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Carl J. Dahlman and Larry E. Westphal

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The Meaning of Technological Mastery in Relation to Transfer of Technology

By CARL J. DAHLMAN and LARRY E. WESTPHAL

ABSTRACT: The acquisition of technological mastery—that is, of the ability to make effective use of technological knowledge—is critical to the achievement of self-sustaining development. Transfers of technology are substitutes for local mastery rather than sources of it. Consequently, the part played by transfers of technology in the process of development, while important, is nonetheless limited. This article considers the role of technology transfer with specific reference to industrial technology, and places it in the broader context of the relationship between the acquisition of technological mastery and the development of an efficiently functioning economy. Based on a review of what is known about technical change in industrial enterprises in less-developed economies and on a case study of one economy's experience, it demonstrates that indigenous effort to assimilate technological knowledge is of overriding importance in the achievement of technological mastery. Various types of technological mastery are distinguished together with the different categories of effort associated with their acquisition. The consequences of increased mastery are also discussed, together with the factors that determine when it is appropriate to rely on transfers. Finally, the authors suggest that further research is needed to determine how technological mastery ought to evolve in relation to industrial development.

Carl J. Dahlman received a Ph.D. in economics from Yale University in 1979. Prior to joining the World Bank in the same year, he spent two years in Brazil studying technological change in the steel industry.

Larry E. Westphal received a Ph.D. in economics from Harvard University in 1969. Before joining the World Bank in 1974, he served on the faculties of Northwestern and Princeton universities, and for a time as resident advisor to the Economic Planning Board of the Republic of Korea. He has written extensively on industrial policy and development, on investment analysis under increasing returns, and on empirical analysis of production relationships and technological choice.

NOTE: The views and interpretations expressed here are the authors' and should not be attributed to the World Bank, its affiliated organizations, or any individual acting on behalf of these organizations.

THE exploitation of technological knowledge is central to the development process. Less-developed economies typically obtain this knowledge from more advanced ones rather than by creating it themselves. This is to be expected, given the vast pool of foreign technological knowledge available to them for exploitation. Transfers of technology are one means of acquiring foreign technological knowledge and can consequently play an important part in the development process. Nevertheless, their nature is such that transfers of technology can represent no more than an initial step in the exploitation of available knowledge.

Following are some important definitions.

—Technological Knowledge: Information about physical processes which underlies and is given operational expression in technology.

—Technology: a collection of physical processes which transforms inputs into outputs, together with the social arrangements—that is, organizational modes and procedural methods—which structure the activities involved in carrying out these transformations.

—Technological Effort: the use of technological knowledge together with other resources to assimilate or adapt existing technology, and/or create new technology.

—Technological Mastery: operational command over technological knowledge, manifested in the ability to use this knowledge effectively and achieved by the application of technological effort.

—Interrelationship of the Terms: technological mastery is the effective use of technological knowledge through continuing technological effort to assimilate, adapt, and/or create technology.

Technology is the translation into practice of technological knowledge. When technology is acquired by transfer, however, this process of translation is undertaken by foreigners. Transfers of technology thus substitute for indigenous technological mastery and make it possible to acquire technology without indigenous technological effort. Recognition of this fact leads to a question of central importance to less-developed countries: to what extent can effective use be made of available knowledge without indigenous effort to master it? This is the question dealt with in this article.

In order to give the discussion a manageable focus, our primary concern is with technological effort and mastery as they relate to physical processes.[1] This is not to deny the fact that these physical processes are undertaken within a framework of social arrangements—organizational modes and procedural methods—that condition their operation.[2] Similarly, we deal only with industrial technology. But it should be understood that the relationship of technology transfers to the acquisition of technological mastery is the same in all important respects for all sectors.

The sections that follow treat the transfer of technology in the context of a broader evaluation of the relationship between the acquisition of technological mastery and the development of an efficient indus-

1. Under this narrow definition, a firm or an economy could have a great deal of technological mastery and yet not deploy it effectively, owing to inappropriate organizational or procedural arrangements.

2. Harvey Brooks, "Technology, Evolution, and Purpose," *Daedalus*, 109 (1): 65-81 (Winter 1980); N. Bruce Hannay and Robert E. McGinn, "The Anatomy of Modern Technology: Prolegomenon to an Improved Public Policy for the Social Management of Technology," *Daedalus*, 109 (1): 25-53 (Winter 1980).

trial sector. The first section discusses what is meant by technological mastery and considers how it is related to transfer of technology and to technological effort. The empirical evidence for local technological effort and experience as sources of increased mastery and of the associated gains in industrial productivity is then summarized in the second section. Based on the perspective established in the preceding discussion, the third section outlines the factors that determine when it may nevertheless be appropriate to rely on transfers of technology rather than indigenous technological effort and indicates the various forms that transfers can take.

