Development and commercial banks increasingly aware of advanced technology.
Stock market increasingly important, and lists many small and medium-sized businesses.
Private financing available for risky businesses, some of them technology-driven.
Specific institutions are established for financing research and innovation.
Scientific research is recognized as an activity important to economic development, and attracts political support and increased funding for this reason.

Human Resources

Improved science teaching. Increased attention to public awareness of science.
Educational system making vigorous efforts to remove remaining restraints and to become quickly responsive to the needs of the economy.
Expatriate scientists, engineers and technical managers beginning to return.

Scientific and Technological Infrastructure

Scientific and technological infrastructure proliferates and its quality improves.
First high-tech spin-offs from universities and public sector laboratories.
Basic science may be excellent, especially in larger countries.
Research increases. Coordination, administration and links to productive sector improve.

Substage 2c: Threshold of Technological Competitiveness

(Singapore, Korea, Taiwan)

General State of Productive Sector

Manufactured exports competitive with developed countries across a wide range of products, although at lower levels of technology and labor productivity.
Wages and labor productivity increasing.

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Table II-3 (continued)

Substage 2c (continued)

Technological Capacity in Productive Sector

Technology is a major contributor to competitiveness in world markets in agriculture and manufacturing.
Major source of technology for other developing countries.
Advanced technology well established in many fields. Some high-technology exports.
Most technology is still of foreign origin, but level of technology being imported rises. Local and imported technology are well integrated.
Research and development in private sector increases, not so much because of government promotion but rather to insure competitiveness.
Piracy and reverse engineering continue, but the economy as a whole has an increasing interest in playing by the rules of the world technology market.
Many local brand names are well accepted on international markets.
Foreign companies sometimes purchased in order to acquire technology or as a window on technological progress.

Technology Policy

Many examples of strategic investments in advanced technology.
Major locus of technology development now shifts to private sector.
Business and government collaborate closely in technology strategy and policy.

Financing of Science and Technology

Stock market well developed.
Risk capital institutions well developed, proliferating and differentiating into niches.

Human Resources

Literacy virtually universal.
Expatriate scientists, engineers and technical managers returning in response to expanded professional opportunities.

Scientific and Technological Infrastructure

Links of public sector infrastructure with productive sector improve in response to increased demand for improved technology.

Table II-4. PROGRESSION THROUGH THE DIFFERENT ASPECTS OF SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT

General State of the Economy

Substage 1a: (Bhutan, Laos)

Basic infrastructure largely lacking.
Effective government influence on economy still minimal.

Substage 1b: (Nepal, Papua New Guinea)

Basic physical infrastructure under construction.
A few well-established parastatals in mining or basic services.

Substage 1c: (Sri Lanka, Tunisia, Jordan, Indonesia)

Commercial agriculture well established.
Modern small industry developing.
Industrial exports based on labor-intensive technology growing rapidly from a small base.

Substage 2a: (Malaysia, Turkey)

Manufactured exports continue rapid growth and increase in technological sophistication.

Substage 2b: (India, Thailand, Hong Kong)

Many manufactured products competitive on world markets. Exports continue to grow.
Transition from family-based to professionally managed companies.
Locally based multinational corporations beginning to form.

Substage 2c: (Korea, Singapore, Taiwan)

Manufactured exports competitive with developed countries across a wide range of products, although at lower levels of technology and labor productivity.
Wages and labor productivity increasing.

Table II-4 (continued)

Technological Capacity in the Productive Sector[1]

Substage 1a: (Bhutan, Laos)

Little technological capacity in productive sector.
The economy is dominated by traditional technology whose rational basis is poorly understood by the user and is sometimes unknown to science.

Substage 1b: (Nepal, Papua New Guinea)

A few enclaves of capacity for choice, operation, and management of technology exist in larger production units in agriculture, in industries connected with natural resources, and in parastatal authorities concerned with infrastructure (telecommunications, highways, power).
Many small and tiny enterprises are ingeniously managed in the face of difficult external conditions.
Modern technology for public sector and larger private sector plants is usually operated by foreigners under management contract.

