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Technological Effort in Industrial Development

An Interpretative Survey of Recent Research

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6 Technological effort in industrial development – an interpretative survey of recent research*

CARL DAHLMAN and LARRY WESTPHAL

INTRODUCTION

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. It does not follow, however, that technological effort has only a minor role to play in the process of industrial development. Such an inference would only be valid if technological effort were conceived narrowly, as the employment of resources solely for the purpose of creating new knowledge. In fact, however, resources are also needed for the task of learning to make effective use of existing knowledge. It is in this broader and more realistic sense that the term 'technological effort' is used in this chapter – i.e. as the employment of resources not just to create technological knowledge, but also to master it.

It is worth defining at the outset some items of terminology used in this chapter. We define *technological effort* as the use of technological knowledge together with other resources to assimilate or adapt existing technology and/or to create new technology. A *technology* may be defined as a collection of physical processes which transforms inputs into outputs, together with the social arrangements (i.e. organisational modes and procedural methods) which structure the activities involved in carrying out these transformations (see Brooks, 1980; Hannay and McGinn, 1980). Thus technology may be thought of as the translation into practice of *technological knowledge* (see Salter, 1960; pp. 13 ff), which we define as information about physical processes which underlies and is given operational expression in technology. Finally, *technological mastery*

* The authors are members of the Development Policy Staff of the World Bank. The views and interpretations expressed here are theirs and should not be attributed to the World Bank, to its affiliated organisations, or to any individual acting on behalf of these organisations. Peter Bocock edited the manuscript for publication.

is defined as operational command over technological knowledge. Mastery manifests itself in the ability to use knowledge effectively, and is achieved by the application of technological effort. In summary, all four terms may be dynamically linked as follows: *technological mastery* is the effective use of *technological knowledge*, through continuing *technological effort* to assimilate, adapt and/or create *technology*.

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, and a narrow conception of technological effort would be appropriate. 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 particular one (Leibenstein, 1966).

Thus, the shorthand expression 'transfer of technology' is misleading, to the extent that it suggests that technologies can in fact be transferred wholesale and in working order. Capital goods can be transferred, but capital goods alone do not constitute a technology; they represent only that part of the technology which is embodied in hardware. As noted above, the remainder is comprised of disembodied technological knowledge and related social arrangements – 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.

In this chapter we are primarily concerned with technological effort and mastery as they relate to physical processes.[1] It is important to bear in mind, however, that these physical processes are undertaken within a framework of social arrangements which condition their operation; it is sometimes necessary, therefore, to broaden the boundaries of the concept of mastery to encompass the development of appropriate social arrangements as well. This is particularly true when discussing choice of technology (see pp. 109–13).

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:

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

More will be said about the acquisition of mastery in these categories of activity in later sections of this paper. Several general observations are none the less in order at this point.

Engaging in any of the first three activities at a given level of mastery does not involve technological effort. Those carrying out these activities may, however, find themselves involved in the solution of technical problems not previously encountered; such problem solving represents an exercise of technological effort (i.e. the use of technological knowledge to adapt technology), and may lead to a higher level of 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 either be 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 specialisation, of the acquisition of new technological knowledge.[2]

Technological mastery is a relative concept. Thus the extent of a firm's or an economy's mastery can only be gauged in relation to that of other entities. Moreover, mastery is not something which can be fully quantified. For one thing, it is only possible to make unambiguous measurements of comparative technical efficiency between entities which 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.

Moreover, 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.

The discussion is organised as follows. The rest of this section provides an introduction to the next four sections, which survey the main areas of past research on the relationship between technology and industrial development. The survey focusses on those findings which are of greatest relevance to understanding the acquisition of technological mastery, and is necessarily brief; thus it does not cover all the findings that might be relevant in different contexts. The sixth section reviews the evolution of technological mastery in relation to one country's industrial development. The case study is of the Republic of Korea, which has been chosen because of the authors' comparative ignorance of other economies and — more importantly — because of the interest that attaches to understanding the sources of its successful attainment of semi-industrial status. The concluding section highlights several important issues that have not yet been given adequate attention in empirical research.

Past research has been prompted less by interest in the acquisition of technological mastery than by uneasiness about problems associated with imports of technology — most notably about the failure of the industrial sector in most developing economies to generate expected levels of employment (see Eckaus, 1955). The question typically asked in this connection is whether methods of production developed in capital-abundant, labour-scarce industrial economies are appropriate for economies with the opposite relative factor endowments. In addition to addressing this question, research on choice of technology provides an empirically-grounded understanding of technology. For this reason, and because the ability to choose technology is a critically important aspect of technological mastery, we begin our survey with this research.

A central problem in choosing appropriate technologies is the lack of experience with which decision-takers typically approach the process of choice. If choice is to be informed, some prior experience would appear to be essential, but it is all too often absent; moreover, it appears that technological mastery in practice is more a function of indigenous problem solving at the plant level than of acquiring ready-made experience from abroad. The empirical evidence for local technological effort and experience as sources of mastery is discussed in the third section.

In addition to the problem of appropriate choice, reliance on imported technology also raises the problem of the ways in which technology is often transferred. The proposition that foreign technology may sometimes be acquired on terms that are highly unfavourable is well known. This problem, though important, is touched on only briefly in this paper. Less extensively studied but gaining increased attention is the near certainty that some forms of technology transfer have the effect of undesirably retarding the development of indigenous technological mastery.

This problem, which is examined in the fourth section, is generally perceived to be of secondary concern compared to the issue of the undue capital intensiveness of foreign technology, which is considered to have an immediate bearing on employment generation. But employment generation suffers from the capital intensiveness of foreign technologies only when they are inappropriately chosen.[3] The acquisition of increased technological mastery, on the other hand, is what ultimately underlies the movement of labour from lower to higher productivity employments. The effects of technology transfers on the development of local technological mastery are thus of central concern.

