Managing Technological Development

Lessons from the Newly Industrializing Countries

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Abstract

This survey, written in language untrammeled by technical words and concepts, looks at the technological development of the newly industrializing countries to draw some important lessons for firms and governments in other developing countries.

The main lessons are clear. First, inventing products and processes is not at the center of the technological development needed for successful industrialization. It is at the fringe. What is at the center is acquiring the capabilities needed for efficient production and investment. Second, some countries have overemphasized the drive for technological self-sufficiency and paid a high price in poor productivity. What makes the best economic sense is to combine foreign and local technological elements -- and to do this in a way that progressively develops local capabilities in areas where they can be more efficient. Third, the acquisition of technological capability does not come merely from experience, though experience is important. It comes from conscious efforts -- to monitor what is being done, to try new things, to keep track of developments throughout the world, to accumulate added skills, and to increase the ability to respond to new pressures and opportunities. Fourth, the economic environment, through its influence on the technological efforts of firms, is very important in determining the productivity of a country's resources. The environment is shaped by the incentives and penalties that affect the way firms use and adapt technology. It is also shaped by the activities of specialized technological agents that can provide technological information, means, and understanding to firms.
Cette étude, écrite dans une langue dépouillée de termes et de concepts techniques, examine le développement technologique des pays en voie d'industrialisation pour en tirer certaines leçons importantes pour les firmes et les gouvernements d'autres pays en développement.

Ces leçons sont claires. Premièrement, le progrès technologique indispensable à une industrialisation réussie n'est pas axé sur l'invention de produits et de procédés, laquelle n'est que d'importance marginale. Il est axé sur l'acquisition des moyens nécessaires pour produire et investir efficacement. Deuxièmement, certains pays ont accordé trop d'importance à l'autonomie technologique et leur productivité s'en est trouvée réduite. La stratégie la plus valable du point de vue économique consiste à combiner les éléments technologiques étrangers et locaux, et ce de manière à développer progressivement les compétences locales dans les domaines où elles peuvent être efficaces. Troisièmement, l'acquisition de compétences ne vient pas seulement de l'expérience, bien que l'expérience ne soit pas négligeable. Elle vient d'efforts consciemment déployés sur plusieurs fronts : suivre ce qui se fait, expérimenter, se tenir au courant des progrès réalisés dans le monde, accumuler de nouvelles connaissances, et s'adapter plus facilement aux pressions et occasions nouvelles. Quatrièmement, l'environnement économique d'un pays est très
important lorsqu'il s'agit d'évaluer la productivité des ressources d'un pays d'après son influence sur les efforts technologiques des firmes. Or, l'environnement est déterminé par les stimulants et sanctions qui influencent la façon dont les firmes utilisent et adaptent la technologie. Il est également déterminé par les activités d'agents technologiques spécialisés qui peuvent fournir aux firmes des renseignements, des moyens et des connaissances.
Extracto

En este estudio, escrito en lenguaje exento de vocabulario y conceptos técnicos, se examinan los avances tecnológicos de los países de reciente industrialización a fin de extraer algunas enseñanzas importantes para las empresas y los gobiernos de otros países en desarrollo.

Las principales enseñanzas son claras: en primer lugar, la invención de productos y procesos no está en el centro del desarrollo tecnológico necesario para el éxito de la industrialización, sino más bien en la periferia. Lo fundamental es la adquisición de capacidades necesarias para la producción y la inversión eficientes. En segundo término, algunos países han dado excesiva importancia al impulso de la autosuficiencia tecnológica y han pagado un alto precio en productividad deficiente. Lo que tiene mejor sentido económico es combinar los elementos tecnológicos extranjeros y nacionales y hacerlo de manera que progresivamente se formen capacidades locales en esferas donde pueden resultar más eficientes. En tercer lugar, la adquisición de capacidades no proviene solamente de la experiencia, aunque ésta es importante. Proviene de esfuerzos conscientes para supervisar lo que se hace, probar cosas nuevas, mantenerse informado sobre los adelantos en todo el mundo, acumular mayores conocimientos y aumentar la capacidad para reaccionar ante nuevas presiones y oportunidades. En cuarto término, el ambiente económico es muy importante para determinar la productividad de los recursos de un país a través de su influencia en los esfuerzos tecnológicos de las empresas. El ambiente está conformado por los incentivos y sanciones que afectan a la manera como las empresas utilizan la tecnología y se adaptan a ella. También está conformado por las actividades de los agentes tecnológicos especializados que pueden proporcionar información, medios y comprensión de la tecnología a las empresas.
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Summary

In this paper we draw on the experience of developing countries to summarize some general lessons about what is important in managing their technological development.

First, we describe the technological development of an archetypical successful firm, and we use that description to introduce basic concepts. We define technology as a method for transforming inputs into products. We disaggregate technology into three basic elements: information about the method, means of using the method to undertake the transformation, and understanding how and why the method works. We also distinguish three kinds of technological capability -- that in production, investment, and innovation. And we distinguish changes that modify existing technology and those that introduce radically new technology.

Second, we describe the steps firms must take in choosing technology. One of the most important steps is identifying local needs and constraints at the outset -- to establish the framework for assessing technology. Another important step is collecting information to broaden the field of technologies that might be brought to bear on each technological problem. However obvious these steps may seem, they are frequently bypassed, with costly consequences. The third step is to evaluate the benefits and costs of different choices of technology. The fourth is to assess the technological paths opened by each choice -- and to incorporate these dynamic considerations with conventional benefit-cost analysis. These steps should be followed whenever decisions are to be made about upgrading technology, scrapping technology, or establishing new production.

Third, we describe how firms (and countries) augment their technological capability. Experience in production is generally needed to know what makes sense in expansions and new plants. Experience in production and investment is generally needed to know what is wanted and what is possible in the way of new products and processes. Acquiring this experience is not automatic, however. Nor is it rapid and effortless. It takes conscious efforts over a long period of time. Which of the many capabilities needed in production, investment, and innovation should producing firms develop? The
ones they will use all or most of the time. The others should be obtained from specialized repositories of those capabilities. If such repositories do not exist in the country and if the size of the market warrants, they should be created, relying on foreign repositories in the meantime. The idea is to use foreign repositories to complement domestic repositories and to develop domestic repositories when it makes sense.

Fourth, we describe what is involved in combining foreign and domestic technological elements -- that is, in combining foreign and domestic information, means, and understanding. Sometimes it makes sense for a country to expend the effort and take the time to develop all the technological elements needed, whether to upgrade existing production or to establish new ventures. Other times it makes sense to buy some of those technological elements overseas. But more important than deciding whether to rely on foreign or local sources for a given element of a technological package is deciding which combination of foreign and local elements can do the most to help a firm progress faster and more efficiently along its optimum technological path. The key is choosing packages that do the most to develop local capabilities in production, in investment, and in innovation -- and to do this in the most effective sequence.

In discussing ways to determine the best combination of foreign and domestic technological elements, we assess the efficacy of different transactions for acquiring foreign technology. We begin by spelling out the conventional wisdom about the advantages and disadvantages of licensing, purchasing capital goods, entering joint ventures, allowing multinationals to establish wholly owned subsidiaries, and contracting for technical assistance and technical services. Because the arguments surrounding these transactions are well known, the discussion moves quickly from comparing transactions to examining what is possible within each transactional mode. The key point is that the technological benefits to developing countries depend less on the mode selected, more on how the mode is implemented. It is possible, for example, to get more experience from a turnkey project with a big training component than from purchasing the various technological elements separately. It also is possible to find one supplier that will transfer much more information under a technical agreement than another. The transactional
mode thus determines only the structure for a transfer. Within that structure, there is much room for maneuvering. That is why countries should avoid blanket policies for or against various transactional modes. To be pursued instead is knowing how to get the most from each transfer, whatever the mode. To be pursued is using the transfer as a stepping stone to exploit the opportunities further along a technological path.

Fifth, we assert that the environment is crucially important for the technological efforts of firms. What is wanted is to have all firms engaging in purposive technological effort to increase their productivity -- effort to use existing capabilities and acquire new ones in ways that improve technology and the use of technology. There are three main elements in the environment for technological change. The first is the system of incentives and penalties that encourage producing firms to improve their technology and the way they use it -- and that induce specialized technological agents to develop and interact. The second is the array of specialized technological agents that promote the flow of technological information, means, and understanding to firms. The third is the intervention by government when markets fail. If the environment is wrong, firms and other technological agents in a country will soon face technological deadends characterized by low productivity. If the environment is right, those enterprises can stride along a path of technological progress that continually increases the productivity of the country's resources.

The focus here on technological effort and change should not be construed, however, as advocating efforts for effort's sake, or change for change's sake. The focus should be construed as advocating effort and change that make economic sense, for a firm and for a country.
Managing Technological Development

The technological problems of a developing country can be broadly summarized in a few questions. How, where, and at what cost should it acquire the technology it needs and accumulate the capabilities to use the technology effectively? How is that technology and technological capability to be diffused? And how best can it use the technology it already has? Each question applies to the full range of production, to all cells of an input-output table.

The questions seem remarkably straightforward. But they are far more complicated than they appear on the surface, for each implies an array of subsidiary questions that introduce time and the interdependence of products and processes -- questions that imply planned, ad hoc, or natural sequences. Which products should a developing country produce now, which later? Put differently: Which products does it have to produce now if it is to produce other products now and in the future? Which elements of technology does it need to acquire now, which later? Which capabilities does it need in production, investment, and innovation to use the technology effectively, both now and later? And what agents should supply those elements and capabilities at various stages of technological development?