The evolution of technological mastery in relation to one country's industrial development is reviewed in section four. The case study is of the Republic of Korea, which has been chosen because of our comparative ignorance of other economies and—more important—because of the interest that attaches to understanding the sources of its rapid and highly successful industrialization. Finally, the concluding section highlights several important issues that have not yet received adequate attention in empirical research. These issues concern the relative efficacy of the alternative technological strategies that can be followed by less-developed economies.

MASTERY RESULTS FROM EFFORT, NOT TRANSFER

Industrial technology is sometimes misunderstood as being thoroughly documented in codified form—in "blueprints," as one prevalent metaphor would have it. If this simplistic view were valid, technologies could be transferred and assimilated effortlessly. Available evidence, however, belies this view in that ostensibly identical technologies are employed with vastly unequal levels of technical efficiency, or productivity, in different economies and even by different firms within a particluar one.[3]

Capital goods can be transferred, but capital goods alone do not constitute a technology; they represent only that part of the technology embodied in hardware. The remainder is comprised of disembodied knowledge—and although knowledge can be transferred, the ability to make effective use of it cannot be. This ability can only be acquired through indigenous technological effort, leading to technological mastery through human capital formation.

The application of technological knowledge within industry can usefully be broken down into four broadly defined categories of activities. In the order in which mastery is typically thought to be achieved in the development of particular industrial processes, they are as follows:

—production engineering, which relates to the operation of existing plants;

—project execution, which pertains to the establishment of new production capacity;

—capital goods manufacture, which consists of the embodiment of technological knowledge in physical facilities and equipment; and

—research and development (R&D), which consists of specialized activity to generate new technological knowledge.

3. Harvey Leibenstein, "Allocative Efficiency vs. 'X-Efficiency'," *American Economic Review*, 56: 392-415 (1966).

More will be said later about the acquisition of mastery in these activities. Several general observations are nonetheless in order at this point.

In the process of undertaking the first three activities, those carrying them out often find themselves involved in the solution of technical problems not previously encountered. Such problem solving represents an exercise of technological effort—that is, the use of technological knowledge to adapt technology—and may lead to a higher level of technological mastery. More generally, technological effort is also used in the assimilation or generation of new technological knowledge and hence in the invention of new technologies, which may be either adaptations of known technologies or radically new ones. Seen in this light, R&D is merely an extreme case, with respect to its degree of specialization, of the acquisition of new technological knowledge.

Technological mastery is a relative concept. Thus the extent of a firm's or an economy's mastery can be gauged only in relation to that of other entities. Moreover, mastery is not something that can be fully quantified. For one thing, it is possible to make unambiguous measurements of comparative technical efficiency only between entities that use ostensibly identical technologies. But—as we hope to make clear—technological mastery, even narrowly defined, involves far more than technical efficiency as conventionally understood. For example, an important aspect of mastery is the ability to adapt technologies so as to make them better suited to local circumstances—either by altering output characteristics to reflect local needs and preferences or by modifying input specifications to permit the use of locally available materials and resources.

In addition, even if an entity's overall level of mastery could be measured, the separate contributions of the various types of mastery—corresponding to the categories of activity listed above—cannot be, because it is difficult to be precise about the interrelationships between them. This is particularly unfortunate, because many of the questions about technological mastery concern the relative importance of different types of mastery. For example, up to what point in a particular industry's development is mastery of production engineering sufficient? What is the relationship between mastery in production engineering and mastery in project execution? Is local capacity in capital goods manufacturing, or in R&D, necessary before socially warranted adaptations of technology can be made? These and similar questions can all be subsumed under a more general one: how should technological mastery in its various manifestations evolve in relation to industrial development? In addition to this question, the ensuing discussion deals with the question of how technological mastery is acquired.

EXPERIENCE AS A STIMULUS TO EFFORT

Technological mastery is not achieved by passively importing foreign technology. The extent of indigenous effort required for the successful assimilation of technology is most clearly demonstrated by case studies of technological changes that have occurred over time in individual firms. Much of this research has been prompted by dissatisfaction with a simplistic view of technology, which excludes the possibility that indigenous effort directed toward technological change in less-developed economies is an important part of the industrialization process.