Issues of technological choice, the promotion of indigenous technological mastery and the need to guard against some of the more damaging effects of certain kinds of technological transfer lead naturally into consideration of the part which public policy in developing countries might appropriately play in this area. The fifth section reviews the available evidence on various policy approaches adopted by governments, discussing in particular the relative merits of explicitly interventionist instruments on the one hand, and the promotion of a general climate for industrial development conducive to purposive technological effort at the entity level on the other. Finally, the sixth section provides data on Korean experience and the last section offers some tentative conclusions and questions for further examination.

CHOICE OF TECHNOLOGY

Research on technology choice has first had to ascertain whether there are in reality any efficient alternatives to the 'best-practice' technologies of the industrial economies and, indeed, whether there is only one 'best-practice' technique for any individual activity.[4,5] It is now well established that there is scope for choosing between techniques with different levels of labour intensity and productivity, but that the scope for choice is by no means uniform. The conventionally accepted method for choosing between alternative techniques is to evaluate each in terms of its associated benefits and costs, using shadow prices which properly reflect the relative scarcities of different factors of production (Sen, 1962). The best (or appropriate) technique is that which has the highest net benefit.

Where the scope for choice is quite broad (e.g. in textile weaving), relatively labour-intensive techniques, rather than the current 'best-practice' techniques of the industrial economies, tend typically to be most appropriate for developing-country economies.[6] These techniques often represent an older vintage of technological best practice in the industrial economies. They can frequently be obtained by buying used equipment which no longer has profitable uses in the industrial economies because of changing relative factor scarcities.[7] In addition, capital-goods producers somewhere in the world may continue to embody these older vintages in new machinery and equipment. Sometimes, however, the best technique may be one which originated in a developing economy, usually as an adaption of a former 'best-practice' technique in the industrial economies. Much less frequently, it may be innovative and radically different from others currently in use.

For most activities in the majority of industries, no single technique is best for all circumstances. Local factor endowments and requirements vary widely — both among different developing economies and between them and the developed economies. As well as differing significantly in their relative use of capital and labour, techniques may also exhibit equally and sometimes more important differences in regard to intermediate input requirements and joint production possibilities. Thus it is important to ask whether the techniques actually chosen in particular circumstances are the appropriate ones. A number of studies have found that they often are not.

The choice of an appropriate technology depends on the availability of technological information and on the choice-maker's ability to utilise the information effectively in making evaluative judgements. Lack of technological mastery is sometimes wholly responsible for the selection of inappropriate techniques. The causes generally extend beyond poor technological mastery, however; institutional behaviour and relationships often also play a part. Lack of motivation to search for appropriate alternatives is occasionally to blame. For example, government policies, such as excessive protection from imports, can effectively destroy rational incentives for search. Such policies can also induce producers to search for the wrong kinds of techniques (e.g. when they create artificial distortions in factor prices). More generally, inappropriate techniques frequently result from the absence of incentives for producers to make choices which are consonant with social objectives. In addition, producers sometimes fail to respond to price signals, and base their choices on criteria that are independent of economic forces (Wells, 1973). Finally, it is often not possible to choose appropriate techniques for activities that produce related products without giving explicit recognition to the interdependence between these choices (see Rhee and Westphal, 1979). The way in which activities are organised among producers affects whether and how such interdependencies are taken into account and has a major influence on whether appropriate choices are made.

Past research also suggests that the implementation of appropriate technology choices often requires complementary investment to enhance local technological mastery, because technological parameters are highly sensitive to local circumstances and experience-related elements. Technological parameters for a specific plant should not be confused with 'engineering norms'. The latter, which serve as points of reference for various modes of engineering analysis, are values for the former which are valid under an assumed set of 'standard conditions' for plant establishment, maintenance, and operation. Depending on whether or not the technology is established and its use has been widely researched, they may be based on extensive experience with numerous plants or they may simply be engineering estimates, based only on theoretical analysis and experimentation within a controlled environment. In any event, they pertain to conditions, real or ideal, which generally differ in important respects from the conditions which confront a specific plant.

A variety of local circumstances can cause plant technological parameters to depart from engineering norms. For activities connected with plant establishment, these sources of variation may comprise the particular characteristics of the site and the stage of development of local construction and engineering services. For plant maintenance activities, they include the availability of skilled maintenance workers and the capabilities of local machine shops to produce replacement parts. For plant operation, they encompass such factors as the level of labour skills and the characteristics of the intermediate inputs to be used. Managerial ability affects virtually all technological parameters.

Many studies of technology choice have been based on engineering norms, but studies based on actual plant data suggest that factors of the kind listed above can affect the operational outcome of a particular choice in extremely important ways. An example taken from a study of the operation of Korean textile weaving firms (Rhee and Westphal, 1977) illustrates the point. Based on a careful survey of a number of establishments, the average number of semi-automatic looms tended by a single operator was found to be 5.1, with a standard deviation of 4.0 looms per operator. Statistical analysis which eliminated the influence of loom and fabric specific differences indicated that differences in firm-specific characteristics – that is, in management practices and labour quality – accounted for variations between establishments which averaged more than 1.5 looms per operator. The standard deviation of the output per loom in the same sample was more than 20 per cent of the average output per loom. Thus differences in firm-specific characteristics alone were estimated to produce variations which on average were roughly equal to the standard deviation. The high degree of unexplained variance in the underlying statistical analysis, which employed standard textile engineering relationships, is further evidence that the key technological parameters in textile weaving are far from being universal constants.

In sum, while the parameter values potentially achievable under the best possible conditions may be universally given, the extent to which these conditions are realised depends upon local circumstances and varies widely between plants (Leibenstein, 1966). Differences in management ability and labour quality are of special importance, but other factors such as differences in available infrastructure (e.g. machinery repair facilities or the physical properties of available intermediate inputs) may also significantly affect operational outcomes.