Finding general answers to these questions is not easy because there are so many products, so many technologies, so many elements of technology and technological capability, and so many technological agents. One firm might be internationally competitive in one product, but not in others. Other firms might be fast on the heels of the leader, while the rest fall farther and
farther behind. One sector might be technologically advanced; all others, technologically immature. For each product in each country, then, the range of technological combinations is considerable. It nevertheless is possible to draw some important lessons from the experience of developing countries.

In the first section of this paper we describe the technological development of an archetypical successful firm, and we use that description to introduce some basic concepts. In the second we describe the steps firms must take in selecting new technological paths. In the third we describe how firms and countries augment their technological capability -- in production, investment, and innovation. In the fourth we describe what is involved in combining foreign and domestic technological elements: that is, in combining foreign and domestic technological information, means, and understanding. In the fifth we describe the main elements of the environment for technological change. We conclude by asserting that what is most important is an environment that stimulates firms and specialized technological agents to engage in ongoing technological efforts and to develop added technological capabilities -- efforts and capabilities that improve productivity and overall economic performance.

Technology and Technological Capability

To introduce the basic concepts developed in this paper, we describe the technological development of an archetypical successful firm. The firm (Usiminas) is an integrated steel producer in a developing country (Brazil), but many of the characteristics that make it successful are the same in other
The firm got its start in the late 1950s because local entrepreneurs and authorities wanted to establish a large integrated steel plant to obtain greater value added from the country's abundant iron ore exports. But they had neither the technology nor the experience for setting up and operating such a plant. So they commissioned feasibility studies and sent teams to visit foreign steel plants and get first-hand experience of different processes and equipment. They also solicited offers from foreign producers of different technologies for electric arc and basic oxygen steel-making -- in modes ranging from direct foreign investment and turnkey projects to individual licensing and technical assistance. Then they chose a coke-based, basic-oxygen, blast-furnace process and entered a joint venture with a consortium of thirty Japanese steel makers and steel-equipment suppliers. They felt that the direct involvement of foreigners would give them access to extensive experience in steel production. The foreigners agreed to give them full responsibility for the plant after developing enough capability to operate it. The foreigners also arranged very favorable export credits for steel-making equipment.

The foreigners did the engineering and project management for establishing the plant, but the locals worked closely with them from the beginning. This proved to be an excellent way of learning many aspects of the design, equipment selection, installation, construction, start-up, and operation of the plant. There was also extensive training in Japan, including hands-on operational experience with blast furnaces, basic oxygen converters, and rolling mills similar to those that would be used in Brazil.

The start-up and initial operation of the plant was not as smooth as
hoped, however. Although there had been detailed studies of local ores to determine the specifications for the equipment to be used, the source of ore had to be changed after the plant was built because of transportation bottlenecks. The foreigners also had problems transplanting their administrative structure from a large plant at home to a smaller one in a setting with fewer experienced technical personnel and less-skilled workers. To remedy this, the locals hired a specialized foreign management consulting firm to recommend a new administrative structure. That new structure was put in place when the locals took over administrative and operational control of the firm. The reorganization also included introducing a line-staff system of administration and creating departments for testing, metallurgy, quality control, and industrial engineering to strengthen local production capability.

The changeover in operational responsibility -- after three years of technical training and production experience under the foreigners -- occurred in the midst of a financial crisis due to a severe recession in steel demand. The only way the firm could break even was to expand its production to get better use of its rolling section, which had been overdimensioned (because of scale economies) in anticipation of future expansions. But because of the financial crisis, the firm could not obtain funds for the expansion. This forced it to stretch the capacity of its blast furnace and steel-making sections in order to improve its overall capital-output ratio and cash flow. Over the ensuing six years the capacity of those sections was more than doubled, with almost no additional investment in equipment.

Several efforts by the firm's technical and engineering personnel made this capacity-stretching possible. They found better ways of selecting the chemical and physical characteristics of ores and of controlling and
homogenizing raw materials. They improved the operating procedures of the iron and steel-making sections to increase the service life of the refractories and make the most use of the volume of the furnaces. They grafted some technological advances in auxiliary equipment and operating procedures onto existing equipment. For example, they changed the type of oxygen lance used in basic oxygen converting to inject more oxygen with greater control and reduce the cycle time of each heat. And they put strong emphasis on increasing the quality of the steel produced as a way of differentiating the plant's output from that of competitors in the saturated market. Various new special steels, such as thick ship-plate, were introduced through licensing and technical assistance contracts.

A key element in the firm's capacity-stretching phase was the implementation of a standard time and cost system to monitor performance and compare it with best world practice. The strategy, once the basic production capability had been acquired under the guidance of the foreigners, was to move beyond the cookbook phase to study what was behind the recipes and how to make the most of the ingredients. The monitoring system helped break the recipes into their basic ingredients so that the ingredients could be studied independently to see how they fit together. The output of blast furnaces, rolling mills, and other equipment was compared with that of similar equipment used in other plants throughout the world to learn where the firm was behind and where improvements could be made. This required the expansion and specialization of the internal technical support infrastructure which included various engineering departments and the development of a new department to obtain information on equipment and performance of other plants and on new developments in the technological frontier. The firm carefully studied the
advantages and disadvantages of its equipment and operating procedures, not just from what the manufacturers had suggested, but from experience. In addition, plant personnel were sent abroad for courses and practical experience in specific problem areas, such as testing, quality control, preventive maintenance, and optimal control of steelmaking and rolling.

As the plant's specialized personnel gained more understanding of steel production, they continued to make minor adaptations of the equipment to obtain the maximum performance from the initial plant. This called for more technical support and led to the creation of a research center in the firm. This center, established eight years after the plant's start-up, initially focused only on technical support activities. The staff of the center studied raw materials to improve their use in blast furnaces. They studied the metallurgical factors affecting yield and quality. And they studied the structural characteristics of steel to solve some problems their customers were having. For example, the analysis of why Volkswagen was having problems making paint stick to steel sheet led to successful modifications of Volkswagen's painting processes. As they accumulated more experience and solved the more pressing operational problems, they gradually moved into applied product and process research, some of which led to the development of new products and processes patented locally and abroad. For example, they patented a process for the use of coke-oven gas in the direct reduction of iron ore to iron.

After the first expansion phase, based on stretching the capacity of the original plant, the firm undertook a series of investments in new plant and equipment. These investments tripled its capacity when the market was once again booming. The firm first did an intermediate expansion, in which
its personnel again worked very closely with foreign technical advisers to learn the intricacies of designing an expansion, selecting the new technology to be used, specifying the equipment, calling for bids, choosing the winner, negotiating the details of the specifications, and controlling all the work of installation and start-up. To do this work the firm expanded its engineering staff specializing in plant expansion and the design and procurement of capital goods. These staff did about a third of the engineering for the expansion.

By the end of this intermediate expansion, the firm had the capability to do all the engineering for its next expansion more cheaply than if it had relied on foreigners (although it still had the plans reviewed by foreign specialists as a precautionary measure). It could scan the world technological frontier and draw up its own specifications for what it wanted to purchase. It could take advantage of its accumulated experience in the local environment to specify what special characteristics should be embodied into the new equipment units to be purchased. Equipment was bought from suppliers in many countries, not just Japan, and from local companies that had received technical assistance from the firm in the specification and design of the equipment required. In fact, the firm eventually spun off the part of its engineering department as a subsidiary to manufacture capital goods for the steel industry. The parent firm has also provided engineering and technical assistance services for the design and installation of a new steel firm in the country, in much the same way that these services had originally been provided to it by foreigners. Furthermore, it has started exporting technical services to neighboring countries, including training in how to set up and operate a research department.
This description shows that successful technological development depends on a long-term effort to build systematically on foreign technological inputs and on accumulated experience. The first phase of this process involved accepting the practices and advice given by the foreigners in the initial design and operation of the plant. As understanding of the technological package increased through production experience, the firm passed from the stage of knowing how to operate the plant to analyzing the contents of the package. Having learned by doing, having made modifications, and having evaluated its experience and the performance of others, it entered the more difficult stage of studying and understanding different elements of its technology in order to pinpoint its deficiencies and to correct them. This involved additional specialization and foreign training, the purchase of more specifically focused foreign technical assistance, and the creation and expansion of the research center.

Although the process involved much foreign technical assistance, the firm assimilated the technology purchased at each stage, built on it, and progressively moved the type and nature of assistance received to higher and more specific levels. By developing its technological capability and its base of information about what was available at the world technological frontier, the firm learned what technology it could use, how it could obtain the technology effectively, and how to obtain from outsiders what it could not do efficiently itself. After operating for twenty years and achieving considerable capability in production and investment, the firm has moved beyond importing and adapting foreign technology to developing some capability in creating new techniques, new processes, and new products. It thus exemplifies what can be accomplished by following a long-term strategy of
consciously building on foreign technological elements and accumulated experience -- and of investing in the development of the human infrastructure to undertake technological efforts that have a high return.

This description of the technological development of Usiminas also shows that technology is not simply a product to be bought and sold. It is a method for doing something, and using that method requires three things: information about the method, the means of carrying out the method, and some understanding of the method. Moreover, the term, technology, refers to more than just the physical processes that transform inputs into outputs and the specifications for those inputs and outputs. The term also refers to the procedural and organizational arrangements for carrying out the transformations.