The simplistic view holds that technology is something absolute and static: knowledge of a particular production technology either exists or it does not. A more realistic perception is that "manufacturing technology is characterized by a considerable element of tacitness, difficulties in imitation and teaching, and uncertainty regarding what modifications will work and what will not."[4] In other words, important elements of the technology appropriate to a particular situation can be acquired only through efforts to adapt existing technological knowledge. Any venture—for instance, the initiation of a new production activity—requires a great deal of iterative problem solving and experimentation as the original concept is refined and given practical expression. This sequential process lasts as long as changes continue to be made in the operation of the venture. Research on technological change at the firm level has demonstrated that this process can continue indefinitely, that it can produce technological changes that greatly increase productivity, and that it can yield substantially increased technological mastery.

Case studies of technological effort

Dahlman and Fonseca, for example, examined the technological history of an integrated Brazilian steel producer whose first plant was established with the help of Japanese steel makers.[5] In order subsequently to increase the plant's annual production capacity, the firm gradually built up its technological mastery through a carefully managed process of selectively importing technical assistance where needed to supplement its own engineering efforts. As a result, the plant's capacity was more than doubled from its initial nominal rating by means of a sequence of capacity-stretching technological changes implemented over seven years. Because these changes required very little additional capital investment and no additions to the work force, they more than doubled the plant's productivity. Moreover, as a result of the increased technological mastery this process stimulated, the firm was subsequently able to design and execute further additions to its capacity and to sell technical assistance to other steel producers, principally in Brazil, but elsewhere in Latin America as well.

More generally, firms in less-developed economies have been found to undertake substantial technological efforts in order to achieve a wide variety of technological changes.[6] These changes include, for

4. Richard R. Nelson "Innovation and Economic Development: Theoretical Retrospect and Prospect," IDB/ECLA/UNDP/IDRC Regional Program of Studies on Scientific and Technical Development in Latin America Working Paper, No. 31 (Buenos Aires: Economic Commission for Latin America, 1979), p. 18.

5. Carl J. Dahlman and Fernando Valadares Fonseca, "From Technological Dependence to Technological Development: The Case of the Usiminas Steel Plant in Brazil," IDB/ECLA/UNDP/IDRC Regional Program of Studies on Scientific and Technical Development in Latin America Working Paper, No. 21 (Buenos Aires: Economic Commission for Latin America, 1978).

6. The largest block of case-study research has been carried out under the auspices of the Regional Program of Studies on Scientific and Technical Development in Latin America, jointly sponsored by the Inter-American Development Bank, the United Nations Economic Commission for Latin America, the United Nations Development Program, and the International Development Research Center in Canada, and under

example, stretching the capacity of existing plants through various adaptations, as in the case just cited, breaking bottlenecks in particular processes within existing plants, improving the use of byproducts, extending the life of equipment, adjusting to changes in raw material sources, and altering the product mix. Some of the firms studied appear to have followed explicit technological strategies aimed at specific long-term objectives. Others seem merely to have reacted defensively to changes in their circumstances or to obvious needs to adapt imported technology. On the other hand, some firms have undertaken no appreciable technological effort and have consequently experienced no technological change.[7]

Significance of indigenous effort

Most of the technological changes uncovered in existing research can be characterized as minor, in the sense that they do not create radically new technologies, but rather adapt existing ones. Nonetheless, as shown by the example of the Brazilian steel plant, a sequence of minor technological changes can have a pronounced cumulative effect on productivity. In fact, the cumulative sequence of technological changes following the initiation of a new activity may have a greater impact on the productivity of employed resources than that produced by its initial establishment.[8] This possibility has not, to our knowledge, been explored, but it is consistent with what has been learned about the process of technological change in the industrialized countries.

Studies of major technological changes in developed countries have found it useful to distinguish between what Enos refers to as the alpha and beta stages.[9] The former includes all efforts leading to and including the introduction of a radically new technology. The latter covers all of the subsequent minor technological changes undertaken to modify and adapt it. In his own analysis of the development and diffusion of six new petrochemical processes between 1913 and 1943, Enos found that the cumulative reduction achieved in production cost per unit during the beta stage was greater than the initial reduction obtained in the alpha stage. Studies show that other major technological changes have followed the same pattern.

From the standpoint of a developing economy, the assimilation of a technology newly imported from abroad is a major technological change. The initial transfer is parallel to Enos's alpha stage. The comparable beta stage is the subsequent,

the direction of Jorge Katz. For a summary of the research so far, see Jorge Katz, "Technological Change, Economic Development and Intra and Extra Regional Relations in Latin America," IDB/ECLA/UNDP/IDRC Regional Program of Studies on Scientific and Technical Development in Latin America Working Paper, No. 30 (Buenos Aires: Economic Commission for Latin America, 1978).