Variations in local circumstances typically affect alternative techniques in different ways, and may correspondingly affect the appropriateness of a particular choice. In textile weaving, for instance, the relevant choice is often between semi-automatic and automatic looms. The former embody a far more labour-intensive technique – suggesting that they might be an appropriate choice for a plant in a developing economy. The two techniques differ in other ways as well, however. For example, the probability of yarn breakage during weaving is higher with semi-automatic looms, and the skills of the weavers determine whether yarn breakages can be repaired without causing imperfections in the cloth. In this respect, the prevalence of low skill levels would suggest choice of the automatic technology; indeed, it is sometimes argued that automatic looms are the appropriate choice in all cases where weavers have not attained exceptionally high skill levels.[8] Similarly, the absence of local machinery repair and spare-part production facilities – or, more generally, low levels of technological mastery in these activities – discourages the selection of older-vintage, more labour-intensive techniques embodied in used equipment for which maintenance services and replacement parts can no longer be obtained from the original manufacturer.

Thus, mechanisation — that is, the substitution of capital for labour — often does permit the substitution of less-highly skilled for more-highly skilled labour, and smaller-scale and/or more labour-intensive production methods often do require a larger input of a different type of management and organisational skills. Nevertheless, to the extent that they can be changed or offset through investments to upgrade levels of technological mastery, local circumstances need not impose absolute constraints upon the adoption of what would otherwise be appropriate techniques. Labour and management skills can be augmented through investments in human capital formation; local machinery repair and spare-part production facilities can be developed. Alternative choices should thus be considered in conjunction with whatever complementary investments may be desirable or necessary for their successful implementation.

In short, social objectives are often best served by choosing techniques whose input requirements are most nearly in line with relative scarcities in the economy, supplemented as necessary by complementary investments to enhance local technological mastery in the relevant sector and the sectors which provide necessary inputs. This point is forcibly illustrated by research on the scope for capital-labour substitution in civil construction (Sud *et al.*, 1976). In the first phase of this research, labour-intensive methods were found to be technically feasible for a wide range of construction activities, achieving product standards equal to those of more capital-intensive methods. They were, however, found to be economically non-competitive, even at extremely low wage rates. In subsequent phases it was found that traditional methods could be made economically competitive, even at more reasonable wage rates, by adapting them through the use of improved tools, proper wage incentives, better project organisation and more careful work management. It thus proved possible to make the traditional methods competitive with more recent capital-intensive methods as a result of an injection of technological mastery from outside (in the form of the researchers' ability to design improved tools and to upgrade management practices in the use of the traditional technology).

EXPERIENCE AS A SOURCE OF TECHNOLOGICAL MASTERY

As the preceding discussion has indicated, technological mastery is not achieved by passively importing foreign technology. Research on the transfer of technology, which will be discussed in some detail in the next section, leads even more directly to the same conclusion. The extent of indigenous effort required for the successful assimilation of technology is most clearly demonstrated, however, 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 towards technological change in less-developed economies is an important part of the industrialisation process.[9] Uneasiness about this view has led researchers to seek direct evidence of technological effort and change in the industrial sectors of developing economies, and to develop a more realistic conception of technological mastery.

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 'manuacturing 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' (Nelson 1979; p. 18). 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 for 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 which greatly increase productivity, and that it can yield substantially increased technological mastery.

Dahlman and Fonseca (1978), for example, examined the technological history of an integrated Brazilian steel producer whose first plant was established with the help of Japanese steel makers. 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 selectivity importing technical assistance where needed to supplement of 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 total factor productivity. Moreover, as a result of the increased technological mastery which 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.[10] These changes include, for 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 by-products, extending the life of equipment, adjusting to change 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.[11] As yet too few case studies exist for it to be possible to generalise about what determines the extent and direction of technological effort by individual firms. Nevertheless, it is apparent that economic forces have an impact, as do characteristics peculiar to individual firms and types of technology.

Some of the technological changes described in the case studies appear to be inconsistent with social objectives. For instance, when account is taken of the effort involved, some capacity-stretching technological changes may be socially more costly than the alternative of building additional plants. Teitel (1981) argues that this is true of some of the technological effort found in case studies of Latin American firms; he further speculates that this is the result of the inward-looking development strategies and protectionist policies that have been followed by the countries involved. Most of the available case studies do not include sufficiently detailed information to permit even a partial quantification of the costs and benefits of the technological changes they describe. It is clear, however, that most of the effort so far examined has had social benefits in excess of social costs, even though the extent of the excess is unknown.

Most of the technological changes uncovered in existing research can be characterised as minor, in the sense that they do not create radically new technologies but rather adapt existing ones. None the less, 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.[12] 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 industrialised countries.

Studies of major technological changes in developed countries have found it useful to distinguish between what Enos (1962) refers to as the alpha and beta stages. 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 state. Studies show that other major technological changes have followed the same pattern – the economic impact of replacing the old technology by the new is generally less than the cumulative impact of gradual improvements made afterwards.

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' alpha stage. The comparable beta stage is the subsequent, 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' 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 the 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 semi-industrial economies have even exploited their mastery to export technologies on a continually expanding scale to other developing economies (Lall, chapter 8, this volume). In more general terms, the increased mastery which 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.

Most of the technological changes so far uncovered can also be characterised 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 peformance. In addition, circumstances vary constantly over the life of a plant: input prices change, demand patterns shift, new competitors emerge and so on. (The many possibilities for improving performance and reacting to changing circumstances can be appreciated by recalling that inputs and outputs alike are highly differentiated in most industries.)

This process of capitalising 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 technology activity distinguished in the first section. Moreover this form of technological effort often extends to changing the basic design of a plant 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 above. 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.

To understand this point, it is worth listing the tasks involved in project execution and considering the types of experience which are required to perform them effectively. Project execution includes:[13]

preinvestment technical and economic feasibility studies, using readily available information to ascertain the viability of the project by examining alternative product mixes, input sources and specifications, plant scales and locations, and choices of production technology;

if viability is established, more *detailed studies*, 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;

if viability is confirmed, *basic engineering* 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);

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 so on;

procurement, which includes the choice of equipment suppliers and firms to construct and assemble the plant, coordination and control of the various subscontractor's activities, and inspection of work in progress;

training of the plant's prospective personnel at all levels in various aspects of the plant's operation and maintenance, often through experience working temporarily in a similar plant elsewhere;

construction and assembly of the plant;

startup of operation, to attain predetermined project-specific norms and to complete the provision of training in the plant's operation; and

trouble-shooting, to overcome the various design problems encountered during the early part of the plant's life.