The description of Usiminas's technological development shows, in addition, that capabilities needed to acquire, assimilate, use, adapt, change, or create technology can be placed in three categories -- production, investment, and innovation. Production capability is needed to operate productive facilities. It is reflected in productive efficiency and in the ability to adapt operations to changing market circumstances. Investment capability is needed to establish new productive facilities and expand existing facilities. It is reflected in project costs and in the ability to tailor project designs to suit the circumstance of the investment. Innovation capability is needed to create new technology. It is reflected in the ability to improve technology or to develop new products or services that better meet specific needs. Each category has many subsidiary capabilities, involving information, means, and understanding. Moreover, the different capabilities often interact in ways that make them indistinguishable. For example, the
capacity-stretching at Usiminas involved all three capabilities, not just production capability, with each contributing to and benefiting from the others. The change in administrative structure and the introduction of the system for controlling raw materials reflected and enabled increasing production capability. The installation of the new oxygen lance and the carrying out of other modifications reflected and enabled increasing investment capability -- and increasing innovation capability.

The description of the technological development of Usiminas shows, above all, that a firm (or country) does not need everything -- in technology or in technological capability -- to expand and modernize its industrial production. For example, a firm can use outside consultants to trouble shoot, buy licenses to move nearer the world technological frontier, and import equipment until the capability to produce capital goods is developed locally. It thus is possible to start only with the barest production capability and, with that as foundation, to build increasingly the base of other technological capabilities. Doing this takes time -- it is matter of decades, not years. Doing this follows a sequence -- it generally starts with production capability and proceeds to investment and innovation capability. Doing this is not inevitable -- it hinges on the allocation of resources to systematic efforts to develop increased capabilities. And doing this makes sense not for its own sake but only to the extent that the benefits exceed the costs.

Assessing Technology

When firms choose technology, they choose more than a method for making
something at expected costs, benefits, and engineering norms. They also choose the capabilities they can acquire from experience with the technology -- capabilities that would enable them to move on to new activities or that could be used elsewhere in the economy. Different technologies also afford different possibilities for subsequent adaptations and improvements -- possibilities that enable the firm to increase its productivity. Taking these considerations into account is as important as examining the more conventional static criteria of costs and benefits when deciding which technologies to choose, which to abandon, which to upgrade, which to replace by newer technologies. Properly assessing and choosing new technology thus require substantial effort.

The first step in selecting technology or technological elements -- whether to upgrade existing production or to establish new lines of production -- is to identify local needs and conditions. Doing this is essential in developing countries, where the needs and conditions are very different from those in the developed countries, where much technology comes from. These differences in needs and conditions often mean, moreover, that the technology transferred from developed countries has to be adapted considerably for use in developing countries. The identification of local needs and conditions is important, then, in establishing the framework for assessing technology. Without such a framework, it is unlikely that the technology that opens the best technological path can be chosen.

The benefits of such identification of local needs are so straightforward that it is hard to imagine that they would ever be forgone. Yet time and again that is exactly what happens, and not just for ventures involving small amounts. In most developing countries the failure to identify
local constraints is usually as much of a problem as the failure to identify needs. The typical constraints are in the areas of energy, transport, capital, skilled labor, and the supply of raw materials and other intermediate inputs. The failure to identify such constraints has undermined many new investments throughout the developing world.

The second step in selecting new technologies is to collect information to broaden the field of technological possibilities. However obvious this step may seem, it too is frequently bypassed, with costly consequences. One reason firms fail to search for the better technological solution, even if such a search is within their capability, is that the cost can be great. These costs can be reduced if firms can turn to specialized technological agents that capture economies of scale in their searches and that know what will work in local circumstances.

The third step -- which involves economic considerations -- is to evaluate the benefits and costs of different choices of technology, seen simply as methods for doing something. The conventional criterion is that the best (or most appropriate) technology is that which yields the highest net benefit, using prices that properly reflect the relative scarcities of the inputs and factors of production.

The fourth step is to look beyond the methods and to attempt, in addition, to assess the various possibilities that different technologies might open for acquiring added capabilities and for modifying technology to increase productivity. Some technologies open more possibilities than others. And some enable the development of more capabilities beneficial both to the firm and to society. True, these dynamic considerations can, in theory, be incorporated with conventional benefit-cost analysis. But they
seldom are, and we consider them separately here because of their importance for technological development.

Take watches, for example. A static comparison of the choice of technology to make mechanical watches or electronic watches in a labor-abundant economy may show that the technology for mechanical watches has the highest benefit-cost ratio among existing technologies. But because electronic watches probably will soon make mechanical watches and their technology obsolete, the better choice may be electronic watches, despite their lower apparent benefit-cost ratio. This choice is more apposite if little of the experience acquired by producing mechanical watches can be transferred to the production of electronic watches. Moreover, producing electronic watches from the start may enable the building of skills that will later be useful for more complicated electronic watches and other products that have electronic components.

Future possibilities determine the economically useful life of the original investment in physical means and in understanding. The proper assessment and choice of technology thus involves attempts to answer several imponderables. How fast are different technologies likely to improve? How many of the improvements are likely through minor organizational and physical changes rather than through radical changes possible only by making major new investments? What are the likely spinoffs from each technology for future learning and experience? Though impossible to answer with precision, such questions should be considered because choosing the right technology involves simultaneously optimizing the static and dynamic elements of the choice.

How, then, does a firm respond to the possibilities opened by the technologies it has chosen in the past? Perhaps the firm has chosen a
technology that enables it to make minor changes that can lead to higher productivity. Perhaps it has reached a dead-end that forecloses future improvements. Or perhaps, to restore the potential for productivity improvements, the firm has to move on to a radically different technology.

The first two possibilities imply decisions about upgrading or scrapping existing production units. The third implies decisions about establishing new production units.

**Upgrading existing production units**

The low productivity of a plant may be less a matter of outmoded equipment, more a matter of simple inefficiency. Often, much can be done to increase the productivity of existing plants, even with their existing equipment. For example, by making human and organizational changes, some Indian foundries greatly increased productivity. They did not add any new equipment. They rearranged the organization for using the equipment they already had; they kept the shop floor cleaner; and they managed inputs and inventories better. Those rearrangements set in motion a series of subsequent changes, each in response to the identification of bottlenecks. Simply identifying bottlenecks seems to launch efforts to open them, which leads to new bottlenecks. Such efforts to increase the efficiency of a plant can go far to increase productivity. But the returns diminish and the new drive loses steam as the firm squeezes more and more from its technology. If the firm is to sustain its productivity growth, it eventually has to change its physical means -- either incrementally, by grafting something new onto the set of processes and equipment already in place, or radically, by shifting to entirely new processes and equipment.
The productivity increases achieved by the Usiminas steel plant in Brazil during its first phase of capacity-stretching exemplify what is possible in upgrading technology through a sequence of minor changes to the original plant and equipment. The managers of Usiminas, rebuffed in their request for capital to finance an expansion, began to search for and experiment with modifications of products and processes to reduce costs and increase capacity without major new investments. Between 1966 and 1972 the modifications that worked were incorporated to more than double the output of the plant. Important in this improvement was the introduction of a standard cost system, which helped in identifying production problems and provided the information needed to assess how and why performance varied. Some of the modifications stemmed from simple experience with the production system. But others came from relatively small investments in licensing, consulting services, and specialized equipment — the results of a worldwide search to determine what might work in Brazil.

The example shows what is possible. But the possible is not the inevitable. Other evidence reveals stagnant or substantially lower productivity growth after the rapid increases during the start-up phase of investment. This was true for most other steel producers in Latin America, for galvanizing operations in Thailand, for some iron and steel producers in India. Even when efforts to increase productivity continue after the start-up phase, they meet with less success when they rely only on experience in operating existing production systems. What distinguishes the success stories in upgrading existing production through a sequence of minor changes is the following. The modifications of the original product or production process, and the effort surrounding the modifications, opened for the firm a new set of
technological possibilities that could be exploited by continuous efforts at sequential modification and bottleneck-breaking, efforts stemming from an explicit strategy to embark on a new series of incremental changes. Other firms, even those modifying their products and processes, did not use the modifications to progress to new sets of technological opportunities that could sustain productivity improvements.

What is important in upgrading technology for existing production is to get as much as is economically justifiable from the existing production system, to look outside that system for improvements, to choose improvements that will enable further modifications, and to introduce the technology in a way that launches a new series of minor improvements. Such minor changes to existing productive systems can thus substantially increase productivity. But just as efforts to increase efficiency through organizational changes run out of steam and eventually call for some physical changes to the production system, so the efforts to introduce minor changes run out of steam and call for radical changes that can help the firm cross technological discontinuities on its route to higher productivity. In other words, firms sometimes face technological deadends that call for scrapping a production line and jumping to a radically different new path.

Establishing new production units

There is a tendency in developing countries to go for the latest technology -- presumably to get on an equal footing with developed countries. But in going for the latest, what typically is acquired is one of three technological elements: the means of transformation. Typically ignored are information about the method and, even more, understanding of how and why
the method works. That naturally has implications for the ability to adapt the technology to local conditions, operate it efficiently, and upgrade and further adapt it once it is operating. And in going for the latest, what typically is sought is one of three technological capabilities: that in production. Capabilities in investment and innovation are ignored. And that has implications for the ability to have domestic resources progressively supplant foreign resources in successive investments. There is a danger, too, that selecting technology on or very near the frontier (without understanding how or why it works) can lock firms into a situation of continuously receding from that frontier as it advances.