7. Martin Bell, Don Scott-Kemmis, and Wit Satyarakwit, "Learning and Technical Change in the Development of Manufacturing Industry: A Case Study of a Permanently Infant Enterprise," Science Policy Research Unit Working Paper (Brighton, Great Britain: University of Sussex, 1980); Ruth Pearson, "The Mexican Cement Industry: Technology, Market Structure and Growth," IDB/ECLA/UNDP/IDRC Regional Program of Studies on Scientific and Technical Development in Latin America Working Paper, No. 11 (Buenos Aires: Economic Commission for Latin America, 1977).

8. The reference here is to technological changes that occur after the achievement of predetermined project-specific norms—for example, the nominal capacity rating.

9. John L. Enos, "Invention and Innovation in the Petroleum Refining Industry," in *The Rate and Direction of Inventive Activity: Economic and Social Factors*, ed. Richard R. Nelson (Princeton: Princeton University Press, for the National Bureau of Economic Research, 1962), pp. 299-321.

gradual improvement in the productivity with which the technology is used. The relative significance of the beta stage for a developing economy's assimilation of a new technology appears to be much greater than the analogy suggests, however. To introduce a radically new technology into the world—as in Enos's alpha stage—requires mastery of that technology; by contrast, to import a technology—as in the technology transfer analogy—does not require mastery of it, at least not at the outset. Rather, the case study research suggests that it is in the beta stage that most of the increase in developing economies' technological mastery is achieved.

Only part of the impact of this increase is reflected in higher productivity using that particular technology; much of the impact spills over into related activities. For example, the mastery gained in assimilating one technology enables greater indigenous participation in subsequent transfers of related technologies, thereby increasing the effectiveness with which they are assimilated. A number of semiindustrial economies have even exploited their mastery to export technologies on a continually expanding scale to other developing economies.[10] In more general terms, the increased mastery that results from experience with previously established technologies contributes to an economy's capacity to undertake independent technological efforts, including replication or adaptation of foreign technologies as well as creation of new technologies.

Types of mastery acquired

Most of the technological changes so far uncovered can also be characterized as having been derived from plant operating experience. Even within the confines of an existing plant, production processes do not remain static, certainly not if the firm is able to prosper within a relatively competitive environment. Production experience provides insight into how the operation of a plant can be altered to improve its performance. In addition, circumstances vary constantly over the life of a plant: input prices change, demand patterns shift, new competitors emerge, and so on.

This process of capitalizing on experience and reacting to varying circumstances requires continued technological effort to modify existing processes, which in turn represents an important source of increased mastery in production engineering—the first category of technological activity distinguished in the first section. Moreover, this form of technological effort often extends to changing the basic design of a plant, as when capacity is stretched or particular bottlenecks are broken. Thus it can also be a source of mastery in project execution—the second category in the typology provided in the first section. Nevertheless, although the type of technological mastery acquired through plant operating experience may overlap somewhat with that exemplified in project execution, the overlap can never be complete.

Mastery of almost all the tasks involved in project execution (see Table 1 for stages of project execution) requires extensive "learning by doing." Only for preinvestment feasibility studies does formal education alone suffice to impart the skills required. For the other tasks, the attainment of tech-

10. See Sanjaya Lall, "Indian Technology Exports and Technological Development," in *The Annals* of the American Academy of Political and Social Science, vol. 458 (Nov. 1981).

TABLE 1
STAGES OF PROJECT EXECUTION

1. *Preinvestment Feasibility Studies,* technical and economic, using readily available information to ascertain the viability of a project by examining alternative product mixes, input sources and specifications, plant scales and locations, and choices of production technology
2. *Detailed Studies,* following establishment of viability, using more specific engineering norms obtained from prospective sources of technology, leading to tentative choices among the alternatives considered previously and to refined estimates of capital requirements, personnel needs, cost and mode of financing, construction timetable, and the like
3. *Basic Engineering,* following confirmation of viability, to supply the core process technology by establishing the process flow through the plant and the associated material and energy balances, as well as designing specifications and layouts for major items of equipment and machinery
4. *Detailed Engineering,* to supply the peripheral technology, by providing complete specifications of equipment and materials, detailed architectural and civil engineering plans, construction specifications, installation specifications for all equipment, and the like
5. *Procurement,* which includes the choice of equipment suppliers and firms to construct and assemble the plant, coordination and control of the various subcontractors' activities and inspection of work in progress
6. *Training* of the plant's prospective personnel at all levels in various aspects of the plant's operation and maintenance, often through experience gained by working temporarily in a similar plant elsewhere
7. *Construction and Assembly* of the plant
8. *Startup* of operation, to attain predetermined project-specific norms and to complete the provision of training in the plant's operation
9. *Trouble-Shooting,* to overcome the various design problems encountered during the early years of the project's life