Mastery of almost all these tasks involves extensive 'learning by doing'. Only for pre-investment feasibility studies does formal education alone suffice to import the skills required. For the other tasks, the attainment of technological mastery requires previous experience in the same or closely related activities. Basic engineering, for example, calls for highly specialised knowledge of the core processes, which can frequently be acquired 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 trouble shooting calls for somewhat more knowledge of the principles, but not necessarily as much as is involved in basic engineering. Detailed studies (the second task in the sequence) do not demand precise knowledge of the industry. By contrast, 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 specialised knowledge whatsoever of the particular industry, but instead require other forms of specialised 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. 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 specialised R&D to develop new products or processes.[14] 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.[15] Likewise, these efforts often involve changes in the design of capital goods. Relatively little is known, however, about capital goods producers and specialised R&D performers as initiators of technological change, or about their roles in successful industrialisation.[16] The rest of this paper therefore focuses on the achievement of mastery in production engineering and project execution; the discussion concentrates on how the development of this mastery is affected by the ways in which foreign technology is obtained, and by government policies regarding technology transfers and industrial development.

RELIANCE UPON 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; copying foreign products etc. As Korean experience indicates (see later dicussion), 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 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 ought to depend upon 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 upon 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 upon 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 experience (if any), or of diffusion or explicit transfers from other domestic firms.[17] 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 aids to the process of increasing productivity.

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 transfer. This is frequently the case in the kinds of transactions instanced above which 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 later description of Korea's experience).

Significant though they may be, indirect transfers have not received much attention in past research. There has likewise been very little research into the acquisition of foreign technological knowledge through activities in which foreigners play a passive part. Information about these sources of knowledge is hard to obtain while the problems associated with direct transfers in which foreigners play an active part are more easily inferred. Thus past research has concentrated on transfers made through transactions for which a primary motivation is clearly to purchase technology.

Explicit transactions to transfer technology without any other elements 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 which 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. Transfers of technology embedded in direct foreign investment are sometimes accomplished through turnkey contracts given to independent general contractors, but more often it is the foreign investor who acts as the general contractor. Either way, with respect to the division of labour between local and foreign technological effort, direct foreign investment is usually indistinguishable from a turnkey contract. Turnkey contracts, together with their counterpart in the form of direct foreign investment, are perhaps the most frequent mode of transferring technology for activities which are entirely new to an economy. Even if turnkey contracts are not used, the scope and scale of technology transfers involving the creation of a new industry are almost always greatest in the case of the establishment of the first, or the first few, plants.

For policy-making purposes, there are two critical distinctions to be made among the various forms of transactions to transfer technology. The first is between transactions which simply transfer technological knowledge and ones which incorporate other components as well. As we have indicated, these other components sometimes include proprietary elements, such as trademarks and brandnames; they may also involve transfers of capital, management, and marketing. The significance of this distinction will be indicated further below. The second distinction relates to whether the transaction involves multiple elements of technology transfer.

The problem confronted in the more all-inclusive forms of technology transfer is that tasks which could be performed locally are carried out by foreigners. This can increase project costs, because the services could have been provided more cheaply by local suppliers, and because intimate knowledge of local conditions may be required to optimise plant design. Moreover, failure to use qualified local suppliers precludes the possibility of local accumulation of human capital through experience-based learning. The economy is thereby deprived of experience that is directly relevant to the industry's subsequent development. (It is also worth noting that developing countries' inability to make effective use of such human capital as they have acquired is a contributing factor to the loss of highly trained local personnel through the 'brain drain'.)

In addition, turnkey contracts often deliver a plant together with instructions for operating it under the conditions assumed in its design, but 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 which 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 upon foreign mastery for technical assistance in troubleshooting); 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'. Some foreign technology suppliers may be unwilling to permit such participation, however, for fear that it will transfer too much of their technological mastery.

The crucial role of experience in acquiring technological mastery has already been emphasised. Experience produces not only increased technological mastery but also greater productivity in supplying given elements of technology. Unless carried out with the explicit objective of doing so, technology transfers associated with project execution do not necessarily provide the experience which is critical to the development of indigenous technical and engineering services. For example, it has already been suggested that conventional turnkey contracts are not intended to provide mastery in any of the phases of project execution, and that they may fail even to transfer an adequate understanding of production engineering. In short, imports of technology need not transfer any of the technological mastery needed for the subsequent replacement of foreign by local expertise.

Given this state of affairs, it may be asked whether domestic firms have adequate incentives to take appropriate advantage of opportunities to increase domestic mastery through experience in supplying technology from local resources. Domestic firms may prefer to import technology when social objectives would dictate using local suppliers because of the increased experience which the latter would gain. In turn, where imports are consistent with social objectives, domestic firms may prefer methods of technology transfer which do not adequately provide for the kinds of local participation that would increase domestic technological mastery. Even the simplest form of participation — intelligent observation — entails a cost.

A rational firm seeking to acquire technology seeks to pay the lowest possible price consistent with having the greatest possible assurance of obtaining a technology which is reliable and well-suited to its circumstances. It is unlikely to use inexperienced local resources or to provide for their participation unless it expects to gain a long-run benefit that more than compensates for greater risks and/or higher costs in the short-run. The social benefit of increased technological mastery, however, generally exceeds the benefit which an individual firm can expect to capture; there are many avenues by which technological mastery can diffuse to other firms, and not all of these avenues are under the control of the firm that finances the initial acquisition. In addition, the firm may value the benefits that it does capture at less than their true social worth; likewise, the cost of acquiring technological mastery as seen from the firm's perspective may exceed the true social costs. Unless influenced by some form of public intervention, a firm acting alone may therefore not find it in its individual interest to take advantage of opportunities to increase domestic technological mastery as much as social objectives would dictate.[18]

The motives that underlie the packaging of multiple technological elements and of various non-technological components within a single transaction are different but no less powerful. Participants on both sides of the transaction benefit from packaging in so far as it increases their respective net returns. Thus, to the extent that packaging lowers the total cost of the undertaking,[19] and to the extent that the supplier and the recipient share in the savings, each has an incentive to accept a compound transaction. More than simply cost reduction may be involved, however, particularly as regards the inclusion of non-technological components.