By picking technology behind the frontier, many firms have opened technological black boxes in ways that would bring later benefits. A Mexican chemical producer selected such technology for a new plant because it could get information from the technology supplier about why the process worked, information the supplier of the first-best technology would not provide. The firm wanted the information to be able to adapt the process to conditions in Mexico and to make later modifications that would bring its productivity near that possible with the best technology that was available. A Brazilian petrochemicals firm did much the same. It looked for and found a French manufacturer that was getting out of petrochemicals and was thus willing to transfer information (20,000 pages of procedures and specifications) and understanding (several man-years of training in France and ongoing technical assistance at the new plant) as part of the package. The new plant was brought up to capacity more rapidly than was planned. And the experience gained during construction has enabled the Brazilian firm to build other plants -- at home and abroad -- with little foreign assistance.
This is not to say that firms should never pick technology at the frontier. If they understand such technology, or can make provisions to understand it, they may be better off with the newest vintage because it offers better possibilities for incremental changes than older vintages that have had those possibilities realized.

Two questions are thus basic in choosing the technology for any new venture. What technological elements does the purchaser get with the package? What technological capabilities will the purchaser gain from putting that package into use? The answers affect the prospects for adapting the technology to local conditions. They affect the prospects for modifying the technology to sustain productivity improvements and move closer to the international frontier. And they affect the prospects for augmenting domestic capabilities in production, investment, and innovation.

Developing Technological Capabilities

The usual sequence in developing technological capabilities with entirely new technology is from innovation to investment to production. Innovation often is the product, however, of experience in other investment and production activities. And the activities in new investment and production often lead to minor innovations. Because the developing countries can in many instances purchase technology that already exists, they usually reverse the sequence and use production capability as the foundation for developing capabilities in investment and innovation. Experience in production is generally needed to know what makes sense in expansions and new plants. Experience in production
and investment is generally needed to know what is wanted and what is possible in the way of new products and processes. Acquiring this experience is not automatic, however. Nor is it rapid and effortless. It takes conscious effort over a long period of time.

**Production capability**

One area of production capability is production management -- that is, the ability to oversee and improve the operation of established facilities. A second area is production engineering -- to obtain and act on the information required to optimize operations. That information comes from systems of raw material control, production scheduling, and quality control -- and from trouble-shooting to overcome problems and adapting processes and products to increase productivity and respond to changing circumstances. A third major area of production capability is the repair and maintainance of physical capital, as needed or according to schedule. A fourth is finding uses for possible outputs and marketing those outputs.

Although firms can become proficient in operating new processes in one, two, or five years, it typically takes them 10 or 20 years to acquire the full range of production capabilities -- if they ever do or, indeed, if they ever need to. In the meantime they augment their capabilities by those of others. They hire outsiders to do repairs and maintenance, to solve their problems of adapting processes to changes in the quality of raw materials, and to graft modifications onto their production system and train their personnel in operating the modified system. Or they can go without those capabilities, either ignoring them or waiting until they develop them. The requirements for possessing these capabilities are greater to the extent that inputs and
outputs change, that production technology cannot be codified, and that production technology is embodied in people rather than machines.

What is apparent from the experience of some of the more successful ventures in developing countries is that much can be done to accelerate the acquisition of these capabilities. The main way is by starting the study, training, and practice well in advance of the start-up of a new project. Examples abound of firms sending their operating personnel to work in plants elsewhere to gain experience with a process. The Koreans sent fifty workers to a shipyard in Scotland while constructing their first large shipyard. That helped them turn out their first world-class tanker thirty months after breaking ground for the shipyard. The Brazilians sent many technical personnel for training at a petrochemical plant in France, enabling them to speed considerably the process of getting a new plant up to capacity. And practice with a new facility need not wait for the start-up period. Korea's Pohang Steel Company had workers rehearse tasks and shout instructions first in an open field and then on site as their new integrated steel plant was being built.

Some capabilities in production management and engineering can be acquired by working side-by-side with others who have these capabilities -- with those brought in to train regular staff or to perform specialized tasks. The Koreans, for example, have assiduously insinuated themselves in every opportunity to find out how and why something is being done, how and why something works. In the process they have accumulated a remarkable amount of capability in production. Other capabilities in production management and engineering can come only from gathering and interpreting information from the production system, from attempting adaptations and modifications, from
understanding why some things work and others do not, and from keeping records to preserve such information. Doing these things requires an allocation of effort and resources. Some firms embark on these efforts only when shocked by changes in input or product markets. Other firms, rare in many developing countries, systematically make such efforts to increase their understanding of production. The continuity of such systematic efforts distinguishes productive firms from less productive ones.

**Investment capability**

One investment capability is project management -- to organize and oversee the activities involved in establishing or expanding facilities. A second is project engineering -- to provide the information needed to make technology operational in a particular setting. The three main areas of project engineering are detailed studies (to make tentative choices among design alternatives); basic engineering (to supply the core technology); and detailed engineering (to supply the peripheral technology). Procurement capabilities are needed to choose, coordinate, and supervise hardware suppliers and construction contractors. Capabilities of embodying technology in physical capital are needed to accomplish site preparation, construction, plant erection, and the manufacture of machinery and equipment. Capabilities are also needed to start up operations to attain predetermined norms. All the foregoing capabilities relate to project execution -- that is, to expanding or establishing production facilities. Also involved in investment capability are manpower training -- to impart skills and abilities of all kinds -- and preinvestment feasibility studies -- to identify possible projects and to assess the prospects for different design concepts.
As firms increase their capability in production, they can progress to develop their capabilities in investment -- in the appraisal, design, construction, and start-up of projects. The main way of beginning the process is to take part in the expansion or establishment of plants -- and to begin acquiring some capability in some activities. Usiminas, the Brazilian steel manufacturer described in the first section, had little responsibility during the turnkey construction of their original plant by the Japanese joint-venture partner, which did everything from the basic design to the initial operation of the plant. But the project was a box more open than black because Usiminas had teams of its people take part in all aspects of the investment. During a later expansion these teams were able to take over some responsibility for feasibility studies, detailed engineering, supervising construction, supplying capital goods, and overseeing the technical control of production. The teams had already acquired enough production capability to learn how things worked. They had observed how investment activities were orchestrated and had begun to undertake many of those activities themselves. By the third expansion Usiminas's technical personnel were able to do all the engineering work, although they contracted with outsiders to check the master engineering plan.

The Koreans have adopted a similar approach. To start production in a new sector, they often contract for a turnkey plant. And just as they insinuate themselves in the production process, so they do in investment. Sometimes they have to pay to do this; other times they can do it without paying. As a result of their growing investment capability, they have been able progressively to take on more of the tasks of investment in the expansion of the original plant to world scale and in the later construction of new
plants. The progression has not been so linear in all instances, but the progression in accumulating investment capability and in performing more of the tasks of investment has been relentless. One result is that Korea, of all developing countries, now exports the most plant construction to other developing countries.

A Mexican cement manufacturer had motives similar to those of the Koreans and achieved similar success. When contracting for the construction of a new plant, it applied the investment capability it already had to insist on a package of technological elements designed to give them the added capability to build more plants quickly and efficiently. It standardized the basic plant design and the suppliers of equipment and engineering. And it concentrated on developing its investment capabilities in the execution and start-up of new projects. The Mexican firm has since built several other plants -- all using the same basic design and the same suppliers of engineering and capital goods. That has made it possible to reduce construction costs (30-40 percent), reduce start-up time (again 30-40 percent), keep down the requirements for spares, and train and transfer personnel more easily.

The foregoing examples show the pattern of apprenticeship in developing investment capability. Another pattern is imitation. Many capital-goods producers get their start as repair shops. As the volume of their work grows, they establish small foundries and forges to make spare parts. Then, through reverse engineering they make all the spares -- and assemble whole machines. With this experience, they often proceed to making new machines. That is the progression FAMA (Fabricacion de Maquinas) followed in Mexico. Because a glass producer operating since early in the twentieth
In the 20th century had trouble getting spares during the second world war, it set up FAMA as a repair shop to service the main plant -- with a small foundry, a small forge, and some machining equipment. Over time the shop progressed from making spares to copying machines to buying designs for making other models. Experience from the production side of operations in various plants fed into the machine-making side, eventually enabling FAMA to produce improved machinery for glass-making (something described in the discussion of innovation capability).

**Innovation capability**

Innovation capability consists of creating and carrying new technical possibilities through to economic practice. We use the term to cover everything from invention (the conception of a new device, product, process, or system) to innovation (the first commercial use) and include improvements in existing technology. A radically new technology (a major innovation at the world frontier) may be developed from breakthroughs in basic research for which a market is subsequently found, or from the identification of a need for which research and development are allocated to find a technical solution that can be taken to economic practice. A modification or improvement of existing technology (minor innovation) involves more narrowly focused applied research and development as well as trial and error experimentation. Most innovation activity in developing countries is of this type.

Minor innovations are important because their cumulative impact can lead to productivity increases greater than those initially possible from major innovations. As firms (and countries) accumulate production and investment capability, they concurrently develop some capabilities in
innovation. The interaction of all these capabilities often makes them indistinguishable from one another. The nascent capabilities in innovation, when interacting with production and investment activities, open the possibility for enlarging the capabilities in innovation. In all instances, however, the acquisition of innovation capability -- like the act of innovation -- comes from explicit allocations of money and people to solve technological problems.