Substage 1c: (Sri Lanka, Tunisia, Jordan, Indonesia)

Modern technology for public sector and larger private sector plants is imported, mainly as equipment or turnkey plants.
Local civil works construction capability well established.
Reasonable local operating and trouble-shooting skills.
Improved negotiating skills in larger enterprises for extracting concessions from multinational corporations.
Limited export marketing capability. Product specifications and production technology specified by buyers.
Limited information on technological alternatives and overseas market opportunities.

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1. The productive sector is defined here to include both industry and agriculture, whether publicly or privately owned.

Table II-4 (continued)

Technological Capacity in the Productive Sector (continued)

Substage 2a: (Malaysia, Turkey)

- Quality and quality control improving throughout the industrial sector.
- Larger industry operates conventional technology competently. Its competence spreads through technical assistance to subcontractors and through movement of technical personnel.
- Negotiations with multinational corporations beginning to focus on absorption of technology.
- Some capacity to adapt technology and product design, and to innovate to meet local needs or maintain competitiveness in changing circumstances.
- Improving local capacity to identify export markets and to match product specifications and production technology to them, and to control marketing.
- Some limited investment in developing firm-level technological capacity.
- Applications of advanced technology beginning, especially in agriculture and manufacturing.

Substage 2b: (India, Thailand, Hong Kong)

- Capacity to choose and operate conventional technology fairly general throughout economy.
- Capital goods industries, technical services, consulting and engineering development organizations well established.
- Reverse engineering well developed. Piracy is a major activity and a source of friction with developed country trade partners.
- Local manufactures beginning to be exported under their own brand names.
- Some reexport of imported technology.
- Substantial local innovation. Occasional world-class innovations.
- Negotiating capacity improves, more mature relations with multinationals. "Unpackaging" of foreign technology common.
- More extensive applications of advanced technology.
- Beginnings of technology transfer from enclaves of offshore manufacture to indigenous industry.
- Some research and development within firms. Research and development joint ventures beginning.
- Substantial technology transferred to smaller firms through subcontracting, but usually at the end of the product cycle.

Table II-4 (continued)

Technological Capacity in the Productive Sector (continued)

Substage 2c: (Korea, Singapore, Taiwan)

Technology is a major contributor to world competitiveness in agriculture and manufacturing.
Major source of technology for other developing countries.
Advanced technology well established in many fields. Some high-technology exports.
Licensing continues as the major source of foreign technology, but level of technology being imported rises. Local and imported technology are well integrated.
Piracy and reverse engineering continue, but the economy as a whole has an increasing interest in playing by the rules of the world technology market.
Research and development in private sector increases, less from government promotion than to insure competitiveness.
Many local brand names are well accepted on international markets.
Foreign companies sometimes purchased in order to acquire technology or as a window on technological progress.

Technology Policy

Substage 1a: (Bhutan, Laos)

Policy concerns focussed on basic education and services.

Substage 1b: (Nepal, Papua New Guinea)

Macro-economic and trade policy begin to affect scientific and technological development.
Policy focus on vocational training, establishment of universities and basic scientific and technological infrastructure.

Substage 1c: (Sri Lanka, Tunisia, Jordan, Indonesia)

Economic policy clearly affecting scientific and technological development, but these effects receive little explicit attention.
First laws regarding patents, standards, and technology transfer.

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Table II-4 (continued)

Technology Policy (continued)

Substage 2a: (Malaysia, Turkey)

First serious understanding of the impact of economic policy on technological development.

First serious attention to basic policy framework for science and technology.

Substage 2b: (India, Thailand, Hong Kong)

Efforts to integrate technology into economic policies and strategies.
Business well represented in technology policy making.
First attempts at strategic investments in advanced technology.

Substage 2c: (Korea, Singapore, Taiwan)

Many examples of strategic investments in advanced technology.
Major locus of technology development shifts to private sector.
Business and government collaborate closely in technology strategy and policy.

Financing of Science and Technology

Substage 1a: (Bhutan, Laos)

First development banks established.