What ultimately enables certain suppliers to impose packaging is their possession of some form of monopoly power, such as that conferred by a well-known brandname. In such cases, the price paid for the package necessarily includes a monopoly profit and can in that sense be considered 'excessive'. The principal motive behind the recipient's acceptance of the package is typically the desire to acquire the same monopoly power, at least within the domestic market. There is a convergence of interests between the domestic firm and the foreign supplier to agree on a compound transaction, since the domestic firm can offset the promise of monopoly profits against the excessive price paid.

Thus some compound transactions which transfer more than just technology are not socially desirable even though they are clearly in the interests of the domestic firms involved. That is, the motives which give rise to technology imports can sometimes be at variance with social objectives, because of the characteristics of the production which they make possible and the monopoly power which they confer.[20] Moreover, as indicated above,these motives can also be at variance with social objectives concerning the development of indigenous technical and engineering services.

GOVERNMENT POLICIES

Research on transfer of technology has shown that government intervention can serve several important purposes, including the following: to foster the choice of the most appropriate among alternative foreign techniques; to obtain imports of technology on the best possible terms; to avoid compound transactions which include components that are socially undesirable; to promote, where appropriate, the use of local suppliers rather than foreign sources; and to ensure, where technology is imported, that the method of transfer provides for adequate local participation designed to increase domestic technological mastery.[21] Some of these aims can be achieved through defensive measures, such as protecting local suppliers from import competition. Others can only be attained by taking positive steps, such as requiring local participation so as to ensure adequate absorption of imported technology.

Governments of many developing countries have intervened in transfers of technology, generally by imposing defensive measures to control the terms on which transfers are made and to protect local suppliers. These measures discriminate strongly against compound transactions and in favour of single-element technology transfers. They also prohibit foreign suppliers from imposing undesirable conditions — such as restrictions on exports produced using the technology, or obligations to make available to the supplier any improvements made in the technology. These measures often have the explicit aim of offsetting the asymmetry that exists in the relative bargaining strengths of foreign technology suppliers and domestic recipients; they may also be complemented by various forms of positive assistance in the negotiation process. The asymmetry results in large measure from the very differences in technological knowledge and access to information that the transfer is meant — at least in part — to remove. As a way of offsetting these differences, various governments also provide assistance to increase the knowledge available to technology-seeking firms. To promote the use of local suppliers, some governments maintain registries which give information about suppliers' capabilities. In a number of countries, local suppliers are protected by requirements that the prospective importer provide evidence that the desired technology cannot be obtained domestically.

It is difficult to evaluate the impact of these measures. Their proponents assert that they have reduced expenditures on imported technology and have helped to eliminate undesirable conditions without reducing the inflow of desirable technology imports (see Stewart, 1981), It is unclear, however, whether changes in the formal terms of transfer have been counterbalanced by the addition of informal terms, or whether the imposition of controls over formal terms has reduced the willingness of foreigners to supply technology. Positive assistance to increase the technological knowledge available to domestic firms, and to enhance their bargaining strength and negotiating ability, has undoubtedly had beneficial results, but their extent is unknown. In turn, no systematic body of evidence currently exists which could be used to assess the effects of promoting the development of local technology suppliers, whether by protection or by other means. Indeed, there is very little basis for judging what role the government should appropriately play in the development of local technological capacity.

To address this question, cross-country comparative evidence is needed which shows how government policies have affected the achievement of technological mastery, and how mastery of the various uses of technological knowledge is related to the attainment of social objectives through industrialisation. The research that comes closest to providing such evidence is the Science and Technology Policy Instruments (STPI) project, the results of which are summarised in Sagasti (1978).[22] This project sought to establish the comparative efficacy of different government policies aimed at creating technological mastery. It focused on what were termed 'explicit' policy instruments. These included the creation of technological infrastructure through institution building; the establishment of science and technology plans; promotion of the use of local technology suppliers; the provision of fiscal incentives and direct subsidies to various kinds of technological effort; the regulation of technology imports through measures of the kind discussed above; and other public actions directly in support of indigenous technological effort.

The central conclusion of the research was that explicit instruments had far less impact on technological change and the acquisition of technological mastery than did other policies (for example, related to trade, credit allocation, investment licensing, and the like) which affected industrial development more generally.[23] Explicit instruments did, however, appear to assume increasing importance as industrial development progressed.

It is unclear why the explicit instruments were found to have relatively little effect. It is possible that their ineffectiveness was a consequence of another finding of the research, which was that these instruments tended to be poorly implemented and often to work at cross-purposes. Thus, if properly applied, explicit instruments might have a much greater impact. It may equally be true, however, at least up to a certain stage of industrial development, that what is most important is to gain mastery in production engineering and project execution, that such mastery derives principally from technological efforts related to the experience of industrial firms, and that what matters most in this regard is the general climate for industrial development. These possibilities were not explicitly considered at the outset of the STPI project; consequently, they cannot be assessed on the basis of the information gathered by it, though the project did include a number of somewhat sketchy case studies that showed considerable technological effort at the firm level.

Other research, described in earlier sections of this paper, has found that firms in developing countries acquire increased technological mastery by engaging in purposive technological effort to assimilate and adapt technology, an effort which typically takes place in relation to experience gained in production engineering and project execution. These findings, cannot, however, be taken to show that experience *necessarily* leads to greater technological mastery and thereby to beneficial technological changes. Whether experience produces such results depends crucially on the extent and character of purposive effort to capitalise upon it, and this effort is by no means automatically forthcoming. Whether and in what directions the effort takes place depends – at least in part – on the combined impact of a wide variety of incentive policies which condition the climate for industrial development. Moreover, it is by no means certain that the technological changes which follow from such effort are always consistent with social objectives, or that sufficient effort will be forthcoming in all appropriate directions. Discussion of this last point is deferred to the concluding section.