nological mastery requires previous experience in the same or closely related activities. Basic engineering, for example, calls for highly specialized knowledge of the core processes, which can frequently be gotten only through applied R&D, including pilot plant experimentation. Startup of operation often demands less familiarity with the principles underlying the core processes, but entails knowledge that can come only from previous production engineering experience in operating similar plants. Post-startup troubleshooting calls for somewhat more knowledge of the principles, but not necessarily as much as is involved in basic engineering. Detailed studies—the second stage of project execution—do not demand precise knowledge of individual core processes but do call for rather sophisticated knowledge of the industry. In turn, many of the individual detailed engineering tasks—for example, providing architectural and civil engineering plans that conform to requirements determined in the basic engineering stage—require no specialized knowledge whatsoever of the particular industry, but instead require other forms of specialized knowledge such as ability to design structures and civil works.

Production engineering and project execution are not the only broadly defined uses of technological knowledge, or types of technological mastery. Although they are not well incorporated into the existing research on technological change in developing countries, the two other categories of activity distinguished in the first section should not be overlooked. One is capital goods manufacture, which consists of embodying technology in machines. The other is specialized R&D to develop new products or processes.

These activities have strong links to production engineering and project execution, because to some degree they are prompted and given direction by the problems and opportunities that arise in connection with production and investment. Indeed, the kinds of technological effort associated with production engineering and project execution are frequently indistinguishable in concept from those involved in R&D. Likewise, these efforts often involve changes in the design of capital goods. Relatively little is known, however, about capital goods producers and specialized R&D performers as initiators of technological change, or about their roles in successful industrialization.[11]

RELIANCE ON TRANSFERS OF TECHNOLOGY

There are many means whereby less-developed economies can have access to foreign technological knowledge. Among them are various activities in which foreigners play a passive role, with the subsequent translation of this knowledge into technology being done indigenously. These activities include sending nationals abroad for education, training, and work experience; consulting technical and other journals; and copying foreign products. As Korean experience indicates—see the following section—these kinds of activities are tremendously important channels of information; almost invariably, some of the technological knowledge underlying new industrial initiatives in developing countries comes via one or the other of them. By contrast, transfers of technology constitute a crucially different class of activities, in that the translation of technological knowledge into operational form is made by foreigners.

Whether technology should be obtained locally or from abroad should depend on the relative costs and benefits to the recipient of acquiring it from different sources. In this connection, the degree of local mastery in the various uses of the underlying technological knowledge is of critical importance. If little previous effort has been made to acquire mastery of the specific technology, reliance on domestic sources will entail either the replication—and perhaps also the adaptation—of foreign technology or the creation of new technology through indigenous effort. Local development, however, is rarely the most effective way of initially obtaining all of the necessary elements of a technology. More generally, an economy's capacity to provide the various elements depends on the stage of development of the relevant sector and those closely related to it.

Firms starting up or already engaged in traditional or well-established activities may often be able to acquire additional elements of technology relatively easily—either through their own developmental efforts or through the diffusion of expertise from other domestic firms. The hiring of personnel with previous work experience elsewhere plays an extremely important part in the diffusion of expertise among firms, as does the interchange of information among suppliers and users of individual products, especially in the case of intermediate products and capital goods. Firms engaged in newly or recently initiated activities typically have much less opportunity to take advantage of previous ex-

11. For surveys of what is known, see Howard Pack, "Fostering the Capital Goods Sector in LDCs: A Survey of Evidence and Requirements," World Bank Staff Working Paper, No. 376 (Washington, DC: The World Bank, 1980); Diana Crane, "Technological Innovation in Developing Countries: A Review of the Literature," *Research Policy*, 6: 374-95 (1977).

perience—if any—or of diffusion or explicit transfers from other domestic firms.[12] Firms in such a position are likely to find it more cost-effective to rely heavily on foreign suppliers of technology. Even in relatively highly developed sectors, selective transfers from abroad may be equally cost-effective as aids in the process of increasing productivity.