Substage 1b: (Nepal, Papua New Guinea)

Staffs of development banks gaining experience and competence.
First mechanisms for support to university scientific research.

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Table II-4 (continued)

Substage 1c: (Sri Lanka, Tunisia, Jordan, Indonesia)

Staffs of development banks reasonably competent in reviewing business plans and in economic and financial aspects of project analysis.
Stock exchange begins to operate, but lists only large companies.
No private venture (risk-oriented) capital.
First attempts at coordination of scientific research. Budget still very small.

Substage 2a: (Malaysia, Turkey)

Staffs of development banks reasonably competent at assessing conventional technology.
Stock market assumes larger importance. Beginnings of private risk financing.
Strengthened coordination of funding of scientific research.

Substage 2b: (India, Thailand, Hong Kong)

Development and commercial banks increasingly aware of advanced technology.
Stock market increasingly important, and lists many small and medium-sized businesses.
Private financing available for risky businesses, some of them technology-driven.
Specific institutions are established for financing research and innovation in industry.
Scientific research attracts political support and increased funding.

Substage 2c: (Korea, Singapore, Taiwan)

Stock market well developed.
Risk capital institutions well developed, proliferating and differentiating into niches.

<u>Human Resources</u>

Substage 1a: (Bhutan, Laos)

Low literacy rates, few highly trained manpower.
Little experience with modern production technology.
Pre-scientific world-view in most of the population.
No higher education or research in-country.

Table II-4 (continued)

Human Resources (continued)

Substage 1b: (Nepal, Papua New Guinea)

Basic industrial discipline being established.
Large areas still without contact with modern technology.
Serious manpower shortages at all levels of science and technology: skilled workers, supervisors, managers, engineers (especially civil and agricultural), scientists, primary and secondary school teachers, university faculty.
Universities established, chiefly for training undergraduates.
A few professional disciplines in engineering and agriculture well established.
Most technical graduates work in the government bureaucracy.

Human Resources (continued)

Substage 1c: (Sri Lanka, Tunisia, Jordan, Indonesia)

Substantial majority of at least the younger male population is literate.
Basic industrial discipline is well established.
Increasing contact with modern technology throughout the country.
Spot shortages of personnel in fields where global demand is high, such as computers and electronics.
Universities well established and their graduates may be of excellent quality.
Rigid institutional structure of universities hampers their efforts to meet the country's changing manpower requirements. Few links with business community.
Shortages or gluts of human resources in other fields, depending on the state of the economy, due to mismatches between the educational system and the labor market. Problems of educated unemployed and brain drain may be severe.
Government requirements for technical manpower largely satisfied. Technical graduates open to alternative employment opportunities.

Substage 2a: (Malaysia, Turkey)

Last isolated pockets are linked to the modern economy.
Demand for scientific and technological manpower increases rapidly. Supply may have difficulty in keeping up.
Most science and engineering disciplines well established.
Educational system making first efforts to shake off institutional rigidities and to become more responsive to the needs of business and the labor market.

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Table II-4 (continued)

Human Resources (continued)

Substage 2b: (India, Thailand, Hong Kong)

Improved science teaching. Increased attention to public awareness of science.
Educational system making vigorous efforts to remove remaining restraints and to become quickly responsive to the needs of the economy.
Expatriate scientists, engineers and technical managers beginning to return.

Substage 2c: (Korea, Singapore, Taiwan)

Literacy virtually universal.
Expatriate scientists, engineers and technical managers returning in response to expanded professional opportunities.

Scientific and Technological Infrastructure

Substage 1a: (Bhutan, Laos)

Little or no formal scientific and technological infrastructure.

Substage 1b: (Nepal, Papua New Guinea)

Beginnings of research and of scientific and technological infrastructure.

Substage 1c: (Sri Lanka, Tunisia, Jordan, Indonesia)

Basic scientific and technological infrastructure in place, but quality and links to productive sector usually inadequate.
Non-governmental organizations diffusing low-cost technology with little relation to formal scientific and technological infrastructure.
University-based "small science" well established although poorly funded. Pockets of excellence exist, usually with international support.
Limited national funding and coordination of research. Few links to the economy.

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Table II-4 (continued)

Scientific and Technological Infrastructure

Substage 2a: (Malaysia, Turkey)

Sectorally specific associations, technical service facilities, and applied research centers established, with varying success.
Consulting and engineering development organizations fairly well developed for design and construction tasks.
Research and research coordination and management increasing. Links to productive sector still weak.

Substage 2b: (India, Thailand, Hong Kong)

Scientific and technological infrastructure proliferates and its quality improves.
First high-tech spin-offs from universities and public sector laboratories.
Basic science may be excellent, especially in larger countries.
Research increases. Coordination, administration and links to productive sector improve.

Substage 2c: (Korea, Singapore, Taiwan)

Links of public sector infrastructure with productive sector improve in response to increased demand for improved technology.

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TABLE II-5: QUANTITATIVE INDICATORS OF SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT

General State of the Economy

General Economic Environment

Overview of Economy

GNP per capita
Composition of GDP by subsector
Composition of employment by subsector
Composition of exports by subsector
Contribution of public sector enterprises (by subsector)
Workers' remittances and foreign aid as a % of GNP
Raw materials export as % of GNP
Distribution of farm and firm sizes
Foreign direct investment

Recent Economic History

Growth rate of GDP
Debt burden (as % of exports)
Growth of manufactured exports
Terms of trade

Physical Infrastructure

Km of roads
% of population within 1 day's walk of a road
Vehicles per capita
Telephones per capita
Energy consumption per capita
Radios, televisions and libraries per capita

Equity and Quality of Life

Literacy
Life expectancy
Infant mortality
% Access to safe water
Unemployment
Income distribution
Regional terms of trade

Economic Geography

Area
Population
Natural resources reserves
Natural resources exports (including tourism)

Table II-5 (continued)

Economic Policy Environment

Conversion factor for foreign exchange
Index of distortion of interest rates
Index of distortion of prices of major industrial raw materials (steel, cement, energy)
Index of distortion of major agricultural inputs (fertilizer, pesticides, irrigation water)
Index of distortion of farm gate prices of food crops
Terms of trade among major sectors
Levels of effective protection by subsector

Technological Capacity in the Productive Sector[1]

Composition of industrial and agricultural exports
Destination of manufactured exports
Imports and exports of technical services and technology
Survey of experiences of foreign investors and technical partners
Survey of level of technical capacity of firms
Contribution to GDP of capital goods and technical service industries
Census of businesses spun off from offshore manufacturers
Total factor productivity in agriculture and industry
Number and types of computers in different sectors of the economy
Research and development spending in the productive sector
National and international patents and trademarks of domestic origin

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1. The productive sector is defined here to include both industry and agriculture, whether publicly or privately owned.

Table II-5 (continued)

Technology Policy

- Practical effectiveness of national economic policies in determining prices and incentives at the firm level
- Number and qualifications of policy-makers in government, academe, and the banking and business communities who are trained in technology policy and are working in that field
- Public statements and published official policies regarding the importance and objectives of national science and technology policy; existence of an explicit plan for science and technology development
- Existence, size and reputation of technology policy units in line ministries and in planning or other cross-cutting agency, and of non-governmental institutes doing research, analysis and training in this area
- Existence of a body of law and policy explicitly directed towards the promotion of scientific and technological development
- Existence of policies and programs addressed to the technological problems of poor and disadvantaged people

Financing of Science and Technology

- Research and development budget for current and capital expenditure in the productive sector, by field of specialization and by sector
- Budget for research in academic and free-standing research institutions, by source, by field of specialization, by sector, and by major socio-economic objective
- Investment available for technologically oriented business ventures at various levels of technology and risk, and for a range of firm size
- Expenditures on "technological effort" other than research: assessment, choice and acquisition of technology, mastery, adaptation, evaluation, etc.