Minor innovations based on production experience often come from efforts to increase productivity. For example, a Mexican firm (VITRO) set out to increase the productivity of a process that it had bought from a U.S. firm for producing tableware. Because the process is paced by the time it takes for molten glass to solidify in molds, the Mexicans focused on and succeeded in developing a new mold that would absorb heat faster, doubling the speed of glass-making and the productivity of equipment. This improved technology was later sold to a Brazilian firm, whose engineering team made numerous small changes to the process and the equipment because energy inputs in Brazil cost three times those in Mexico. These changes reduced the energy consumption per unit by half. Similar examples abound for almost all industries throughout the developing world. But not for all firms. Such capability for small innovations stems only from efforts to develop the capability, and a remarkably small proportion of firms organize those efforts. Some firms mount such efforts to adapt processes to a new environment or to respond to shocks in their input and product markets. Fewer still mount an ongoing systematic effort to increase productivity. This, despite the prospects for getting as much or more in the way of productivity increases from a sequence of minor innovations as from such major innovations as the introduction of utterly new
processes.

Major innovations can also come from production experience, even in the absence of investment capability. A Mexican producer of steel cable watched despondently as Pemex, the national petroleum company, imported electromechanical logging cable for its oil wells. Made by only two companies in the world, the steel logging cable was being used to protect a bundle of other cables driven into the wells for testing. The Mexican producer assembled a team of engineers to determine how logging cable was made and, with their knowledge from production of regular steel cable, to come up with a design for the machinery to produce it. Then, lacking an investment capability in the manufacture of capital goods, they took the design to Krupp in West Germany and had them fabricate the machinery to their specifications. The Mexican company is now exporting its surplus production of logging cable and has set up subsidiaries in Canada and the United States to compete with the original two producers.

Major innovations stemming from R & D in the developing countries are less common, mainly because so much technology can be purchased, which obviates the need to develop technology at great expense. (See the discussion of R & D -- when it is useful and when it can pay off -- in the section on the environment for technological change.) Successful R & D nevertheless has borne some fruit, mainly in the newly industrialized countries, as can be seen from two examples, one of informal R & D, the other of formal.

HYLSA (Hojalata y Lamina S.A.) in Mexico was producing beer bottle caps from scrap metal. Confronted with the uncertain supplies and roller-coaster prices for scrap and with impurities that would cause the rolled metal to snap rather than bend, HYLSA wanted a reliable source of iron for its
steel-making. The problem was that the scale of conventional processes for making iron was far too large for HYLSA's needs. So they put an electrical engineer and a foreign chemical engineer in a corner of the plant to produce a substitute for scrap by assessing different processes that used natural gas to remove oxygen from iron ore. Several such processes had been patented, but none had been successfully developed on a commercial scale. The team looked at all existing patents on these processes and began experimenting with different possibilities. One possibility, advanced by the electrical engineer but scorned by his colleague as something sure to blow up, finally worked. It was then scaled up to a pilot plant and, after sorting out the details of the design, to commercial scale. Used in Mexico, the process has also been exported to five other countries.

Another example, also from Mexico, shows what can come from formal R & D. The Mexican Petroleum Institute was given the task of developing a process for demetalizing and desulphurizing crude oil. One department of the Institute started the development with a bibliographic search. Another did preliminary studies to define the basic characteristics of what was to be accomplished and the technical and economic characteristics the process should have to make it viable. Other departments did basic process research, developed pilot plants in the laboratory, and undertook the project engineering for the commercial-scale plant. Finally, the Institute did the promotion of the process's commercial use and assembled a technical assistance package for construction and field-testing. The process is now widely used in refineries in Mexico and several other countries.

Which of the many capabilities needed in production, investment, and innovation should producing firms develop? The ones they can use cost-
effectively all or most of the time. The others should be obtained from specialized repositories of those capabilities. The advantage of specialized domestic repositories is their ability to draw on the experience of a wide variety of firms in different situations and to deliver their wisdom to many firms in situations they know something about. The disadvantage is the client's lack of control over such firms. That lack of control often induces firms to maintain captive suppliers, within the enterprise, with all the inefficient duplication that can entail across firms. If such repositories do not exist in the country and if the size of the market warrants, they should be created, relying on foreign repositories in the meantime. The idea is to use foreign repositories to complement domestic repositories and to develop domestic repositories when it makes sense.

**Combining Foreign and Domestic Technological Elements**

The technological policies of many developing countries reveal the perception that technology is singular and that it must be either imported or created at home. But technology is not -- or need not be -- singular, for it consists of technological information, technological means, and technological understanding. Thus disaggregated, the technological question is not whether to import technology or create it at home. The question is which elements to import, which to obtain from domestic sources. The answer is found in the same way as that for choosing technology. The appropriate choice between foreign and domestic sources depends on an evaluation of associated benefits and costs, using prices that properly reflect relative scarcities. The best or most
appropriate source is that yielding the highest net benefit.

But just as in assessing technology, it is necessary to look beyond static cost comparisons in deciding which technological elements should be imported, which supplied locally. What is needed is to combine foreign and domestic technological information, means, and understanding in ways that enable the firm and the country to progress quickly and efficiently along their optimum technological paths. Also needed is combining these elements in ways that enable the firm and the country to increase their capabilities in production, investment, and innovation. An economy's ability to provide the necessary elements depends on the stage of development of the relevant sector and of closely related sectors. Firms engaged in well-established activities may often acquire technological elements locally -- either through their own efforts or from other firms. Firms engaging in new activities often must rely initially on foreign technological packages including all the elements. As they develop their technological capability, they can disaggregate these packages so that they import only the technological elements that cannot be efficiently supplied locally.

Much discussion about the acquisition of foreign technology focuses on how the technology is transferred rather than on what technological elements are being transferred and why they are being acquired overseas. We therefore open this discussion with a recital of the conventional wisdom about the advantages and disadvantages of each of the main methods of transfer.

Direct foreign investment, whether in a wholly owned subsidiary or in a joint venture with minority or majority local participation, is likely to be the only way to obtain the latest information from abroad. Such arrangements can ensure a rapid transfer of technology to a developing country -- that is,
a rapid transfer of technological information and means, but not necessarily understanding. The lack of local control in such investments can nevertheless have several deleterious outcomes for local technological development. The opportunity cost of having such ventures absorb local human resources can be high. Nor is it clear what is part of the local economy and what is part of the foreign company. The product design or process technology may not be the most appropriate for local conditions, and even in joint ventures it may be impossible to change the design or process to suit local conditions. For example, Escort Tractors, the Indian partners in a joint venture with Ford, has run into obstacles in trying to make some design modifications of the Ford tractor: Ford wants a uniform design worldwide. And it may be impossible to shift to other foreign sources for technological inputs, however superior they may be.

Licensing can also enable the rapid acquisition of product or process know-how. It can permit more local control over adaptations and modifications, especially after the license expires. And it can broaden the variety of sources for technological and other inputs far beyond what is possible under direct foreign investment. The main problems with licensing are in absorbing the foreign technology and in keeping current with advances in that technology. To begin with, licensing often covers only older technology. And the terms of the license can work to the disadvantage of licensees. It is not unusual for the licensor to provide little or no initial assistance, to allow few changes or adaptations during the period of the contract, to restrict exports or local diffusion of the technology, to insist on tie-in provisions for purchases of inputs, and to demand access to improvements made locally while denying access to information about the
technology and about improvements or new developments made overseas.

Turnkey projects, like direct foreign investment and licensing, can bring technology to a developing country quickly. Because outsiders are responsible for all aspects of construction and start-up, the turnkey project is the quintessential black box. A turnkey project may be the most appropriate method of transfer if a country has no experience in the area. But to the degree that such projects include the means of producing something without the information and understanding of how and why the process works, the prospects are slim for keeping operations up to capacity, adapting those operations to changing conditions, and knowing what to do when something goes wrong. Failures to transfer information and understanding also makes it difficult to use turnkey projects as the first step in developing local technological capability to increase participation in the design and construction of future plants.

Purchases of capital goods are black boxes on a smaller scale. Such purchases provide another way of acquiring the means of production without the transactional baggage of licenses and direct foreign investment — and a cheap way, if they can be used as models for reverse engineering to produce the machines locally. The Korea Steel Pipe Company bought a production line from the Japanese and copied it to make a second line, even while assembling the first. But just as with turnkey projects, such purchases can bring the means of producing something without the information and understanding of how and why the method works. If a country does not have the technological capability to use and adapt the machine efficiently, the frequent result is machinery that is either damaged or operating far below its rated capacity. Many times the new operating environment for a machine requires changes that the
instructions do not cover because they pertain to the original environment. Modifications may be needed to enable the machinery to run at higher temperatures, with different grades of raw materials, and under the eye of less skilled operatives than those in the developed countries. And sometimes the machinery is not even used.