Modes of transfer

Transfers of technology take place in a large number of ways and often incorporate not only the translation of technological knowledge into information about operational processes but other elements as well. Imports of machinery—an extremely important mode of technology transfer—represent a case in point, in which the additional element is the embodiment of the technology in hardware. Another example is direct foreign investment when used as a means to acquire technology, with the additional elements typically being financial capital, management, and marketing.

Many modes of transfer do not involve explicit and separate payment for the transfer. This is frequently the case in the kinds of transactions instanced previously that incorporate additional elements, as it is with indirect technology transfers. As an example of the latter, exporting firms often receive valuable free technical assistance as a result of their dealings with foreign buyers; in the conduct of their normal business operations, these buyers frequently provide various forms of assistance in such areas as the upgrading of product specifications and the achievement of improved quality control—see the following section outlining Korea's experience.

Explicit transactions to transfer technology without any other elements also take many forms. Among the simplest forms of transaction are contracts for the services of individuals or consulting companies to provide individual elements of technology—for example, to undertake specific design or process engineering tasks, to give technical assistance during various phases of the establishment and operation of a plant, or to provide technical information services. Other transactions include licensing and trademark agreements that transfer particular proprietary product and process designs.

The most all-inclusive form of transaction is a turnkey contract under which a general contractor is hired to assume complete responsibility for project execution, with the obligation to deliver an operating plant. Turnkey contracts, together with their counterpart in the form of direct foreign investment, are perhaps the most frequent mode of transferring technology for activities that are entirely new to an economy.

Turnkey contracts often deliver a plant together with instructions for operating it under the conditions assumed in its design, but they may fail to provide the recipient with an understanding of the full details of how the plant operates or of why it operates as it does. This hampers the recipient entity's ability to improve plant operating productivity or to adapt to changes that may occur over time in the circumstances that affect how the plant is best operated. As a result, the plant is likely to operate at lower productivity than could optimally have been achieved, with the entity probably also continuing to depend excessively on for-

12. The opportunity is least when new process technologies must be mastered. It is much greater if the new activity simply involves applying known process technologies to the production of a new product.

eign mastery for technical assistance in trouble-shooting. Alternatively, the entity will need to make greater efforts to achieve internal mastery than would have been needed if more complete information had initially been provided. These outcomes can be avoided by having the entity's personnel participate in every phase of project execution, even if only as intelligent observers who merely follow the work in progress and learn which are the relevant questions in gaining mastery of the "hows" and "whys."

The foregoing discussion points to the possibility that government intervention might be warranted to ensure that transfers of technology contribute appropriately to the development of indigenous technological mastery. This possibility raises a variety of issues, many of which are dealt with in the other articles in this issue. For the purpose of the present discussion, however, it is relevant to examine one important component of the knowledge required to design effective policies—the question of how technological mastery should evolve in relation to industrial development. It is to this issue that we now turn.

KOREAN TECHNOLOGICAL MASTERY

Historical evidence forms the principal basis for considering the relationship of technological mastery to industrial development. The Republic of Korea—often referred to as South Korea and hereafter simply as Korea—provides an instructive example. The broad outlines of Korea's remarkably successful achievement of semiindustrial status are well known and need not be repeated here. Less well known are what Korea's technological mastery consists of and how it was acquired. Available evidence on these points is summarized below for the period from the end of the Korean war through approximately 1978.[13]

The fundamental elements of Korea's industrialization have been directed and controlled by nationals. Foreign resources have made substantial contributions, but the transactions involved have typically been at arm's length. Thus, although Korea has relied quite heavily on capital inflows, these have overwhelmingly been in the form of debt, not equity, and technology has been acquired from abroad largely through means other than direct foreign investment. The purchase of technology through licensing agreements has been of modest importance as the initial source of process technology. Machinery imports and turnkey contracts have been of much greater consequence in the transfer of technology, and a tremendous amount of expertise has been obtained as a result of the return of Koreans from study or work abroad. Moreover, in only a few sectors—such as electronics—have Korean exports depended critically on transactions between related affiliates of multinational corporations or on international subcontracting.[14]

Nature of the technologies mastered

Korea's success in assimilating technologies acquired through

13. The following discussion is based on detailed evidence given in Larry E. Westphal, Yung W. Rhee, and Garry Pursell, "Foreign Influences on Korean Industrial Development," *Oxford Bulletin of Economics and Statistics*, 41: 359-88 (1979).