Human Resources

- Literacy rate
- Student enrollment at various levels
- Teachers per thousand population at various levels by field of specialization, by degree of qualification, with age distribution
- Performance of students and graduates in international tests, and in admissions to foreign universities
- Percentage of work force employed in the formal sector
- Scientists and engineers employed in a technical, managerial or research capacity, by level of qualification, by field of specialization and by sector
- Numbers of scientists and engineers and trained managers leaving and returning to the country

Table II-5 (continued)

Scientific and Technological Institutions, Services, and Research

Number, size and sectoral and disciplinary coverage of scientific and technological institutions and services

Proportion of their income due to fees for client services.

Number of publications, and their quality as indicated by citations in overseas scientific journals

Peer recognition in international scientific and technological community (prizes, invitations to speak at international conferences or visit overseas laboratories, membership in advisory panels, editorial boards, and academies)

Proportion of research and technical services on problems of small industry and on social and environmental problems, especially of the poor and disadvantaged

Table II-6: CONSTRAINTS AND POLICY MEASURES
AT DIFFERENT STAGES OF SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT

Stage I: "Emerging Islands of Modernization"

CONSTRAINTS

People

Lack of experience and understanding of science and technology among the work force.

Shortage of engineers, technical managers, teachers, skilled workers, and technologically oriented policy makers

Scientific and Technological Capability in the Productive Sector

Insufficient technological capacity and technological effort, especially for assessment of needs and resources, for choice, operation, and management of technology, and for negotiations with multinationals, in larger industrial, energy, and parastatal agricultural organizations

Inadequate attention by small and medium industry to quality, quality control, and efficiency in use of resources, in part due to lack of availability of technological information, services, and technical advice

Institutional Capability

Inadequate capability for operation and management of basic social services (education, health, nutrition); insufficient or misdirected technological effort in these sectors

Basic scientific and technological infrastructure lacking or poorly managed and funded; little capacity for research or innovation

Inability of financial institutions to assess technology

Technology

Inadequate supply of improved technology suited to local conditions for small-scale agriculture, especially in rainfed areas, for low-cost infrastructure and services, such as health delivery systems, shelter and sanitation, and for the treatment and cure of poverty-oriented disease

Technology Policy

Lack of price signals or other incentives for efficient resources use, technological effort, efficient management

Inattention to scientific and technological aspects of non-market, social, environmental problems

Table II-6 (continued)

Stage I (continued)

STRATEGY

Build human resources, basic scientific and technological infrastructure, scientific and technological education at all levels, public awareness of science and technology.

Ensure links between scientific and technological institutions and economy

Be careful not to discourage or misdirect technological effort by discriminating against small-scale production, distorting prices, over-regulating, insulating against market pressure, political interference with parastatals

Achieve enclaves of competence in infrastructure and large-scale industry for choice and operation of technology through systematic attention to training and technology transfer

Encourage research and technological effort in a few critical areas, such as agriculture and environment, where imported technology is unavailable or if an outstanding researcher is in place

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Stage II: "Mastery of Conventional Technology,"

CONSTRAINTS

Institutional Capacity

Lack of capacity in financial institutions to assess innovative and advanced technology

Lack of regional infrastructure to provide technological information, technical assistance and research services to outlying or otherwise disadvantaged areas and populations

Table II-6 (continued)

Stage II (continued)

Constraints (continued)

Scientific and Technological Capacity in the Productive Sector

Insufficient capacity for research management and for intelligence gathering, assessment, and negotiations on the acquisition of technology from overseas suppliers

Untapped possibilities for technological imports

Deficiencies in product design and manufacturing technology, as compared to demands of export markets

Shortage of technological capacity in frontier technology

* Insufficient innovation in product design and manufacturing technology to keep up with the demands of world markets and the increased capabilities of overseas competitors, and to make up for the increasing reluctance of competitors to license technology

Insufficient investment in firm-level technological capacity

Technology Policy

Economic policies encourage non-competitive industry, and do not provide incentives for efficiency in management and resources use, technological effort, innovation

Scientific and technological development uneven across sectors and regions

Need for balance between advanced vs. "appropriate," imported vs. indigenous technology

Inadequate investment in technology and technological capacity for dealing with remaining problems connected with poverty and with other pressing social concerns, such as environment, worker health and safety, traffic safety, etc.