Purchases of technical assistance can fill gaps in technological information and understanding to complement a country's capabilities in production, investment, and innovation. The advantage of such purchases is that it may be easier, cheaper, and quicker to rely on foreigners than to take the time and effort to do it locally, possibly making costly mistakes in the process. For example, steel mills in developing countries often bring in foreigners to dynamite the residues that build up inside blast furnaces. The service is not cheap, but it is considered worthwhile because of the trickiness of measuring residues and using the right amount of dynamite. Such purchases of technical services are not limited to assistance in production or construction. There is no reason, for example, why a firm in a developing country cannot hire (or buy) an engineering firm in a developed country to do some of its research and development. That is what some leading firms in Mexico, Brazil, and Korea have done to complement their R & D capabilities. And the Russians, blocked by Dupont in getting access to the knowhow for producing nylon, hired people that did the design and construction work for Dupont and had them do the same in Russia. The disadvantage of purchasing technical services is the tendency toward persistent reliance on such services, toward doing little to build up domestic capabilities in providing those services easily, cheaply, and in ways that more fully consider local requirements.
More important than the differences in the methods of transferring technology is the maneuvering possible within each method. The point here is that the technological benefits to be gained from foreign technology depend less on the method selected for the transfer, more on how the method is implemented. The method determines the structure for the transfer, but the room for maneuvering within the method suggests that developing countries should avoid blanket policies for or against various methods. To be pursued instead is knowing how to get what is needed from each transfer, whatever the method of transfer. The idea is to use the transfer as a stepping stone to develop new technological possibilities. The main areas of maneuvering relate less to technological means, more to technological information and understanding. The areas include provisions for adapting technology to local conditions, for access to basic information and designs, for continuing assistance in modifying equipment and keeping up-to-date with the latest changes, and for training in production, investment, and design -- areas crucial for the technological development of a firm or industry.

Through judicious policy intervention, it may be possible to capture some important externalities from direct foreign investment -- through links to local suppliers of components, raw materials, and other intermediate inputs. In Brazil, for example, the government imposed requirements on multinational automobile companies to increase the local content of their products. This did much to spur the development of the local machine-tool and components industries. It also fostered the development of such basic industries as steel, glass, and rubber. Volkswagen Brazil, for example, now has more than 1,500 local suppliers, many of which it helped start and then nurtured. Brazil's large domestic market naturally was an important factor in
the success of this intervention. In smaller markets it is unlikely that multinational companies would make the extra effort required to increase local content or that components could be produced at competitive costs.

So, some foreign partners and suppliers will do much more than others in transferring their technology to developing countries. The willingness of suppliers to do more -- say, to supply drawings or explain how something works -- generally increases with the age of the technology. The older the technology, the more the purchaser is likely to negotiate favorable terms of transfer. But even for each vintage of technology, some suppliers will give more, some less, depending on their motives. A supplier that is abandoning a product line will include much more in a technological transfer than a supplier continuing with a product line. The same goes for suppliers interested in nurturing developing country markets for others of their products. The nationality of the supplier can also make a difference. For some technologies, such as those for many basic industries, the Europeans may be more generous than the Americans. For others, such as those for many consumer goods, the Americans may be more generous than the Europeans. The critical thing is to know what is needed and to seek it at the most reasonable price under terms that do the most for the acquisition of technological capability.

The next consideration in choosing the best way of acquiring foreign technology is to get technology that is adaptable or already adapted to local conditions. Because of differences in operating environments, almost all technologies require adaptations to make them work well in developing countries. Generally, the older the vintage, the less likely the supplier is to impose restrictions on modifications and the more easily it can be
adapted. But even for newer vintages, suppliers can be found that will lift restrictions and assist in modifying the technology for use in its new environment. It is also possible to find suppliers that will design new technology to suit the environment. The Hindustan Machine Tool Company found a Swiss joint-venture partner willing to do more than transfer one of its existing designs for lathes to be made and used in India. The foreign partner designed a new lathe that was simple, rugged, reliable, and thus well suited to conditions in India. Another determinant of adapting technology to its new environment is the nationality of the technology. The Koreans found in numerous instances that technology imported from Japan was better suited to Korean factor proportions than was technology imported from Europe and the United States. Other developing countries are finding the same to be true of their imports of Korean technology.

Perhaps most important is getting as much information and understanding during the transfer as is needed. And what is needed depends on the present and future objectives. For example, the Swiss partner of the Hindustan Machine Tool Company agreed to provide a tremendous amount of training in India and Switzerland. For another example, the Brazilian petrochemicals experience cited earlier was successful because the French supplier was willing under turnkey arrangements to part with reams of technological information -- adding information to the means of production -- and to administer comprehensive training programs in France and Brazil -- adding understanding to the information and means. For a third example, a Korean detergent manufacturer insisted, in a deal for a turnkey plant, on getting experience: in the design of the plant, by having its engineers work with the supplier's engineering consultants; in the construction of the plant,
by having the same engineers work side-by-side with the contractors; and in
the operation of the plant, by having its technical personnel work in similar
plants overseas. When the time came later for increasing capacity, the Korean
firm was able to do everything needed for the plant's expansion without having
to pay for expensive foreign assistance. And when changes in government
regulations called for a shift to biodegradable detergent, the firm adjusted
by exporting the output of the original plant and building a new plant for the
more complicated processes of producing biodegradable detergent -- again with
no foreign assistance.

A related consideration is having the freedom or the assistance to
modify technology and to keep up-to-date in improvements of the technology
purchased. Subsidiaries and affiliates of foreign companies are thought to
have advantages in these respects because of their direct ties to the
supplier. But such ties can be a distinct disadvantage if the supplier is
slipping away from the frontier and if other improvements are available
elsewhere. To continue with an earlier example, the Hindustan Machine Tool
Company, constrained by a disagreement over broadening its product mix, bought
out the Swiss partner but maintained a technical assistance agreement with
it. Under that agreement, the Indian company received continuing advice on
the operation and modification of the lathes and sporadic advice on licensing
agreements. It now has more than 30 licenses, many of them specifying the
licensee's freedom to modify machinery and products and the licensor's
obligation to pass on information about any improvements of the original
technology. Such terms need not increase the cost of the transfer, but even
if they do, the benefit may make the higher cost worthwhile.

At issue in any technology transfer, then, is what the purchaser
wants to get from the transfer. If the purchaser already possesses or can quickly gain information and understanding of the process for producing something, it can merely purchase the means. This is the situation in many newly industrialized countries, but only after having acquired considerable capability in production that could be transferred to other processes. Far more likely is the need for information and understanding, a need that can be met through provisions for training and hands-on experience. If the purchaser intends to repeat the original investment, it will gain much from participating in, say, the design and construction of a turnkey plant. Sometimes it will have to pay for the training received through this participation; other times it will not have to pay for the training, so that the only cost is the opportunity cost of the time personnel spend in training. With the information and understanding gained in the construction of the first plant, the purchaser will be equipped to perform more of the tasks in the successive plants — and progressively to gain more information and understanding of how and why the plant works. And if the purchaser intends to move eventually into plant and product design, it will gain much from writing into the terms of that transfer its participation in the design work for the original transfer — as well as explicit provisions for the training of its engineering staff.

What is clear in all this is that the more a purchaser identifies its technological shortcomings — especially in information and understanding — and seeks to remedy them or complement them with foreign technological elements, the more successful it will be in adapting technology to local conditions, in operating it, and in making improvements that can nudge the firm onto a superior technological path. Also clear is that the more
technological capability a purchaser has -- whether in production, investment, or innovation -- the more it will be able to exact from suppliers of technology for a given price and the more effectively it will take advantage of technological possibilities in the future. None of these outcomes is automatic, however. They require a conscious technological effort by the firm to identify what it wants from the acquisition of foreign technology. They require a conscious technological effort to absorb that technology. And they require a conscious technological effort to place the firm on a new technological path and do this in a way that further develops local technological capabilities. These efforts all entail additional cost, with the expectation that the future benefit will be greater still.

The Environment for Technological Change

One big problem the governments of developing countries face in managing technological development is fostering technological effort that leads to the most efficient and productive use of resources. Studies of the total factor productivity in developing countries and industrial sectors show widely different rates of growth for the productivity of all inputs combined. Studies of frontier production functions of industrial sectors show much variation in the technical efficiency of firms in the same sector. They show, too, that changes in total factor productivity in a sector result both from the movement of firms toward the frontier and from advances of the frontier. And detailed studies of firms show that some firms engage in a considerable amount of adaptative technological effort, but that most others do not.
The low productivity of laggard firms in an industry is sometimes caused by their smaller scale of operations and by the older vintage and poorer quality of the technology they use. There nevertheless are many large firms that have established plants that operate at low levels of productivity despite using the most modern technology. In other words, low productivity is sometimes caused by poor efficiency in using technology. One way of reducing the productivity gaps in an industry, then, is to induce low productivity firms to adopt the equipment, make the modifications, and acquire the skills of the high productivity firms. A basic question is whether they are likely to do this, for the initial problem often is not one of diffusing technology. It is diffusing the desire to make the effort to innovate, to change, and to search through the full array of technological possibilities.

Low productivity firms typically are slow to innovate for three reasons. They devote little effort and few resources to keeping systematically informed about their technological options. They have a high risk-aversion to change, preferring to follow rather than lead -- to wait until the experience of other firms reduces the uncertainty about whether and how well something different will work. And they often are unable to absorb new technological elements. For too many such firms, technological change simply involves buying new equipment. But if they do not devote effort to get the most from that new equipment, they would in many instances be better off trying to get more from the equipment they already have.