14. International subcontracting refers to

arm's-length transactions is in part explained by the nature of technology and product differentiation in the industries on which its growth has crucially depended. Many of these industries—such as plywood or textiles and apparel—use relatively mature technologies; in such cases, mastery of well-established and conventional methods, embodied in equipment readily available from foreign suppliers, is sufficient to permit efficient production.[15] The products of many of these industries are either quite highly standardized, plywood, for example, or differentiated in technologically minor respects and not greatly dependent on brand recognition for purchaser acceptance, for example, textiles and apparel. Thus, in most of the industries that have been intensively developed, few advantages are to be gained from licensing or direct foreign investment as far as technology acquisition and overseas marketing are concerned.

Nonetheless, exceptions exist, of which electronics is perhaps the most notable. This is an industry in which technology is changing rapidly worldwide, product differentiation is based on sophisticated technological expertise, and purchasers' brand preferences are evident. Given these characteristics, it is not surprising to find that in this case Korea has relied extensively on direct foreign investment to establish production, particularly for export, and has so far failed to gain local mastery of many key aspects of production engineering. It should be noted, however, that the electronics and certain chemicals industries are unique in Korea in their almost exclusive reliance on direct foreign investment for acquiring the very latest technology and market access.

In other industries, where technology is similarly proprietary, a number of examples attest to the fact that Korean industry has managed to initiate—and in most cases to operate successfully—a variety of "high technology" industrial activities by means of licensing and turnkey arrangements. To cite two cases: Korea used arrangements of this kind to acquire the most modern shipbuilding technology in the world and to incorporate the most recent technological advances in its integrated steel mill. More generally, Korea's recent experience in promoting technologically sophisticated industries indicates that their development may involve greater reliance on licensing as a way of acquiring technology.

Activities leading to mastery

Korea's past strategy for gaining technological mastery has relied heavily on indigenous effort through capitalizing on experience and emphasizing the selective use of technology transfers. In industries for which process technology is not product-specific, the initial achievement of mastery has frequently permitted the copying of foreign products as a means of enlarging technological capacity. The mechanical engineering industries, among others, afford many examples; such processes as machining and casting, once learned by producing one item, can readily be applied

export activity that is wholly organized by an overseas firm; the domestic, exporting firm is responsible only for overseeing production.

15. This does not imply the absence of rapid technological change in the industry in developed countries. It simply means that developing countries can—at least for a while—maintain a comparative advantage, once established, based on mastery of conventional methods more appropriate to their factor endowments.

in the production of others. One case that has been closely studied is textile machinery, in particular semiautomatic looms for weaving fabric.[16] In this as in some other cases, Korean manufacturers not only have been able to produce a capital good that meets world standards, albeit of an older vintage, but have, in addition, adapted the product design to make it more appropriate to Korean circumstances; the adapted semiautomatic looms fall between ordinary semiautomatic and fully automatic looms in terms of the labor intensity of the weaving technology they embody. In other industries in which technology is more product-specific, such as chemicals, mastery of the underlying principles has permitted greater local participation in the subsequent establishment of closely allied lines of production.

Export activity has proved to be a very important means of acquiring technological mastery. As a result of exporting, Korean firms have enjoyed virtually costless access to a tremendous range of information, diffused to them in various ways by the buyers of their exports. The resulting minor technological changes have significantly increased production efficiency, changed product designs, upgraded quality, and improved management practices. Exporting thus appears to have offered a direct means of improving productivity, in addition to the indirect stimulus derived from trying to maintain and increase penetration in overseas markets. The Korean experience also suggests that this beneficial externality of export activity may partly explain why countries following an export-led strategy have experienced such remarkable success in their industrialization efforts.

In addition, the fast pace of Korea's industrial growth has permitted rapid rates of technological learning because of the short intervals between the construction of successive plants in many industries. In some industries, including synthetic resins and fibers, the first plants were often built on a turnkey basis and on a scale much smaller than either that warranted by the size of the market or that which would exhaust economies of scale. Construction of the second and subsequent plants—at scales much closer or equal to world scale—followed quickly, with Korean engineers and technicians assuming a gradually increasing role in project execution.[17]

Significance of the Korean experience

Korea's experience demonstrates that a high level of technological mastery in all aspects of the uses of technological knowledge is not required for sustained industrial development. This is evident from the fact that its mastery has progressed much further in production engineering than in project execution. In addition, Korea has relied on foreign suppliers for necessary capital equipment and has only recently embarked on a concerted program of import substitution in

16. Yung W. Rhee and Larry E. Westphal, "A Micro, Econometric Investigation of Choice of Technology," *Journal of Development Economics*, 4: 205-38 (1977).