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* Stage 2c only

Table II-6 (continued)

Stage II (continued)

STRATEGY

Integrate economic and technological policy and plans

Encourage (or at least remove obstacles to) technological effort, efficient resource use and building of local technological capacity

Improve quality of scientific and technological education

Complete scientific and technological infrastructure and ensure its orientation to practical problems

Develop capital goods, technical services and essential inputs industries

Launch selected advanced technologies and technology-intensive sectors

Catalyze and promote research, development, and innovation across the economy in both public and private sectors

Address the scientific and technological aspects of social, non-market, environmental problems

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Table II-7: HUMAN RESOURCES FOR SCIENCE AND TECHNOLOGY FOR SRI LANKA AND THAILAND

	Sri Lanka	Thailand
S&T Personnel per 1000 Population		
Engineers	0.24	2.21
R&D Engineers	0.02	0.32
Scientists	0.19	1.31
R&D Scientists	0.09	0.30
Technicians	0.19	5.98
R&D Technicians	0.04	0.80
S&T Personnel by Sector of Performance		
Engineers		
% in Production Sector	38.2	49.0
% in Higher Education	4.1	26.6
% in General Service Sector	57.7	24.4
Scientists		
% in Production Sector	24.6	59.7
% in Higher Education Sector	19.3	19.8
% in General Service Sector	56.1	20.5
Qualification Profile		
Engineers		
% Bachelor level	89.1	84.3
% Masters or comparable	9.1	13.7
% Doctoral degree	1.8	2.0
Scientists		
% Bachelor level	72.6	67.8
% Masters or comparable	15.2	26.9
% Doctoral degree	12.2	5.3

Table IV-1: POSSIBLE AID INTERVENTIONS IN SUPPORT OF INDIGENOUS SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT

I. Scientific and technological capability in the productive sector:

Stage 1.

Encouraging the improvement of technology in existing industry by improving access to information on markets and technology, and to technical assistance on management, quality, quality control, and marketing.

Providing access to information and technical assistance for improved decisions on investments, and on prospects for opening new lines of business, especially in expanding export markets.

Stage 2.

Encourage the development of improved products and processes, especially through improved links with US companies.

II. Technology policy:

Stage 1.

Training and awareness building on the need, and assistance to building of the capacity, for market-oriented policy studies and research inside or outside the government.

Assistance to academic disciplines important to technology policy, especially technology management and industrial economics. In economies in need of structural adjustment, these activities offer excellent opportunities to build relations with the US academic community and at the same time to stimulate a change in attitude among intellectuals regarding the market-oriented economy.

Stage 2.

Collaboration in specific studies of issues related to technology policy, such as the future division of labor in specific industries.

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Table IV-1: Possible AID interventions (continued)

III. Financing of science and technology: Identifying and relieving constraints on technological development and innovation caused by imperfections in capital market.

Stage 1. Technical assistance to development banks in assessing technology.

Stage 2. Encouragement of new sources of technologically oriented risk capital.

IV. Human resources:

Stage 1.

Technical assistance to universities to improve responsiveness to labor markets and to business and social needs.

Increasing the exposure to the US educational system as a possible model for reform.

Technical assistance on university and secondary school curricula.

Assistance to the popular understanding of science and technology through museums, science fairs, and the mass media.

Stage 2.

Assistance and collaboration with US scientists in key fields of science and technology.

V. Scientific and technological infrastructure:

Stage 1.

Help launch institutions in key areas through grants of equipment and technical assistance, e.g. to sectoral service centers, standards institutes, natural resources surveys, science parks, etc.

Help establish market-oriented technical services to industry in collaboration with the productive sector.

Help reorient stagnant existing institutions towards client needs.

Stage 2.

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Encourage bilateral relationships with corresponding US institutions at federal or state levels.

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