In the rest of this section we describe in more detail three elements of the environment for technological change. The first has to do with the incentives and penalties that encourage producing firms to improve their technology and the way they use it. The second is a country's array of
specialized technological agents that can promote the flow of technological elements -- the flow of technological information, means, and understanding. The third is the role of government in directly affecting technological development. This third element naturally embraces the first two elements but narrows the focus from the broader economic environment to the environment for technological development.

**Incentives and penalties**

Technological change usually requires more effort than no change, so the environment must compensate the right effort and penalize the wrong effort or the effort unmade. What is a right effort, what a wrong? Economists, concerned with economic efficiency, would insist that the objectives, whatever they are, reflect productive and allocative efficiency. Productive efficiency involves using prices that reflect the relative scarcity value of different inputs to find the minimum cost combination of producing the good. Productive efficiency thus is the primary criterion for judging the economic efficiency of enterprises. Allocative efficiency refers to the way an economy's scarce resources are allocated across enterprises producing goods and services. The allocation of resources is efficient when changing that allocation to increase the production of some goods and services and reduce the production of others would reduce aggregate well-being.

To promote efficiency, the environment must have incentives and penalties to reallocate resources from inefficient uses to efficient uses -- and to develop new and better products and processes. The reallocation operates at four levels: among activities in a firm, among firms in a sector, among sectors in a national economy, and among countries in the international
economy. First, there must be incentives and penalties that lead to the more efficient use of resources by firms and to the development of better products and processes. Second, there must be incentives and penalties to encourage the growth of innovative firms and the shutting down of chronic laggards. Third, there must be incentives and penalties to encourage the development of new (infant) sectors and the gradual demise of old (sunset) sectors. Fourth, there must be incentives and penalties that lead to efficient exploitation of the possibilities for specialization and exchange created by international trade. In a market system, prices, profit maximization, and competition (leading to the birth, growth, and demise of firms) are the mechanisms that are supposed to lead to productive and allocative efficiency.

The incentives and penalties must reflect the relative scarcities of inputs used (productive efficiency) as well as the demand and cost of supplying the goods and services to be produced (allocative efficiency). To the extent that prices affect decisionmaking in developing countries, it is important that these prices properly reflect scarcity values. If the incentives and penalties reflect scarcity values, technological efforts can increase the efficiency of resource use. But if the incentives and penalties do not properly reflect scarcity values, which they often do not, technological efforts can lead to inefficient uses of resources.

One way of having prices reflect scarcity values is to have much of the economy open to the world. Because petroleum prices in Brazil reflected the prevailing world prices in the 1970s, producers developed gasahol to exploit the potential of sun, land, and inexpensive biomass (mainly sugarcane). By contrast, the managers of the Rosario steel plant of the Acindar steel group in Argentina made a tremendous effort to improve the
performance of an outmoded steel mill because the government prohibited the company from setting up a new plant with more modern technology. In the face of the constraint imposed by the government's veto of the new plant — a move that made the price of the new technology infinite — the firm responded rationally by allocating effort to make the best of its outmoded plant. Given the true relative scarcity of resources, however, it would have been more efficient to import new technological elements and allocate the technological effort to assimilating the new technology and improving production with the new technology.

The pressure of international competition on firms can also be an effective inducement to economic efficiency. One of the main things inspiring technological effort by a firm are shocks in its product markets — shocks that threaten its market share by a cheaper or superior product. Trade, of course, vastly increases the number of competitors. When Chile, Uruguay, and Argentina reduced tariffs in their liberalization programs of the 1970s, some local producers -- the surviving ones -- responded with successful efforts to match the quality of the foreign goods suddenly entering their markets. The increases in quality came about from some purchases of new equipment but mostly from purchases of new designs for products that could be produced with existing equipment. For example, several textile firms imported European design for fabrics and fashions. Often, however, the response to shocks in product markets (or to those in input markets) is a one-time effort that flags. And as was pointed out in the earlier discussion of technological capabilities, what is needed is for firms to establish systems that ensure a continuing technological effort. This requires that firms develop a strategy to exploit the compulsive sequences that can be set in motion by beginning to
monitor what they do and how they do it.

Generalizing along these same lines, barriers to trade can lead to much wasteful local technological effort to produce inputs or goods that could be obtained more cheaply outside the country in exchange for other goods that could be locally produced with relatively more efficiency. India's automobile industry still produces a 1950s vintage car at what amounts to twice the cost of a modern Japanese import. In an environment that prohibited imports of cars and imports of new technology for car production, there was not much pressure to improve the local cars. So, little technological effort was undertaken. Moreover, there were diminishing returns to what little effort there was because of limitations of the original design and restrictions on using foreign technical inputs to upgrade it. Recently the government created a joint venture with a Japanese car maker to produce modern models for the local market. Because of scale economies in car production and restrictions on the number of cars the joint venture can produce, that car is still likely to be more expensive than an imported one. But two new conditions -- the competition from even limited local production and the liberalization of restrictions on obtaining foreign technology -- are already leading two traditional local producers to seek foreign licenses and technical agreements to improve their cars.

What is wanted, then, is to have incentives and penalties that lead all firms to engage in purposive technological effort to increase their productivity -- effort to improve technology and the use of technology in ways that enable the acquisition of added technological capability in production, investment, and innovation. The focus here on technological effort and change should not be construed, however, as advocating effort for effort's sake or
change for change's sake. The focus should be construed as advocating effort and change that make economic sense, for a firm and for a country.

Specialized technological agents

The elements of technology flow between firms, plants, and sectors through several mechanisms. Engineering firms, intermediate-goods producers, and capital-goods suppliers serve varied customers in related industries. Competing producers enter agreements for technical cooperation. Technical personnel move within and across industries. And the technological effort of firms in an industry complements and can be complemented by that of research, development, and technological institutions. Technological elements thus move in much the same way in a country as between countries. They move between competing producers and between producing firms and specialized technological agents, which act as repositories of diverse technological capability.

The leading firms in an industry do not regularly go to their competitors and hand them the gift of a succession of major and minor innovations. Instead, they generally use secrecy and patents to hoard their innovations, so that they, and not their competitors, benefit most from the effort that made the innovations possible. But some formal mechanisms enable leading firms to sell their innovations. These include licensing arrangements for technological information and means -- and technical assistance agreements for complementing and perhaps instilling technological understanding.

In addition to these formal mechanisms for the flows of technological elements between competing firms, there are many informal mechanisms. One is to copy unpatented equipment and processes -- or to study patents and then to do R & D to patent around them. This naturally dissuades many innovating firms from registering patents, especially if the patent administration is
weak. Another informal mechanism for diffusing technology is to poach skilled personnel from leading firms. This is what many Korean firms, themselves leaders, do when they establish a new line of production. They simply offer higher salaries to engineers and other technicians from other local firms, technicians already skilled in the installation and operation of the new processes being adopted. Such footloose personnel can speed diffusion considerably, but they also discourage investments by firms in their human capital. Other informal mechanisms are the information flows in technical conferences, technical associations, and personal information networks. For example, trade associations in Korea see that information about technological advances flow quickly to all members of the association. Note, however, that many of these mechanisms of diffusion rely for their success on the initiative of low productivity firms -- initiative that is seldom forthcoming.

The flows between producing firms and specialized technological agents are often far more important than flows between competing firms for the rapid diffusion of the technological information, means, and understanding needed for technological progress. Many of these specialized agents do not always exist in developing countries. And unlike competing firms, whose interest is to control diffusion, the interest of specialized technological agents is to promote and carry out diffusion. These agents -- engineering firms, intermediate-goods producers, machinery producers, research institutes, and information centers -- do work related to production, such as quality control, process optimization, plant and equipment maintenance, and so on. They also do work related to investment, such as feasibility studies, architectural and engineering designs, and the fabrication of physical capital. And they do work related to innovation, providing such services as
training, education, and research and development. If supplying agents do not exist in the country, the services must be imported to be used.

Local repositories of specialized technological capability come into being naturally if the market and the local division of labor justify their existence. As the local market grows and matures, they evolve naturally in several ways. One way is for teams gathered to solve one set of problems, perform one set of tasks, or produce one element of the production system to be formalized in a department in the firm, rather than being disbanded, and then to be spun off as separate entities when there is enough demand for their services elsewhere in the economy. CSN, the first integrated flat-steel producer in Brazil, developed a large engineering department for plant expansions. That department later did much of the engineering work for Cosipa, the second such producer. As other steel producers emerged or undertook expansions and modifications, the market became large enough to warrant spinning off the department as a specialized firm -- Cobrapi -- to supply the growing local demand for its capabilities. Cobrapi is now the largest steel engineering firm in Brazil. Mecon, Cobrapi's equivalent in India, evolved in much the same manner.

Another way for specialized technological agents to come into being is for a group of people with experience in different firms to band together and start a new firm. Bufete Industrial, the largest engineering firm in Mexico, was formed by civil engineers with construction experience in manufacturing companies and in the government's civil works department. And Dastur, India's second largest steel engineering firm, was started by an engineer who returned home after acquiring considerable experience in the United States and by others with engineering experience in India's public and
private sectors. A third way is for a small group to start with simple general skills and to grow and become adept at much more complicated technological tasks. Many large, integrated capital-goods producers in Brazil and Argentina started as repair shops that copied imported equipment that could not be obtained from overseas during the second world war. They gradually adapted the foreign designs to local conditions and in time even developed some original designs.