KOREAN TECHNOLOGICAL MASTERY

Historical evidence forms the principal basis for considering how technological mastery might appropriately evolve in relation to industrial development. The Republic of Korea – often referred to as South Korea and in this Chapter simply as Korea – provides an instructive example. The broad outlines of Korea's remarkably successful achievement of semi-industrial 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 summarised below for the period from the end of the Korean War until approximately 1978.[24]

The fundamental elements of Korea's industrialisation 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 upon transactions between related affiliates of multinational corporations or upon international subcontracting.[25]

Korea's success in assimilating technologies acquired through 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.[26] The products of many of these industries are either quite highly standardised (plywood, for example) or differentiated in technologically minor respects and not greatly dependent on brand recognition for purchaser acceptance (textiles and apparel, for example). 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.

None the less, 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. This is not a matter of absolutes, however; it remains possible to substitute for licensing by replicating foreign technology through local effort. The difference is simply that the cost of doing so is higher in the industries which have been promoted in more recent years. It is unclear, however, whether overseas firms will be willing to license technology without restricting its use. They may impose restrictions on the sales of licensed products, prefer to give access to technology only through direct foreign investment, or even deny access. It is equally unclear whether the shift also implies greater dependence on licensing and direct foreign investment for access to overseas markets, if only to gain rapid consumer acceptance through the use of familiar brand names.

Nevertheless, there can be no doubt that Korea's past strategy for gaining technological mastery has relied heavily on indigenous effort through capitalising on experience and emphasising the selective use of foreign resources. 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 in the production of others. One case which has been closely studied is textile machinery, in particular semi-automatic looms for weaving fabric (Rhee and Westphal, 1977). In this as in some other cases, Korean manufacturers have not only been able to produce a capital good that meets world standards, albeit of an older vintage; they have, in addition, adapted the product design to make it more appropriate to Korean circumstances. (The adapted semi-automatic looms fall between ordinary semi-automatic and fully automatic looms in terms of the labour 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. This beneficial externality of export activity has gone largely unnoticed in the literature on trade and development. The Korean experience indicates that it is very real, and further suggests that it may in part explain why countries following an export-led strategy have experienced such remarkable success in their industrialisation efforts.

Furthermore, 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 fibres, the first plants were often built on a turnkey basis and on a scale which was much smaller either than that warranted by the size of the market or that which would exhaust scale economies. Construction of the second and subsequent plants -- at scales much closer or equal to world scale[27] — followed quickly, with Korean engineers and technicians assuming a gradually increasing role in project execution. To this extent, Korea's technological mastery in these industries can be said to extend beyond production engineering to project execution.

Korea's experience demonstrates that indigenous entrepreneurs can be relied upon to identify profitable ventures, to exercise selectivity in the use of foreign resources, including technology transfers, and to manage industrial undertakings. But Korea's entrepreneurial talent has not been deployed in industry alone; government also has benefited. Indeed, Korea's remarkably successful industrialisation would not have occurred if the government had not designed and implemented effective policies to foster industrial dynamism.

Korea's experience further 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 programme of import substitution in the capital-goods sector. None the less, 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 non-competitive, and that developing countries are either denied access to technology and overseas markets or are granted it only on highly unfavourable terms. It is further asserted that foreigners exercise the initiative in transfers of technology and in the organisation 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 summarise, in the process of its industrialisation, Korea has effectively assimilated various elements of foreign technology, but without much direct foreign participation in its industrial sector. Assimilation was 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. Korea's experience 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

This chapter has stressed the role of technological effort in relation to production engineering and project execution as a source of technological mastery. Such effort involves not only assimilation but also adaptation of technology. Foreign and indigenous technologies alike can be adapted in numerous ways to make them better suited to local circumstances. This fact gives rise to an important question: is the technological effort which takes place sufficient to ensure that all socially warranted adaptations are made?[28]

As indicated in the earlier dicussion, it is clear that individual firms sometimes undertake technological efforts which are inconsistent with social objectives and conversely that they often do not have sufficient incentives to undertake socially warranted technological efforts. Though it is only one of many determinants, market structure exerts a strong influence on the extent and direction of technological effort. Socially wasteful effort tends to be associated with either the exercise or the pursuit of monopoly power. By contrast, producers in highly competitive industries are unlikely to engage in enough technological effort; uncertainty, indivisibilities in the effort required, and inability to appropriate the full benefits all contribute to the latter result (Arrow, 1962).

Government intervention designed to promote socially warranted adaptations can take many forms. Producing firms can be encouraged by subsidies or other means either to undertake technological efforts directly or to contract for them. In addition, the development of specialised agents of technological change can be promoted. In following the latter approach, the governments of a number of less-developed economies have concentrated on establishing publicly-supported R&D institutes to undertake scientific and technological research. Underlying the creation of many of these institutions was the belief that technological change is a linear process which starts with R&D and proceeds by stages automatically to commercial application, with at least the initial stages being quite distinct and easily separable from production activity. R&D institutes were expected to be able readily to identify where their services would have the greatest payoff and to generate the requisite technological changes. Subsequent empirical evidence has shown that the initial faith in the efficacy of creating specialised R&D agents was misplaced, as the newly established R&D institutes almost universally had virtually no contact with or impact upon producing firms.[29]

The adaptation (and creation) of technology cannot be separated from its use. Warranted adaptations must first be identified before they can be implemented. To identify them requires experience-based familiarity with both the technology and local circumstances. Moreover, warranted adaptations emerge in sequential fashion over time, as more is learned and as local circumstances change. Foreign entities are not well placed either to gain the necessary degree of familiarity with changing local circumstances or to make continued use of such familiarity as they may possess. Hence indigenous entities which are able to adapt technologies can be expected to play an important role in the process of industrialisation.

To what extent should or must this role be played by specialised agents of technological change? The past failings of R&D institutes notwithstanding, particular circumstances can provide a strong rationale for their establishment, as long as their activities are properly linked with those of producing firms. For example, centralised publicly-supported R&D may be warranted to adapt traditional indigenous technologies employed in highly competitive industries characterised by small-scale production. Such technologies may not continue to be viable unless adapted, and properly adapted they may be better suited to local circumstances than are competing foreign technologies. A general case can also be made for publicly-supported promotion of the local production of capital goods, since there appear to be many socially warranted adaptations which cannot be accomplished without some degree of local mastery in the embodiment of technology in capital goods.[30]

Among the manufacturing sectors of the industrially advanced economies, R&D activity is concentrated not only in the industries that produce capital goods but also in those that produce the major intermediate inputs (chemicals, fabricated materials) used elsewhere. Underlying this pattern of specialisation are close relationships involving frequent information interchanges between the suppliers and users of producers' goods. This suggests that it may not be enough for developing economies' governments to rely solely on explicitly targeted policies to correct for differences between private and social returns to the development of different types of technological mastery. Government action may also be required to promote and maintain an environment conducive to decentralised technological effort, together with a market structure in which technological changes are rapidly diffused. Furthermore, it must not be forgotten that the acquisition of technological mastery is an element of a country's human capital development – although the implications of this fact for government involvement in formal education and experience-based skill acquisition lie beyond the scope of this paper.

Finally, 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 which 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 which 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; it is equally to be able 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 different policies on the development of indigenous technological mastery have yet to be ascertained. Further research to uncover historical evidence from different country cases is necessary to reach any soundly-based generalisations about the determinants of the extent and appropriateness of technological effort in different directions. Such generalisations are needed to formulate policies that will direct the attainment of increased technological mastery in ways which are in line with social objectives.

NOTES

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 organisational or procedural factors.

2 Nelson (1980) provides an illuminating discussion that relates the possibility of specialisation in the acquisition of new technological knowledge to the feasibility of codifying technology.

3 Up-to-date foreign technology is frequently the appropriate choice in activities

that are inherently capital-intensive, such as the core processes of chemical fertiliser production. Assuming that the products involved should be produced rather than imported, employment generation can be said to suffer from the use of foreign technology in these activities only in the sense that it would be preferable if efficient and more highly labour-intensive alternatives existed.

4 'Efficient' has a very definite meaning in this context. An efficient technique, or combination of inputs, is one that uses less of at least one input than is used by any alternative technique to produce a given level of output. A technique may be efficient at some, but not at other, levels of output.

5 The principal centres for this research have been the World Employment Program of the International Labor Organization, the David Livingston Institute of Overseas Development at the University of Strathclyde in Great Britain, and the Economic Growth Center at Yale University in the United States, though important research has also been carried out by numerous individuals having various institutional affiliations. See Westphal (1978) for a policy-focussed survey and list of references.

6 See Pack (1980) for a succinct compilation of the evidence from a number of industry studies.

7 For a discussion of the difficulties associated with the employment of used equipment, see Cooper and Kaplinsky (1974), where means of circumventing these difficulties are also discussed.

8 The argument is not necessarily valid, since the frequency of breakage can be reduced by using more expensive yarn having greater uniformity and strength. Alternatively, depending upon relative input costs, it may be economical to employ the labour intensive technique and to suffer higher rejection rates, thus using more yarn to produce the same amount of acceptable product in order to save on capital costs.

9 See Stewart (1982). As she indicates, a realistic conception of technological mastery has yet to be incorporated in a theory of dynamic comparative advantage.

10 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 the direction of Jorge Katz. See Katz (1978) for a summary of the research so far.

11 For an in-depth case study, and a highly illuminating discussion of why technological effort is not automatically or necessarily forthcoming, see Bell, *et al.* chapter 7, this volume. For evidence across firms in the same sector in one country, and an equally illuminating discussion, see Pearson (1977).

12 The reference here is to technological changes that occur after the achievement of predetermined project-specific norms (e.g. the nominal capacity rating). Baloff (1966) discusses what is entailed in achieving these norms.

13 Note that several of these tasks pertain to choice of technology, which is a fundamental element of project execution.

14 Several cases of the development of new products or processes through R&D have been observed in research in progress at the World Bank to investigate the technological mastery which underlies exports of technology by Brazil and Mexico. It is important to note, however, that in most of these cases, the R&D was undertaken within producing enterprises, and not by independent institutions.

15 These efforts have typically been found to take place in various production-

oriented departments within firms and engineering companies. Only occasionally have they occurred in separate R&D departments.

16 References to surveys of what is known appear on pp. 130–3.

17 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.

18 See Cooper (1981) for a survey of the various issues involved here.

19 Packaging can reduce costs in numerous ways. Here only a few examples are given. Combining long-term contracts to supply key intermediate inputs together with the supply of core process technology lowers the cost of supplying the latter in cases where the supplier's technological mastery is related very specifically to the use of particular inputs. In turn, the motive for including multiple technological elements, as in a turnkey contract, is sometimes to give the supplier greater control over the transfer in order to minimise the risk of cost overruns. Alternatively, the motive may be to avoid the costs of coordinating with other suppliers. These costs can be quite high, especially when the other suppliers are local companies which may be unfamiliar with standard procedures. There may also be other barriers to communication to overcome when local companies are involved.

20 Product differentiation is frequently the origin of the monopoly power that is packaged with technology transfer. Differentiation may reflect very substantial differences in important dimensions of technological mastery or very trivial ones. Whether particular forms of foreign-induced product differentiation are at variance with social objectives is a matter for public authorities to determine and to act upon through appropriate incentive and control measures. But acceptance of some forms of product differentiation is undoubtedly desirable, since no one specification of a product's characteristics is equally suited to all of its uses.

21 The principal centres for research on technology transfer have been — from the outset — the Science Policy Research Unit at the University of Sussex in Great Britain — and subsequently — the secretariat of the Andean Pact, the Organization of American States, the United Nations Commission on Trade and Development, and the United Nations Industrial Development Organization. Research on the behaviour of multinational corporations also often focuses on technology transfer issues. Such research has been conducted by the United Nations Center on Transnational Corporations and by various faculty members of the Harvard Business School, among others. See Stewart (1981) for a comprehensive policy-focussed survey and list of references.

22 Ten developing economies were included in the project, which was sponsored by the International Development Research Center in Canada.

23 Sagasti (1978) is quite vague about how these other policies affect technological change and the acquisition of technological mastery. Moreover, the project did not attempt to determine whether different development strategies (e.g. inward- versus outward-looking) have distinct, identifiable effects. The case studies of Latin American firms (see pp. 113–19) and Korean experience (see pp.126–30) suggest that they might.

24 The following discussion is based on detailed evidence given in Westphal, *et al.* (1979).

25 International subcontracting refers to export activity that is wholly organised by an overseas firm; the domestic, exporting firm is responsible only for overseeing production.

26 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.

27 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 minimise 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.

28 A particular adaptation is warranted only if the benefits to be achieved can reasonably be expected to repay the costs of the technological effort involved in undertaking it, with benefits and costs being measured in relation to social objectives.

29 See Crane (1977) for a comprehensive review of the evidence.

30 See Pack (1981) for a survey of what is known about the role of the capital goods sector both as an agent of technological change and in relation to industrialisation more generally.

REFERENCES

Arrow, Kenneth (1962). Economic welfare and the allocation of resources for invention, in *The Rate and Direction of Inventive Activity: Economic and Social Factors* (Ed. Richard R. Nelson), Princeton University Press for the National Bureau of Economic Research, Princeton, New Jersey.

Baloff, Nicholas (1966). Start-ups in machine-intensive production systems, *Journal of Industrial Engineering*, 17.

Brooks, Harvey (1980). Technology, evolution, and purpose. *Daedalus*, **109**, 1, pp. 65–81.

Cooper, Charles (1981). Policy interventions for technological innovation in developing countries, World Bank Staff Working Papers, Washington, DC.

Cooper, Charles, and Kaplinsky, Raphael (1974). *Second-hand Equipment in a Developing Country: A Study of Jute-Processing in Kenya*, International Labor Office, Geneva.

Crane, Diana (1977). Technological innovation in developing countries: A review of the literature, *Research Policy*, 6, pp. 374–395.

Dahlman, Carl J., and Fonseca, Fernando Valadares (1978). 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, Economic Commission for Latin America, Buenos Aires.

Eckaus, R. S. (1955). The factor-proportions problem in underdeveloped areas, *American Economic Review*, 45, pp. 539–565.

Enos, John L. (1962). Invention and innovation in the petroleum refining industry, in *The Rate and Direction of Inventive Activity: Economic and Social Factors*, Princeton University Press for the National Bureau of Economic Research, Princeton, New Jersey.

Hannay, N. Bruce, and McGinn, Robert E. (1980). The anatomy of modern technology: Prolegomenon to an improved public policy for the social management of technology, *Daedalus*, **109**, 1, pp. 25–53.

Katz, Jorge (1978). 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. Economic Commission for Latin America, Buenos Aires.

Leibenstein, Harvey (1966). Allocative efficiency vs. 'X-Efficiency', *American Economic Review*, 56, pp. 392–415.

Nelson, Richard R. (1979). 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. Economic Commission for Latin America, Buenos Aires.

Nelson, Richard R. (1980). Production sets, technological knowledge, and R&D: Fragile and overworked constructs for analysis of productivity growth? *American Economic Review*, 70, no. 2, pp. 62--67.

Pack, Howard (1980). Macroeconomic implications of factor substitution in industrial processes, World Bank Staff Working Paper, no. 377. World Bank, Washington, DC.

Pack, Howard (1981). Fostering the capital goods sector in LDCs, *World Development*, 9, 3, pp. 227–50.

Pearson, Ruth (1977). 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. Economic Commission for Latin America, Buenos Aires.

Rhee, Yung W. and Westphal, Larry E. (1977). A micro, econometric investigation of choice of technology. *Journal of Development Economics*, 4, pp. 205–238.

Rhee, Yung W. and Westphal, Larry E. (1979). Choice of technology: Criteria, search, and interdependence, in *International Economic Development and Resource Transfer: Workshop 1978* (Ed. Herbert Giersch) (Institute fur Weltwirtshaft an der Universitat Kiel), J. C. B. Mohr (Paul Siebeck), Tubingen.

Sagasti, Francisco (1978). *Science and Technology for Development: Main Comparative Report on the STPI Project*, International Development Research Center, Ottawa, Canada.

Salter, W. E. G. (1960). *Productivity and Technical Change*, Cambridge University Press, Cambridge.

Sen, Amartya Kumar (1962). *Choice of Techniques: An Aspect of the Theory of Planned Economic Development*, Basil Blackwell, Oxford.

Stewart, Frances (1981). International technology transfer: Issues and policy options in *Recent Issues in World Development* (Eds. P. Streeten and R. Jolly), Pergamon, Oxford and New York.

Stewart, Frances (1982). Industrialization, technical change and the international division of labor, *For Good or Evil: Economic Theory and North-South Negotiations* (Ed. G. K. Helleiner), Croom Helm, London.

Sud, I. K., Harral, C. G. and Coukis, B. P. (1976). Scope for the substitution of labor and equipment in civil construction — A progress report, Papers for Panel Discussion: Indian Road Congress, 37th Annual Session, Bhopal, pp. 1–34.

Teitel, Simon (1981). Towards an understanding of technical change in semi-industrial countries, *Research Policy*, 10, pp. 127–47.

Wells, Louis T., Jr. (1973). Economic man and engineering man: Choice in a low-wage country, *Public Policy*, 21, pp. 319–342.

Westphal, Larry F. (1978). Research on Appropriate Technology, *Industry and Development*, 2, pp. 28–46.

Westphal, Larry E., Rhee, Yung W. and Pursell, Garry (1979). Foreign influences on Korean industrial development, *Oxford Bulletin of Economics and Statistics*, 41, pp. 359–88.

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