17. The observed pattern of time-phased plant construction in these industries might be an optimal strategy, with small scales chosen for the first plants to minimize the costs and risks entailed in learning the technology. It is not known, however, whether these or other considerations were the controlling ones at the time the first plants were constructed.

the capital goods sector. Nonetheless, Korean industry has acquired and exercised the capacity to choose the technologies to be imported, and Koreans have become increasingly involved in other phases of project execution. Fundamentally, however, Korea has become a significant industrial power mainly as a result of its proficiency in production. It thus appears that mastery of production engineering alone is nearly sufficient for the attainment of an advanced stage of industrial development.

Contemporary pronouncements about the nature of, and the constraints imposed by, the existing international economic order are contradicted by Korea's experience. In the context of calls for a "new international economic order," it is frequently alleged that existing international markets are noncompetitive and that developing countries are either denied access to technology and overseas markets or are granted it only on highly unfavorable terms. It is further asserted that foreigners exercise the initiative in transfers of technology and in the organization of export activity. If true, these assertions would imply a severe constraint on industrial development. Far from supporting them, Korea's experience shows them to be false for many important industries.

To summarize, in the course of its industrialization, Korea has effectively assimilated various elements of foreign technology. Transfers of technology have contributed importantly to this process. A wide variety of transfer modes has been used, with machinery imports and turnkey contracts predominating over licensing agreements and direct foreign investment in the initial acquisition of technology. But transfers have been no more than an initial step in the exploitation of available knowledge. Assimilation has been achieved through a succession of technological efforts over time, largely undertaken by domestic firms to extend their technological mastery and to accomplish minor technological changes. These efforts have resulted in continual and significant increases in the productivity of resources employed in the industrial sector and have been reflected in Korea's sustained rapid industrial growth. Korea's experience thus supports the argument that indigenous effort is of overriding importance in the achievement of technological mastery, but the causal forces that contribute both to the presence and to the effectiveness of indigenous effort have yet to be uncovered.

CONCLUSION: ISSUES OF TECHNOLOGICAL STRATEGY

The dependence of an economy's fund of technological expertise on the mastery of previously introduced technologies has important implications. It means that initial decisions about choices of technology and degrees of local involvement in investments to implement them are critical determinants of the directions in which an economy's technological mastery will develop. Although the empirical evidence derived from research is not yet comprehensive enough to provide a clear basis on which to make prescriptions about how an economy's technological mastery ought to evolve in relation to its industrial development, it seems clear that a synergistic relationship can develop between them, with advances in each prompting new gains in the other. As Korean experience demonstrates, however, high indigenous levels of all types of technological mastery are not necessary for the initial stages of industrial development; in the Korean case, a mastery that has been mainly confined to production engineering has been sufficient. The Korean example also suggests that by relying on foreign sources of technology, it is possible to choose a technology without having first mastered its use. In the same way, it is also possible to use a technology without having the mastery required to replicate it through project execution or to manufacture the capital goods involved.

Nevertheless, it should be remembered that, just as the initial choice of production method may greatly constrain the direction of technical change, so the kinds of technological effort in which an economy acquires experience may constrain the type of technological mastery it can develop. Furthermore, there is an important difference between attaining mastery in relation to given circumstances and in attaining the capacity to adapt to changing circumstances. The objective of acquiring technological mastery is not simply to produce in the present; equally, it is the ability to adapt technology and to anticipate changes in world and domestic markets. Thus it is also necessary to develop the capacity to innovate in various respects. It is unclear how far this capacity can be developed solely on the basis of production engineering or project execution experience.

The effects of government policy on the development of indigenous technological mastery have yet to be ascertained. Further research to uncover historical evidence from different countries' cases is necessary to reach any soundly based generalizations about the determinants of the extent and appropriateness of technological effort in different directions. Such generalizations are needed to formulate policies that will direct the attainment of increased technological mastery in ways in line with social objectives. In particular, much remains to be learned about the appropriate phasing of the replacement of technology transfers by indigenous technological effort and about the impact of different policies on the development of the various types of technological mastery.

World Bank
Headquarters:
1818 H Street, N.W.
Washington, D.C. 20433, U.S.A.

Telephone: (202) 477-1234
Telex: RCA 248423 WORLDBK
WUI 64145 WORLDBANK
Cable address: INTBAFRAD
WASHINGTONDC

European Office:
66, avenue d'Iéna
75116 Paris, France

Telephone: 723.54.21
Telex: 842-620628

Tokyo Office:
Kokusai Building
1-1, Marunouchi 3-chome
Chiyoda-ku, Tokyo 100, Japan

Telephone: 214-5001
Telex: 781-26838

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WASHINGTON, D.C. 20433
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