Without a market, however, these capabilities either will not develop locally (and will continue to be imported) or will remain internalized within firms (and will not interact with other producing firms and specialized technological agents in ways that can increase the efficiency and productivity of using resources). Why should some of these capabilities be available from local technological agents? Mainly because not all elements of technology are perfectly tradable. Technological information somewhere in the world does not exist everywhere because of the costs of advertising or discovering its existence. Nor are the international markets for many elements of technology competitive. That is why the technological capability of the purchaser of technological elements greatly influences the price paid and the benefit gained. Also very important, many elements of technology are tacit: they can be understood and effectively used only through experience of the circumstances of their use. Because of this tacitness and because of the costs and problems inherent in intermittent communications over long distances, local capability is needed to combine knowledge of technological elements with knowledge of local circumstances -- if products and processes are to be well adapted to local needs, or if new technological elements are to be developed. Such elements of technology are not tradable in the sense that
they would not have been acquired without having been developed in the local economy.

The proximity of technological agents is important for the information flows needed for adaptations and innovations in ongoing operations and in new investments. This is most striking in the interactions between users and suppliers that underlie many innovations to improve products and processes. For the user, however, the tacitness of technology means that the net benefits to be gained from adopting new technological elements are uncertain. And that uncertainty can be reduced only by testing those elements in local circumstances. Improvements are likely to result only if there are extensive exchanges of information about the actual and desired performance characteristics of products and processes -- and about the value of desired characteristics to the user. It thus is necessary to foster an environment that promotes the formation and growth of local technological agents and their interaction with local users of their services so that technological possibilities are matched with local conditions and requirements in an efficient way.

Local sources of technological elements are likely to be more expensive than foreign ones: that is, until they acquire the experience needed to streamline their products and services. In turn, the first users of local capabilities, the ones paying the higher cost, generally are not able to appropriate fully the benefits of having specialized technological agents evolve. Many such benefits will accrue to others in the economy. And because of indivisibilities and economies of scale, many technological capabilities may not be developed because the potential market for such capabilities is not properly foreseen. Therefore, even where social objectives would dictate the
use of local suppliers to enable lower costs and more productive uses of resources, firms may prefer to continue relying on repeat purchases of foreign technological elements and capabilities. They may even be willing to pay more rather than risk using an untried local source. Such behavior keeps the local market from developing. There may thus be a role for government in promoting the development of some specialized technological agents, such as R & D units, engineering firms, information centers, and capital-goods producers.

The role of government

Government policy plays direct and indirect roles in the development of local technological capability. As already described, one of the most powerful indirect roles is to create the general economic environment of incentives and penalties that reward appropriate technological efforts and punish inappropriate or unmade efforts. But because of market failures and externalities in the choice, creation, and diffusion of technology, there is a more direct role for government policy. One feature common to the success of the newly industrialized countries is an environment that allows market forces to operate for most economic decisionmaking and that provides for government intervention mainly where the market fails or where the motives are more social and political than economic. The small number of these countries points to the difficulty of achieving a balance between allowing market forces to prevail in much of the economy and intervening only in special cases.

The objectives of such government intervention include inducing choices of techniques that are socially most appropriate, importing technology on the best possible terms, and stimulating the development of specialized technological agents. Start with the choice of technology. Choosing
appropriate technology depends on information and the ability to use that information effectively. Because of large economies of scale in collecting and organizing information -- and because information is a public good in the sense that its diffusion and use do not deplete its value -- governments often justifiably subsidize its collection and dissemination. For example, Brazil and Mexico have set up technological information centers that charge private users only a small fee for access to their data banks. And because few firms in developing countries have enough technological capability to evaluate alternative techniques appropriately, governments have a role in emphasizing technical training and in subsidizing the development of that capability. Again, Brazil and Mexico have agencies that subsidize the costs of feasibility and engineering studies for projects. Those agencies also subsidize technical training and equipment purchases by the consulting firms that conduct these studies.

From a social viewpoint, the proper choice also depends on having the prices used to evaluate the net benefit reflect the scarcity values of the goods and other inputs (recall the earlier discussion of incentives and penalties). In many countries, firms use prices that do not reflect scarcity values because of distortions in factor, input, and output markets. Some of these distortions arise from such government policies as those for minimum wages, interest rates, tariff structures, and other regulated prices. In addition, excessive protection against imports can destroy the incentives for producers to search for the most appropriate technology, again pointing to the importance of government policy in forming the general environment for technological development.

Another big concern is preventing foreign technology suppliers from
abusing their monopoly power. To do this, the governments of many developing countries have instituted defensive measures to control the price and terms of technology transfers. These measures generally impose limits on royalty payments and prohibit such undesirable terms as those restricting export production or obliging recipients to inform suppliers of any improvements they might make. The measures often have the explicit aim of offsetting the asymmetry in bargaining strengths of suppliers and recipients. They have also been aimed at protecting and promoting local suppliers of technology by, for example, requiring would-be importers to document that the technology they want cannot be obtained at home.

Defensive measures to increase the bargaining strength of local firms have obviously helped, but by how much is not known. And it is unclear whether new informal terms have offset changes in formal terms. In some instances the defensive measures may have been carried too far, and large benefits have been forgone by keeping foreign technology out. That may explain why some countries with highly restrictive policies, such as India, have recently liberalized their policies for technology imports to give maturing industries access to more advanced technology.

Defensive measures used to promote the development of specialized technological agents are typically augmented by positive measures to require the participation of local technological agents in the transfer and absorption of imported technological packages, to provide subsidies and fiscal incentives for the use of local sources, and to establish and operate R & D units, engineering firms, and capital-goods producers. In some cases government stimuli have developed local capabilities that efficiently substitute for foreign ones. In others, however, the establishment of local capabilities has
proven to be too expensive in relation to the benefits brought to society. Some local capabilities remain costly and inefficient substitutes for foreign capabilities. Some are poorly integrated with the development needs of the country. Why does this happen? Often because the local technological agents are so excessively protected that they do not develop competitive capabilities—or because the market is too small for them to become efficient.

Poor integration with local needs stems from poor assessments of needs and of ways to satisfy those needs. Such mismatches are most evident in the emphasis in many technological development plans on establishing R&D institutes to work on major innovations. Government research institutes that conduct basic research, unlike their private counterparts, face real problems in ensuring their relevance to the productive sector. Basic research usually is warranted only when the technology does not exist, when it exists but is not available, or when it is available but too expensive. Otherwise, research institutes can get on tracks that do little for a country's productivity and efficiency. There is, moreover, much more scope in developing countries for applied rather than basic research, for applying scientific knowledge to problems identified in practice. What appears to be the only way to keep the work of these institutes relevant to the productive sector is forcing them to cover part of their budgets from fees for their services.

The foregoing discussion reinforces the assertion, developed throughout this paper, that the central issue of technological development in the developing countries is not acquiring the capability to invent products and processes. It is acquiring the capability to use existing technology—to produce more efficiently, to establish better production facilities, and to use the experience gained in production and investment to adapt and improve
the technology in use. The main way of doing this is to build on what can be obtained from abroad while developing local capabilities in areas where it makes the most sense. Since all capabilities cannot be developed simultaneously, and since the accumulation of any one capability takes time and experience, the sequence in which various capabilities are developed is crucial. And the required capabilities change as a firm or country matures, because of changes in existing capabilities and because of changes in market conditions.

For a firm, the decisions about the capabilities to be developed and their order of development depend on its plans, on the underlying technology, and on the size and growth of the market. If the market is small and growing slowly, so that investments in new plants are infrequent, the best course may be to concentrate on production capability -- say, by importing a turnkey plant, with the training required to adjust the operation as needed. But if the market is large or growing rapidly, it may be economic to acquire some investment capability. Furthermore, if technology is changing rapidly, it may be desirable to acquire the capability to assimilate new advances quickly or even to innovate new products or processes. For a government, the decision may be to promote direct foreign investment in rapidly changing areas where it would be too costly to keep up with world technological developments. Or it may be not to promote the industry's formation if the cost of keeping up with rapidly advancing technology is too great.

Since everything cannot be done at once, selectivity is at the heart of national policy for technological development. And since markets fail differently in different environments, the policies for government intervention have to be tailored to national and sector-specific
circumstances. Whether new capabilities should be promoted in a sector depends on the relative costs and benefits of using local or foreign sources, now and in the future. How they should be promoted depends on the capabilities already accumulated in the industry and in related sectors. It also depends on the expected evolution of the organization of economic activity -- what is produced, by whom, and in what volume -- in the absence of promotional interventions.

It is seldom clear, however, how to design and implement policy measures most effectively. Defensive steps, such as the ones outlined earlier, are not enough. But positive measures are not always successful either. Moreover, measures to support and encourage local technological effort have frequently been at cross purposes with other elements of industrial and trade policies. The reason is that wage, price, and trade policies can quickly undermine the best-intentioned interventions for technological effort. As a result, firms, even those owned by the state, have often not responded to technology policies. Another difficulty is achieving a balance in promoting the development of specialized technological agents and keeping down the costs of their services. Perhaps the most important role of government is in establishing an environment that stimulates firms and specialized technological agents to engage in ongoing technological efforts and to develop added technological capabilities -- efforts and capabilities that improve productivity and overall economic performance.
Bibliographical Note

Most of the cases described in this paper come from the findings of an ongoing World Bank research project (RPO-672-48) on "The Acquisition of Technological Capability," managed by Carl Dahlman and Larry Westphal. Other sources include:


