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Trade, Technology, and International Competitiveness

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Contents

vhen economies are caught in a spiral of accelerating inflation and declin-ng output. In these situations, reducing expenditures and raising taxes nay not yield economic stability if such steps lead only to further declines n output. Thus, there may be a case for including in reform programs for uch countries explicit growth-enhancing measures targeted at capital accu-nulation and growth in output and productivity.

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The Development of Technological Capabilities

Martin Bell and Keith Pavitt

The acquisition of technology has long been seen in all economies as central to the process of raising productivity and otherwise improving competitiveness. In general, it has been assumed that industries in developing countries can aquire new technology fairly easily. For while the problems of transferring agricultural technologies among countries have been widely recognized, the difficulties of transferring industrial technology have not. Industrial technology is widely viewed as being much less dependent on local factors than agricultural technology and therefore as much more accessible. More specifically, it has been assumed that developing countries can achieve high rates of growth of labor productivity—and probably also of total factor productivity—by investing in the physical capital embodying new industrial technologies and training workers in the necessary operating skills.

These assumptions, however, are generally misplaced. Although developing countries have expanded their industrial production capacities rapidly over the last forty years, correspondingly raising and diversifying their shares of world manufacturing output and exports, a growing body of evidence shows considerable variations in the efficiency with which that industrial expansion has been achieved. Low levels of *static efficiency* in a wide range of industries are evident in numerous sectoral studies of domestic resource costs and effective rates of protection. More detailed studies of fic industries have also shown considerable variations in efficiency in ıse of technologies. Pack (1987) indicates that textile producers in a in the 1980s operated at lower levels of productivity than those in ıtrial countries, despite the presence of similar spinning and weaving ologies—and that textile producers in the Philippines with the same of equipment had not even reached Kenya's productivity levels.

nilar variability is evident in *dynamic efficiency* in the use of technol- In only a few cases have high rates of productivity growth been ved through the transfer of technology from industrial countries. For ıce, in the Republic of Korea, the annual rates of growth of labor pro- ity in manufacturing have typically exceeded 10 percent since the , and the growth rates of total factor productivity in manufacturing been substantially higher than those in the advanced industrial coun- Dollar and Sokoloff 1990). In many other developing countries, how- rates of growth of total factor productivity in industry (or, more wly, in manufacturing) have been a fraction of Korea's and have d either to be lower than those in most of the advanced industrial ries or to remain negative for long periods (see Nishimizu and Page Pack 1988, 1992). Even labor productivity seems to have grown more in manufacturing in most of the developing world (UNIDO 1992).

e effectiveness with which countries have created new areas of com- ve advantage in increasingly technology-intensive industries also widely. Particularly striking has been the limited technological devel- nt in countries where significant industrial growth began in the early es of this century or even before. In the early 1980s, Poznanski (1984) d to the poor performance of the (then) centrally planned economies lustries involving sophisticated technologies, especially compared he newly industrializing economies (NIEs)—a weakness confirmed in recent comparisons by Ray (1991).

in American countries have performed even more poorly than other particularly in electronics production (Riedel 1988; Freeman 1991). In ructural change has been constrained in Latin American industry for es. For example, by the 1950s Brazil had developed a substantial capi- ods sector, but the development of industries such as steel was not fol- by the emergence of internationally competitive production in more ex and specialized areas, such as machinery and instrumentation, or nce-based sectors like electronics. Typically, Latin American econo- egan producing simple machinery and then moved to limited pro- n of more complex machinery, but these economies were rarely able ain internationally competitive (Scott-Kemmis 1988). Similarly, the

automobile industry grew rapidly in Argentina during the 1950s and 1960s, and a nascent structure of specialized supplier industries emerged, but little or no effort was made to develop new models or to keep up with technological improvements elsewhere (Katz and Bercovich 1993).

In contrast, some of the Asian NIEs have changed the structures of industrial production rapidly to keep up with new technologies. Korea, for example, moved rapidly from labor-intensive to scale-intensive industries (automobiles, steel, consumer durables, and chemicals) and later to industries supplying specialized production equipment. Similarly, large firms in the Korean electronics industry have been shifting from labor-intensive assembly production to technology-intensive processes. Singapore simply bypassed the heavy, scale-intensive industries, moving instead from labor-intensive production to engineering-intensive segments of the electronics industry and information-intensive service industries. Other countries in Southeast Asia (including Indonesia, Malaysia, and Thailand) are poised between Latin America and the East Asian NIEs. It remains to be seen whether these economies will shift rapidly to technology-intensive industries or remain locked into areas in which competitiveness rests primarily on relatively low wages and abundant natural resources.

The conventional wisdom is that these variations in the dynamic efficiency of industry can be explained largely by differences in policies that have little direct impact on technology—in particular, macroeconomic and trade policies that distort prices and patterns of comparative advantage, and policies that affect the level and structure of investment in education (see, for example, World Bank 1993a). But this view, while it captures important parts of the story, overlooks key issues in technology and technology-related policy that strongly affect dynamic efficiency and competitiveness.

The central argument of this chapter is that dynamic efficiency does not follow automatically from the acquisition of foreign machinery embodying new technology and the accumulation of related operating know-how. Sustained dynamic efficiency depends heavily on domestic capabilities to generate and manage change in technologies used in production, and these capabilities are based largely on specialized resources (such as a highly skilled labor force) that are neither incorporated in, nor automatically derived from, capital goods and technological know-how. Like other productive industrial assets, they need to be accumulated through deliberate investment—a management problem. But market mechanisms alone are unlikely to ensure socially efficient rates of investment in these assets—a policy problem. Thus, countries concerned with improving their international etitiveness need to address shortcomings in both management and design.

ne assumption that industrializing countries can generate technical e simply by choosing and adopting technologies from industrial ries has often obscured the importance of accumulating pertinent stic assets. The next section discusses the prevailing views on technol- ansfer and acquisition, along with alternative viewpoints that give greater prominence to the local accumulation of capabilities for gen- g and managing technical change. This is followed by sections that n how the sources of technical change differ across industries and the various types of technological capabilities that play different in developing industrial competitiveness. Finally, the role of busi- s, which make key contributions to the accumulation of national tech- ical capabilities, is discussed.

ical Change and Technological Capabilities

nportance of accumulating technological capabilities to the process of trialization has frequently been obscured by a number of influential about the nature of technology and the role of technical change in ndustrializing countries. These ideas must be examined critically in to provide a clearer basis for understanding the development of tech- ical capabilities and competitiveness.

raditional Model of Technical Change

e heart of the prevailing ideas about technical change is the notion that ology takes two main forms: codified information (or disembodied ology), and capital goods (embodied technology).[1] The essential char- stics of these forms of technology are that the technology is readily ferable among organizations and locations and that transfers can be ly effected through market-mediated mechanisms.[2] From this point of there is little need for industrializing countries to develop their own

For some, technology is expressed simply as a ratio between the inputs and its of a production system, but this ratio is seen as largely determined by the ent productivity of the inputs of capital goods, which may or may not be used he skills required to achieve the latent level of efficiency.

Although market imperfections may exist, especially for technology as infor- n (Arrow 1962), these are usually seen as affecting the likely price in commer- ansactions, not transferability.

resources for generating and managing technical change. This theory rests on several contingent assumptions.

- First, a sharp distinction can be drawn between technological innovation and the subsequent diffusion of technology. With minor exceptions, industrializing countries should concentrate on exploiting already existing technologies rather than expending resources on efforts to generate innovation and technical change.[3]
- Second, there is a corresponding distinction between those sectors of the economy producing innovative technology (the capital goods sectors) and those using it (the others).[4] With minor exceptions, efficient industrialization involves concentrating on the latter and leaving the development of capital goods sectors until later.
- Third, industrial technologies tend to be transferred to developing countries at late stages in the product or technology cycle; by that time, the technology is mature and stable, requiring only the appropriate know-how and competitive wage levels.
- Fourth, economies can increase efficiency levels in a relatively short period in ways that have little to do with innovation and technical change. Provided that workers have been sufficiently trained in basic operating skills, efficiency can be improved through the accumulation of production experience, or "learning by doing."
- Finally, technological change occurs only intermittently, and efficiency tends to move forward in distinct "steps" as a result of innovation in industrial countries. Developing countries can take advantage of the relatively slow pace of change by acquiring the latest vintage of capital that embodies new technologies or licensing new product designs.

As noted earlier, these ideas are fundamentally misleading. In reality, technology is so complex that it can be only partially encompassed by either codified information or physical capital. Innovation requires more than codified knowledge, because scientific laws and models cannot fully predict the performance of new products and processes. Both the operation of existing technologies and innovation require tacit knowledge that is

3. This argument is sometimes supported by the assertion that the most successful industrializing economies, like Korea and Taiwan, China, have adopted existing technologies and given very little attention to innovation.

4. This distinction leaves aside product innovation in the final goods sectors, which is in any case seen as largely irrelevant in late-industrializing countries that adopt already developed product technologies.

y specific to particular products, processes, firms, and markets and can fore be acquired only through trial and error and the accumulation of ience in particular contexts. Futher, capital goods in themselves can- onstitute technology, for while much technology is embodied in plants quipment, operational technologies also encompass complex relation- involving equipment, process characteristics, product specifications, vork organization.

eneration and Management of Technical Change

nology were simply a matter of information, competitiveness would latively easy to achieve and sustain, and catching up economically d be much less difficult than it has been. But in fact technology consists nplex "bundles" of information—both codified and tacit—as well as cal capital. Because tacit information is not readily transferable among and countries, technological blueprints do not contain inherent per- nce characteristics (such as set productivity levels). Instead, these rints have to be translated into specifications and procedures that are ic to particular applications—an uncertain creative process that can in highly variable levels of performance. Moreover, even when such les have been created and molded into the configurations required for cations to specific firms, they must be continually remolded if the are to remain competitive in a world where the benchmarks for com- ve efficiency are constantly rising. Thus, technological capabilities include capacities for generating and managing such change. In late- trializing countries, the acquisition of capabilities to generate and ge change is governed by four considerations.

IN PRACTICE, THE PROCESSES OF "INNOVATION" AND "DIFFUSION" ARE TO DISTINGUISH. All too often, the common distinction between these rocesses carries with it a corresponding notion about the international on of labor. Innovation—the development and initial commercializa- f new technology—is assumed to be heavily concentrated in the in- ial countries. According to this thinking, it becomes significant in de- ing economies only as they catch up technologically. In the meantime, economies are expected to concentrate on diffusion—the application dily available and transferable technologies. Because diffusion is seen

mulate capabilities for innovation. From this perspective, therefore, technological accumulation in developing countries is seen as consisting simply of the accumulation of technology embodied in capital goods (and product specifications) and the acquisition of the needed operating know-how.

In fact, diffusion involves more. It also incorporates a process of continuing, often incremental technical change that molds technology for use in a range of specific situations and modifies it to improve on the original performance standards. The importance of building on acquired technology during the diffusion process has long been emphasized by more perceptive observers (Rosenberg 1972, 1986; Metcalf 1988). In addition, many of the improvements are localized and specific to firms, products, and markets, because acquired technology is adapted and improved on in two stages: first, during the investment phase, when the technology is initially brought into use; and second, during the operational lifetime of each project, when a stream of incremental improvements is incorporated into the system.

Although the providers of technology can make important contributions to localized processes of technical change, recipient firms and countries must develop their own capabilities in order to stay internationally competitive. Incremental improvements must continue throughout the operational lifetime of projects, since it is difficult and costly to draw continuously on new capital goods and inputs to facilitate change. Thus, late-industrializing countries may adopt and use technology, but they also need to contribute to its ongoing development. However, it is not necessary for each country to develop a domestic capital goods sector.

(II) TECHNICAL PROGRESS IS GENERATED BY BOTH THE PRODUCERS AND USERS OF TECHNOLOGY EMBODIED IN CAPITAL. As noted above, firms making capital goods are not the sole creators and sources of new processes. In fact, the users of capital inputs often play active and creative roles in changing the technology they use. Some play dominant or even exclusive roles in developing new machines, and many more interact with machinery producers and engineering companies in making incremental modifications and improvements to production technologies. Again, these changes continue throughout the operating lifetime of a project.

This involvement in innovation has been an important feature of Japanese firms' strategies for improving competitiveness. The Japanese did not invent the technique, however: it has also been common among firms in North America and Europe. For example, DuPont, a late entrant to the n European sources in the 1920s. The firm then built up the technologi- capabilities it needed to build new plants and improve efficiency (Hol- der 1965). Similarly, in the 1970s European oil companies acquired from United States the technology needed for offshore exploration and pro- tion in the North Sea. They rapidly built up their capabilities to generate manage improvements in much of the equipment-embodied technol- that they used (Bell and Oldham 1988).

In industrializing countries, firms that use acquired technology and ome competitive have also found the ability to generate change to be ortant in maintaining competitiveness. For example, petrochemical and l companies in Korea rapidly built up their capabilities to design and struct plants and then increased efficiency by incorporating engineering rovements into the plants (Enos and Park 1988). And Korean automo- companies have made substantial efforts to develop and build their n machine tools (Lee 1993).

(III) "LEARNING BY DOING" ALONE WILL NOT KEEP TECHNOLOGY-IMPORT- FIRMS COMPETITIVE. The notion that certain techniques must be learned nherent in most discussions about the competitiveness of infant firms l industries. It is suggested that infant firms, having chosen such tech- ues, may still be inefficient relative to established firms simply because new firms lack the production experience necessary to use the tech- ues at optimum efficiency. Once the firms acquire that experience, they l be able to achieve the levels of efficiency inherent in the chosen tech- ues; if the firms fail, it is because of market distortions and limited incen- es that give rise to various forms of X-inefficiency.

This perspective is mistaken because it suggests that competitiveness olves reaching a particular level of, rather than a particular rate of provement in, efficiency. It implies that a distinction can be drawn ween two types of improvements: improvements in using the given hniques based on experience (or higher utilization rates of the inherent l capacity of capital equipment), and the intermittent introduction of w vintages of physical capital that embodies technology. However, the alized and continuous nature of technical change means that competi- eness is not simply a level that can be reached by combining greater perience with an initial level of skills and a given stock of physical capi- . It is a constantly changing state achieved and sustained by rates of hnical change that surpass or at least match the rates being generated

elsewhere.[5] Accumulating the capabilities to generate these changes is therefore a necessary condition for competitiveness.

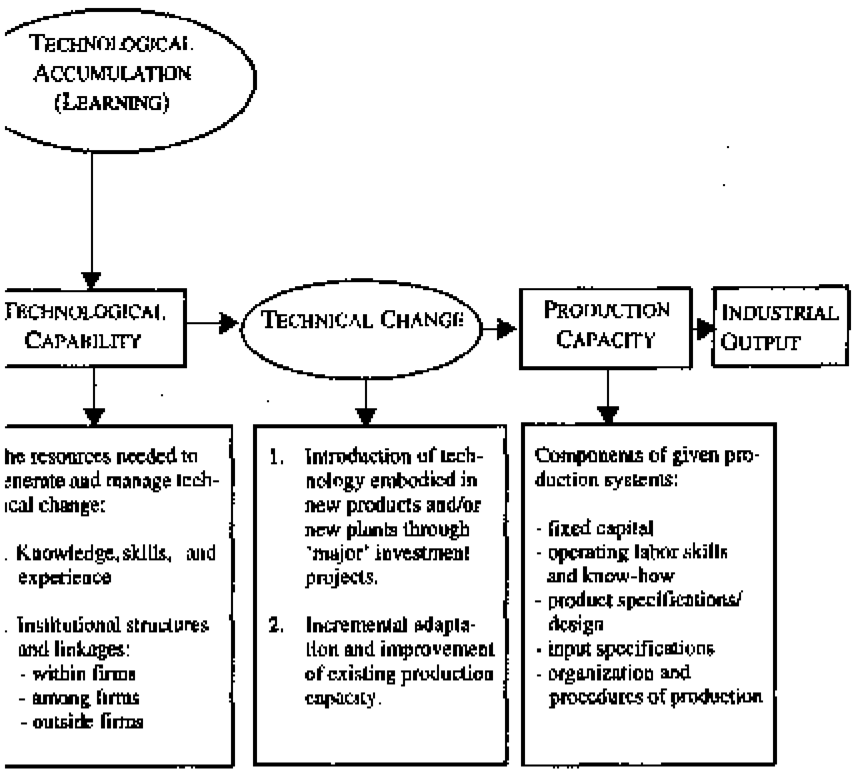
The central feature of this analysis is the distinction between production capacity and technological capabilities shown in Figure 4.1. This distinction reflects an important change over the last century in the processes of technological accumulation in industry—namely, the increasing specialization and professionalization of the activities involved in generating and managing technical change. In the early stages of industrialization in today's technologically advanced countries, the resources needed to undertake these activities were accumulated alongside (and through interaction with) expanding production capacity and output. The knowledge and skills required to generate technical change were relatively close to those needed for production and were frequently developed largely on the basis of cumulated production experience. Both typically existed in the same organizational location—not just in the same firms, but often within the same parts of firms (such as the machine shops of textile factories).

However, across a range of industries and technologies, increasing specialization has widened the gap between the kinds of knowledge and skills required to use given technologies and those required to create and change technology. Skills based only on cumulative operational experience have become progressively inadequate as a basis for generating change, and this differentiation in the knowledge base for industrial activity has been reinforced by increasing organizational differentiation. Some of this differentiation has involved the emergence of distinct engineering departments, design units, and research and development (R&D) centers within firms.

Sectors have also emerged that are devoted exclusively to the design and manufacture of capital goods and the provision of other inputs to technical change in production—what is called "vertical disintegration." In the industrial economies, this distinction between creating and operating industrial technologies has developed within institutional arrangements that have kept the two kinds of capabilities closely linked. However, for newly industrializing countries, these two sets of capabilities are not necessarily so closely and effectively linked. Industrial output can grow and production capacity can be expanded and diversified without automatically giving rise to the development of effective capabilities for generating and managing technical change. Hence the distinction in Figure 4.1 between

5. This holds true unless continuing exchange rate devaluation and the consequent steady erosion of real incomes are used to overcome (probably only temporarily) any shortfall in the real technological base of competitiveness.

ure 4.1. Technological Accumulation: Basic Concepts and Terms



› kinds of resources: *production capacity* and *technological capabilities*. The ner incorporates the resources used to produce industrial goods at given els of efficiency and given input combinations: equipment that embodies nology, operational and managerial know-how and experience, prod- and input specifications, and organizational methods and systems. The nological capabilities needed to generate and manage technical change lude skills, knowledge, and experience that often (but not always) differ stantially from those needed to operate existing technical systems, as ll as the particular kinds of institutional structures and linkages neces- y to produce inputs for technical change.

(IV) THERE IS OFTEN LITTLE TECHNOLOGICAL STABILITY IN THE LATER GES OF THE PRODUCT LIFE CYCLE. It cannot be assumed that technologies ome stable in the later stages of product or industry life cycles and that it onsequently unnecessary for firms acquiring foreign technology to

develop their own capabilities for generating and managing technical change. There are often periods when technological innovation proceeds relatively slowly, and, as has already been mentioned, much of the technology developing countries initially acquire is at relatively late stages in its life cycle. However, it is not the case that phases of technological stability coincide with late stages in product/industry life cycles. Industries and products frequently pass through such periods of stability into phases of renewed and rapid change. The cotton textile industry, for instance, has gone through several such cycles.

Consequently, developing country firms in supposedly mature industries may need to develop substantial capabilities for generating change in order to achieve or sustain competitiveness, especially when new countries with lower labor costs are entering the industries. Developing these capabilities requires constantly improving techniques through actively engineered technical and organizational change, not just the kind of passive "learning by doing" that yields increased proficiency in operating given techniques as a result of increased production experience.

Sources of Technical Change in Industry

One reason it is difficult to make useful generalizations about the correct sequencing involved in the accumulation of technological capabilities is that the nature and sources of technological knowledge differ across industries. In the industrial countries, categories of terms can be distinguished, each with its distinctive sources and directions of technological change (Table 4.1). In *supplier-dominated firms* (primarily in agriculture and textiles), technical change comes almost exclusively from suppliers of machinery and other production inputs. Technical choices reflect relative factor costs, and technological accumulation is focused on improving and modifying production methods and associated inputs, and occasionally on product design. International technology transfers are relatively easy, as technology is embodied mostly in capital goods and other inputs; in the agricultural sector, extension efforts can help to disseminate new knowledge and practices. As such, the choice of technology in supplier-dominated firms bears some resemblance to the substitution possibilities reflected in the conventional production function.

In *scale-intensive firms* (in the steel and automobile industries, for instance), technological accumulation is generated by the design, creation, and operation of complex production systems and products. The main ... of technological improvements are design and production engi-

Characteristics	Supplier Dominated	Scale Intensive	Information Intensive	Science Based	Specialized Supplier
ial Core Sector	Agriculture, housing, private services, traditional manufacturing.	Bulk materials (steel, glass), consumer durables, automobiles, civil engineering.	Finance, retailing, publishing, travel.	Electrical, electronics, chemicals.	Capital goods, instruments, software.
of firm	Small	Large	Large	Large	Small
e of user	Price sensitive	Mixed	Mixed	Mixed	Performance sensitive
n focus of technological tivities	Cost reduction	Mixed	Mixed	Mixed	Product improvement
n sources of technological cumulation	*Suppliers* Production learning, advisory services.	*Production engineering* production learning, suppliers, design.	*Corporate software and systems engineering* Equipment and software suppliers.	*Corporate R&D* basic research, production, engineering, design	*Design and development (advanced users)*
n direction of technological cumulation	Process technology and related equipment.	Process technology and related equipment.	Process technology and related software	Technology-related products	Products improvement
	[Upstream]	[Upstream]	[Mixed]	[Concentric]	[Concentric]
n channels of imitation and chnological transfer	Purchase of equipment and related services.	Purchase of equipment, know-how, licensing and related training, reverse engineering.	Purchase of equipment and software, reverse engineering.	Reserve engineering, R&D, hiring of experienced engineers and scientists.	Reverse engineering, learning from advanced users.
n methods of protection ainst imitation	Nontechnical (marketing, trademarks).	Process secrecy, design and operating know-how.	Copyright, design and operating know-how.	R&D know-how, patents, design, and operating know-how.	Design know-how, patents, knowledge of users' needs.
n strategic nagement tasks	Use technology generated elsewhere to reinforce other competitive advantages.	Incremental integration of new technology in complex systems, improvement and diffusion of best practice, exploitation of process technology advantages.	Design and operation of complex information-processing systems, development of related products.	Development of related products, exploitation of basic science, complementary assets, reconfiguration of divisional responsibilities.	Monitoring of advanced users needs, integration of new technology in products.

Source: Based on Pavitt 1984.

neering, operating experience, and suppliers of equipment and components. Given the potential economic advantages of increased scale, and the complexity of products and production systems, the risks of failure associated with radical change are potentially very high. Process and product technologies therefore develop incrementally. International technology transfer requires the licensing of production and design know-how and related training, in addition to trade in machinery and other inputs.

In *information-intensive* firms (in finance and retailing, for instance), a major new form of technological accumulation has emerged, the result of revolutionary improvements over the last forty years in the capacity to store, process, and transfer information. Technological accumulation comprises the design, construction, operation, and improvement of complex systems for the storage and processing of information. The improvements themselves tend to be incremental, and the main sources are operating experience—the so-called systems departments in large user firms—and suppliers of systems and applications software. Although comprehensive data are scarce, surveys suggest that large firms in the service industries (such as banking and retailing) have become major centers for the accumulation of information technology.

In *science-based firms* in industries such as chemicals and electronics, technology is accumulated mainly by corporate R&D laboratories and is heavily dependent on the knowledge, skills, and techniques emerging from academic research. Technological accumulation focuses primarily on a horizontal search for new and technologically related product markets. International technology transfers require a strong capability for reverse engineering (that is, disassembling competitors' products to see how they work), which itself requires a capacity for R&D and design activities. These transfers also require trained research scientists and engineers with foreign contacts. This style of technical change is best exemplified by the innovative firm described and analyzed in the writings of Schumpeter (1934, 1942).

Specialized supplier firms (for example, in machinery and control instrumentation) provide high-performance inputs into complex systems of production in the form of machinery, components, instruments, and software. Technological accumulation takes place through the design, construction, and use of these production inputs. Specialized supplier firms accumulate the skills necessary to match the advances in machine design, which—given the complexity and interdependency of production processes—put a premium on reliability and performance rather than on price. International technology transfers take place through the purchasing activities of ad- [illegible] firms and through reverse engineering. This type of technical ıge is noted in the writings of Stigler (1956) and Rosenberg (1976) on ical disintegration and technological convergence.

Thus, each category in Table 4.1 represents a different style of technolog- learning and a different organizational location for specialized learning vities:

- production operations (quality control, production planning) in supplier-dominated firms;
- process and product improvements (production engineering, design) in scale-intensive firms;
- exploitation of basic research for product and associated process developments (R&D) in science-based firms; and
- equipment and component development (design) in specialized supplier firms.

Over time, learning processes within sectors have become the basis for l production in other sectors—for example, through the vertical disinte- ion of production activities developed in one type of firm, the transfer ccumulated knowledge and expertise to other types of firms (such as ialized suppliers), the migration of skilled people from firms in one cat- y to firms in another, and the development of new areas of knowledge new skills among local firms and technological institutions. More gen- y, learning-based structural change has involved the emergence of nologically sophisticated sectors that have their roots in technological mulation in less complex industries, including:

- the U.S. textile machinery industry, which became a specialized supplier sector in the nineteenth century on the basis of technological accumulation in textile firms (which became supplier dominated);
- specialized suppliers of production equipment, which are built on the technology accumulated in scale-intensive sectors (such as consumer durables, automobiles, and process industries); and
- science-based industries that have adopted technology used in other industries—electronics, for instance, which drew on specialized supplier sectors, and science-based chemicals, which evolved from less complex process industries.

uch trajectories of technological learning and progress are not preor- ed. Nonetheless, three mechanisms seem to have been particularly ential in the past and will undoubtedly continue to influence strategies

ments; directions of persistent investment, especially those with strong intersectoral linkages; and the cumulative mastery of core technologies and their underlying knowledge bases. The relative significance of these mechanisms changes during the process of industrialization. In the early stages, the directions of technical change in a country or region are strongly influenced by the availability of factors of production, domestic market conditions, and local investment opportunities. At higher levels of development, however, the local accumulation of specific technological skills itself becomes a means of focusing technical change.

Different Types of Technological Capabilities

Several studies have distinguished between different types of technological capabilities (for example, Dahlman, Ross-Larsen, and Westphal 1987). Table 4.2, which is based on the framework developed by Lall (1992), emphasizes the difference between basic production capabilities (elements of what were described earlier as "production capacity") and technological capabilities. It also distinguishes between what can loosely be described "depths" of technological capabilities. A basic level of capabilities may permit only relatively minor and incremental contributions to change, but at the intermediate and advanced levels, technological capabilities may result in more substantial, novel, and ambitious contributions to change. Finally, the table distinguishes between six different functions for which firms may develop technological capabilities (the columns in the table). The first two columns may be described as *primary functions*: generating technical change and managing its implementation during relatively large investment projects to create major new production systems, such as new plants or production lines, additions to existing plant's capacity, and distinct new product lines; and generating and managing technical change during production activities undertaken in the postinvestment lifetime of production facitilities. The last two columns of the table may be considered *supporting functions* that consist of developing change-centered links and interactions with other firms and institutions and producing the capital goods that embody elements of locally created new technology. Over the long term, the capabilities for carrying out these functions help to strengthen the sequences of accumulating technological capabilities and create the basis for diversifying into new products and industries. These functions deserve some elabo-

	Investment		Production		Supporting Activities	
	Facility user's decision-making and control	*Project preparation and implementation*	*Process and production organization*	*Product centered*	*Developing linkages*	*Capital goods supply*
Basic production capabilities Capacities to use existing production techniques	Engaging primary contractor. Securing and disbursing finance. Officiating at opening ceremony.	Preparation of initial project outline. Construction of basic civil works. Simple plant erection.	Routine operation and basic maintenance of 'given' facilities. Efficiency improvement from experience in existing tasks.	Replication of fixed specification and designs. Routing QC to maintain existing standards and specifications.	Procurement of available inputs from existing suppliers. Sale of 'given' products to existing and new customers.	Replication of unchanging items of plants and machinery.
TECHNOLOGICAL CAPABILITIES (CAPABILITIES TO GENERATE AND MANAGE TECHNICAL CHANGE)						
BASIC	Active monitoring and control of feasibility studies, technology choice/sourcing, and project scheduling.	Feasibility studies. Outline planning. Standard equipment procurement. Simple ancillaries engineering.	Commissioning and debugging. Improved layout, scheduling, and maintenance. Minor adaptation.	Minor adaptation to market needs, and incremental improvement in product quality.	Searching and absorbing new information from suppliers, customers, and local institutions.	Copying new types of plants and machinery. Simple adaptation of existing designs and specifications.
INTERMEDIATE	Search, evaluation and selection of technology/sources. Tenders/negotiation. Overall project management.	Detailed engineering. Plant procurement. Environment assessment. Project scheduling and management. Commissioning. Training/recruitment.	Process improvement. Licensing new technology. Introducing organizational changes.	Licensing new product technology and/or reverse engineering. Incremental new product design.	Technology transfer to suppliers and customers to raise efficiency, quality, and local sourcing.	Incrementally innovative reverse engineering and original design of plant and machinery.
ADVANCED	Developing new production systems and components.	Basic process design and related R&D.	Process innovation and related R&D. Radical innovation in organization.	Product innovation and related R&D.	Collaboration in technology development.	R&D for specifications and designs of new plant and machinery.

Source: Lall 1992.

Technological Capabilities and Investment

Basic elements of existing technology that are incorporated into new production facilities are frequently improved or adapted to specific situations. Typically, making these changes is a complex and creative process, the importance of which is widely acknowledged. Voss (1988) discusses the process in terms of the adoption of advanced manufacturing technology in industrial countries; Amsalem (1983) shows the complexity and creativity of the engineering activities involved in acquiring technology during the investment phase for new textile and paper plants in developing countries. Thus, even with apparently established technologies, the initial productivity of new plants will be highly variable, depending on the strength of available capabilities for managing and generating a process of technical change. And, when more novel elements of technology are incorporated into investment projects alongside established technology, the necessary capabilities may require more sophisticated engineering and R&D.

Creativity on the part of the recipients of technology is important to investment projects. Investment in new production facilities obviously draws on a range of suppliers for capital goods, engineering services, project management services, and so forth, but technologically dynamic firms rarely play a purely passive role during the acquisition of technology. They can control key decisions about the choice of technology and its implementation; interact with their suppliers in developing designs and specifications; and generate a significant part of the technology themselves, perhaps also incorporating it into the design of the capital goods that will be used in production. Developing the capabilities needed to perform these functions can have a significant effect on the efficiency of investment. For example, Korean firms have made substantial efforts to build up these capabilities, ultimately speeding up implementation of low-cost industrial investment projects (Amsden 1989; Enos and Park 1988).[6]

6. This contribution to Korea's high rates of productivity growth has sometimes been hidden behind explanations that see alternative investment projects as having *inherent* levels of productivity. According to this argument, efficiency in investment is simply a matter of choosing the most productive alternatives and allocating the necessary resources accordingly. For example, the World Bank (1993a) study of high-productivity growth in the East Asian economies suggests that the region's remarkable productivity performance stemmed from the efficient allocation of capital to high-yielding investments, among other things

ological Capabilities and Postinvestment Production

mphasized earlier, sustaining competitiveness requires that technical ge continue through the postinvestment operational lifetime of proion facilities. The abundant literature on learning curves (the reduction it production costs as a function of cumulative production experience) lights the significance of the economic gains that result from continuimprovements in technologies. Much of this literature obscures the pro- however, for improved performance is not the result simply of rience in operating new technologies but is generated by the continupursuit of creative technical change (incremental innovation).[7] Firms generate change by:

- incorporating incremental improvements in existing process technology that can be introduced into new facilities during subsequent investment projects;
- modifying and improving existing products that can subsequently be incorporated into imitative products; and
- improving or adapting existing materials and components, or developing substitutes for those already in use.

The continuing cost reductions achieved in the DuPont rayon plants the acquisition of European technology illustrate the importance of e types of changes (Hollander 1965). Continuous technological improvnts are widely held to have contributed to the competitive success of nese firms (Imai 1986). The significance of such technological dynan has also been observed in developing countries—for example, in the industry in Brazil and the petrochemical industry in Korea (Dahlman Fonseca 1987; Enos and Park 1988). More recent studies have emphad the importance of ongoing change to the organizational dimension of luction technology (Hoffman 1989; Meyer-Stamer and others 1991; and ly, Suri, and Sanders 1992).

hese contributions to sustained competitiveness require the users of ired technology to contribute actively to ongoing technical and organional change. Technical changes in existing production systems will n draw on inputs from external suppliers, but the firms using the techgy must themselves play a significant role, both independently and in

. See, for example, the review of the frequently cited evidence about learning es in aircraft and ship production during World War II in Bell and Scott-Kem-

conjunction with the external suppliers. As firms acquire deeper levels of capabilities, the functional distinctions may become increasingly blurred—for example, R&D capabilities for improving existing processes may become intermingled with engineering capabilities for incorporating new process technology into major investment projects.

Technological Capabilities and Interfirm Links

Although the technologically creative activities of individual firms often play a central role during both the investment and postinvestment phases of projects, interactions among firms also have a profound effect on the process of technological change. Some of these interactions involve informal collaboration between suppliers and customers in the exchange of knowledge, information, and skills accumulated during the design, production, and use of production inputs (Lundvall 1988; 1992; OECD 1992a). Others involve a wider range of collaborative arrangements—such as licensing, joint R&D programs, and technological exchange agreements—among competing as well as complementary firms (Chesnais 1988; Cainarca, Colombo, and Mariotti 1992; Kleinknecht and Reijnen 1992; Hagedoorn and Schakenraad 1992).

Thus, one important component of industrial technological change is the complex structure of interactions among firms. This structure relies on links connecting the *technological capabilities* of collaborating firms, which often depend heavily on the capabilities of leading firms within emerging networks. Users of components, material, or equipment, for instance, can actively induce their suppliers to make improvements in these inputs; they can use their own technological capabilities to generate those inputs; or they can transfer technical competencies to enable the suppliers to generate the changes. But these interactions will not take place unless significant technological capabilities exist in one or the other (or preferably both) of the firms. Otherwise, interactions will be limited to market transactions for already existing inputs and outputs.

Technological Capabilities and the Production of Capital Goods

Because much technological change is embodied in capital goods, the ability to produce machinery with new specifications (though not just to replicate existing specifications) is another important component of industrial technological capability. This ability can be developed in specialized ines can help develop new technologies and can even start producing inery themselves. In many industries, this user-specific capability s an important contribution to increased competitiveness (von Hippel . Along with other technological capabilities, it contributes to the com- ve strengths of new industries.

nulating Technological Capabilities

sometimes been suggested that firms in developing countries have nulated technological capabilities in particular sequences, moving gh definable stages (Dahlman, Ross-Larsen, and Westphal 1987). It has been suggested that these sequences and stages can provide guide- for both firm-level strategies and government policy (Kim 1980; Lee, nd Choi 1988).

a very general sense, such sequences do reflect realities. For example, and industries seeking to improve their technologies generally have ild on what already exists. Beyond such generalities, however, rigid about sequences and stages may be misleading, especially at the firm The rate at which a firm should proceed in accumulating capabilities, he level of sophistication it should aim for, seem likely to vary widely, es the potential sequencing of accumulation among different func- l areas. For example, in some industries, it may be important to op investment-related capabilities rapidly and to considerable depths e, say, accumulating significant capabilities for improving product ology during the postinvestment production phase—and perhaps before entering production in the first place. The Japanese synthetic industry followed this path in the 1950s (Ozawa 1980). In other situa- precisely the reverse may be indicated, with competitiveness depend- ieavily on the rapid accumulation of capabilities for improving rmance in the postinvestment phase, as the case of the small Jamaican described by Girvan and Marcelle (1990) illustrates.

other firms and industries, competitiveness may depend heavily on ng quickly to sophisticated levels of capability in the design and opment of products and in technological innovation. In such cases, tment-related capabilities may receive little attention, perhaps because najor investment projects are planned, or because the costs and risks of ring and using those capabilities are particularly high. Conversely, in cases it may be especially important to develop substantial capabili- or improving processes (though perhaps not for more radical and com- [illegible]

investment projects. In these instances, product-related capabilities may be less important. This pattern seems to have prevailed in Korean petrochemical firms (Enos and Park 1988).

The variability of these patterns suggests the need for care and clarity in choosing specific strategies for accumulating technologies at the firm level. Although there is a growing body of knowledge concerning the technological strategies of firms in industrial countries that have already accumulated some advanced levels of capabilities, there are few guidelines for firms to follow in designing strategies to move from more basic levels to these advanced capabilities. Nor are there many guidelines for developing strategies of accumulation at the economywide level. A few economies have achieved considerable competitive success in the postwar period, in particular Korea and Taiwan, China, where firms across a wide range of sectors have developed strong capabilities for generating continuous change in technologies acquired from industrial countries; for synthesizing diverse elements of increasingly complex imported technology into new plants and products; for independently replicating technologies already developed elsewhere; and now for more sophisticated innovations. These accomplishments initially depended heavily on the accumulation of various engineering capabilities (Westphal, Kim, and Dahlman 1985; Enos and Park 1988; Amsden 1989). More recently, especially in the electronics industry (but not only there), these firms have drawn on the rapid growth of business-financed R&D, which has included the evolving mix of imitative and innovative technological activities common to countries in the early stages of industrialization (Ernst and O'Connor 1992; Bloom 1992).

In other developing countries (including China, India, and some in Latin America), the accumulation of these kinds of technological capabilities within industrial firms has been much more limited or more narrowly focused—for example, in the aircraft industry and selected informatics product groups in Brazil, and in the defense and space industries in India. In places such as Africa, the intrafirm accumulation of such capabilities has been virtually absent.

Diversification and Structural Change

The technological capabilities for carrying out the various functions outlined above have a major influence on the degree of industrial competitiveness that is based on established comparative advantages. But they also

›lay another long-term role, creating a technological base for new areas of ›otential advantage by opening up opportunities for diversification into elated products and new industries.

The historical experience of today's industrial countries shows that the ›aths they followed toward national technological development were ›ased on cumulative knowledge and experience (see David 1975; and, in a lifferent tradition, Porter 1990). In general terms, technological accumula-.on involved the progressive acquisition of largely country-specific and nternationally immobile intangible capital in the form of personal and rganizational skills and related institutional structures. This capital nabled countries gradually to adopt and develop process and product :chnologies of increasing complexity. Changing bases of international ompetitiveness evolved along with, and increasingly as a result of, these :chnological capabilities. Over time, the learning processes within sectors iid the groundwork for production in other sectors, as the following examles illustrate:

- the creation of capacities to design and develop capital goods outside established user industries through vertical disintegration;
- the transfer of accumulated knowledge and expertise to enhance the competitiveness of other types of firms; and
- the migration of skilled people from firms in one category to firms in another, in general stimulating awareness of new areas of knowledge and new skills among local firms and technological institutions.

However, opportunities for technology-based diversification in today's ›veloping countries are not the same as they were in the past. For exame, in the nineteenth century textile production was the basis for accumuting knowledge on the design and building of textile machinery and lated capital goods. Today, the locus of accumulation has shifted to speilized suppliers of textile machinery. Nevertheless, the experience of large ›rean *chaebols* (conglomerate firms) suggests that experience in one field production (such as cement) can be an important input in the establishent of another (such as automobiles) (Amsden 1989). Furthermore, the oduction of automobiles and consumer durables has become important technological accumulation in industries such as machine tools and ated capital goods. For example, Japan's capability in computer-con-

tion efficiency in automobiles and electronic products. Similar patterns seem to be evolving in these industries in Korea (Lee 1993).

Compared with the experience of earlier industrializing countries, however, there appears to be a much lower degree of automaticity in the diversification and shifting of sectoral structures of production. Accumulating experience in one line of production seems to have become progressively less adequate as the sole basis for diversification. High levels of explicit investment in technological capability are required today, since—as was emphasized earlier—the accumulation of these capabilities is not automatically linked to the expansion of production capacity or to the growth of output. In order to help industries break out of the constraints of past experience, policy mechanisms to induce shifts in sectoral patterns of investment in production capacity may also be necessary (see chapter 5).

The Role of Business Firms

Given the specific, localized, and partly tacit nature of technological knowledge and of the capabilities needed to use and build on it, the business firm is the central agent in creating and managing patterns of technological change. The behavior of firms in accumulating technology is determined in part by market signals and in part by government policy. Within a policy environment, however, firms differ in their responses to a complex present and an uncertain future, depending on the skills they have accumulated and the discretionary judgments their managers have made. Such judgments are particularly influential in deciding the level of intangible investment in training, R&D, and other activities related to change, the benefits of which are often not immediately obvious.

The increasingly global activities of large firms based in industrial countries are accelerating the growth of international production and the international diffusion of technology associated with such production. But the intangible resources for generating and managing change (such as R&D and production engineering) remain heavily concentrated in the industrially advanced countries (Patel 1994). The degree to which firms deploy these change-generating resources in a foreign country depends not only on competitive pressure but on the quality of local human resources (including worker skills and the number of qualified scientists and engineers) and the change-generating capabilities of local business firms. Thus, the design and t as important for developing as for industrial countries.[8] The technolog-l capabilities of local firms are the central features of these systems.

This section examines key features of these national systems of innova-n: the characteristics of successful management, the complementary ks between technology imports and local capabilities, training by busi-ss firms, and the contributions of R&D institutes.

ccessful Management of Technological Change

ere is a flourishing research-based literature on the firm-specific factors t affect the success and failure of innovation in advanced countries, but re is no literature of equivalent scope and depth for developing coun-s.[9] Nonetheless, existing studies do point to several important factors t can be influenced by effective management.

Technology acquired from firms in more advanced countries is obvi-ly important to firms in industrializing countries that are trying to catch technologically. But it is also true for firms in industrial countries. Much rnational trade in technology (either as disembodied knowledge or as nology embodied in capital goods and engineering services) takes place ong advanced industrial countries, and a significant proportion of the ovations developed in these countries is based on imitations of existing nology (De Melto, McMullen, and Wills 1980; Smith and Vidvei 1992; aco 1992). In addition, R&D in industrial countries is often undertaken order to monitor, assimilate, and modify the technological advances of npetitor firms in other countries (Levin and others 1987; Cohen and inthal 1989). There is therefore no clear-cut distinction between the ds of activities and resources required for innovation and those required imitation.

The level of technical competence in senior management is an important or influencing a firm's commitment to change-generating activities. This ling is based on:

- intercountry comparisons showing that strong commitments to industry-funded R&D and training activities are associated with high proportions of scientists and engineers in senior management (Lawrence 1980; Pavitt and Patel 1988);
- intracountry comparisons of firms' performance with the competencies of senior management (Scherer and Huh 1992); and
- the experiences of countries that have been successful in catching up technologically (Gerstenfeld and Wortzel 1977; Amsden 1989).

Technically competent senior managers are obviously necessary if firms are to choose and implement new technology effectively. Choosing the right technology requires the evaluation not only of any measurable economic benefits but also of the potential future benefits of technological learning along alternative and irreversible paths. Conventional project appraisal techniques such as discounted cash flow cannot (and should not) be used in the assessment of the option value of alternative technological paths (Myers 1984; Mitchell and Hamilton 1988). The judgment of experienced engineers may be the only realistic method of forming expectations about the likely benefits of alternative technological paths and policies.

Good communication and effective collaboration, both among internal departments and with sources of knowledge and potential customers, are important distinguishing features of successful innovation in industrially advanced countries (Rothwell 1977). The importance of intrafirm cooperation has also been identified as a significant factor in the successful accumulation of technological capabilities in Korean semiconductor firms (Choi 1993). However, there is some evidence that external linkages, although important for technological latecomer firms in developing countries, differ from those found in state-of-the-art firms in industrial countries. In latecomer firms attempting to catch up technologically, technical feasibility and market acceptance are already established. The main uncertainties and risks relate to the firms' capacity for learning and improvement (see Kim and Kim 1991). The most important external linkages are therefore to organizations able to help the learning process—suppliers, customers, licensers, businesses producing competitive products (for reverse engineering), and technical support institutions. In state-of-the-art firms, the main uncertainties and risks relate to technical feasibility and market acceptance of previously untried technology. Links with repositories of fundamental technical knowledge (such as universities) and with potential customers are therefore

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8. "National systems of innovation" can be defined as the intangible investments accompany tangible investments as necessary inputs into economic growth. e specifically, they can be seen as the national institutions (including their incen-structures and their competencies) that determine the rate and direction of tech-gical learning in a country (see Lundvall 1992; Nelson 1993; Patel and Pavitt).

9. Notable exceptions include Kim and Kim (1985) and Gerstenfeld and Wortzel

:ommon assumption that policymakers have made is that importing ;n technology and creating it locally are substitutable means of gener- technical change in industrializing countries, even though there is ;h evidence to suggest that imported technology and local technologi- ccumulation are complementary. In other words, generating change res considerable domestic innovative effort as well as the acquisition ported technology. Even when technical change depends heavily on rted technology, new equipment and techniques may be comple- ed by intensive efforts to accumulate locally the capabilities for wing the acquired technology, generating new components, and pro- ıg technological independence.[10] Investment in related technological ilities can begin before technology is imported, providing the knowl- buyers need to make the best deal and speeding up the assimilation of naterials. Japan followed this path when it first undertook synthetic production (Ozawa 1980). The exchange of information through edu- ıal and other formal or informal channels is also important to the sition of new technology and the development of local capabilities. eers and managers from developing countries who study and work in trial countries not only are trained in technological problem-solving lso have access to the informal international networks that are so tant in science-based technologies. For example, one study of Korea s that experience acquired through overseas employment was much important than the acquisition from abroad of basic process and pro- m technology (Westphal, Rhee, and Purcell 1981).

mplementarity between imported and local technology is often less e (but more intense) in commercial technology transactions among —for instance, when the licensing of process specifications is accom- d by access to design data; training in design routines or production eering; or opportunities to acquire experience in design, engineering, &D activities. Firms in the East Asian NIEs have used international ology transfers as an active investment in learning. The training com- its of technology transfer agreements with foreign companies fre- ly cover much more than the acquisition of the skills necessary to te and maintain new facilities. They also focus on acquiring various

See Hollander (1965) on the DuPont Corporation. On various aspects of Jap- technological accumulation, see Tanaka (1978, 1992); Fukasaku (1986); ka (1987); Odagiri and Goto (1992); and Ozawa (1974, 1985).

combinations of design, engineering, and project management skills that can be used to generate change (Enos and Park 1988; Hobday 1994a). Further, customers in industrial countries have been used as an important source of knowledge and expertise, especially in industries that rely primarily on assembly (Westphal, Rhee, and Purcell 1981).

This aspect of the East Asian experience suggests that successful firms go through what might be described as a "reverse product cycle" (Hobday 1994b). The firms begin with simple assembly processes but gradually and systematically accumulate the capacity to modify, design, and build their own product and process technologies. Customers play a major part in this cycle, which proceeds through successively higher value-added forms of production. Finally, some firms in the more knowledge-intensive segments of the electronics industry (especially Korean firms) have set up their own operations in the industrial countries to facilitate the acquisition of new information. They have started their own R&D centers (concentrating heavily on technological learning in advance of the acquisition of existing technology) or acquired established firms in those countries in order to gain access to particular skills, experience, and knowledge.

Again, there seem to be wide variations in the extent to which developing countries have been able to develop these two forms of complementarity. Firms in the East Asian NIEs have commonly entered new industries in much the same way as firms in other developing countries—by drawing very heavily on imported inputs of core technology, engineering services, equipment, and know-how. But as these industries expand, successive projects draw increasingly—though very seldom exclusively—on local sources. The East Asian NIEs have been massive importers of industrial technology through:

- direct foreign investment (largely as joint ventures in some countries);
- subcontracting and original equipment manufacturing agreements with foreign customers; and
- licensing and other contracts with unrelated suppliers of know-how, designs, equipment, and services (Hobday 1994b).

But these inflows of technology have been complemented by locally sourced technology, which emerged after intensive efforts to improve what was initially acquired. In other words, firms did not choose between imported and local technology as sources of technical change: instead, they chose both.

In other late industrializing countries, particularly the formerly centrally planned economies, international technology transfers have not been as closely integrated into the process of domestic technological accumulation (Girvan and Marcelle 1990). They have played a major role in the expansion of production capacity but a minor role in building local technological capabilities. Commercial technology transfer arrangements have been used in some industries (steel and petrochemicals, for instance) in the large Latin American countries to augment technological capabilities as well as production capacity (Dahlman and Fonseca 1984; Sercovich, 1980). However, such cases appear to have been relatively infrequent.[11]

The East Asian NIEs have also benefited from the interfirm migration of skilled personnel in the development of technological capabilities. The skills workers gained through this workplace experience were determined to be the second most important source of production technology for firms entering export markets (Westphal and others 1981). Interfirm flows of workers embodying new technology have often been important in creating nuclei of competence that form the basis for the acquisition of new types of technology. For example, the effectiveness with which the firm that led Korea's entry into the petrochemical industry acquired foreign technology was greatly enhanced by the company's ability to draw on engineering capabilities previously accumulated by another firm in the refinery industry (Enos and Park 1988). Similarly, the engineering and project management capabilities accumulated by the Korean Electric Power utility were subsequently diffused to enhance the efficiency of firms entering the power engineering and equipment industries (UNCTAD 1985). More generally, close interactions with customers and domestic users of related foreign products have been an important stimulus to technological accumulation in the Korean machine-building industry (Kim and Kim 1985). Behind these flows of change-generating interactions lies substantial investment in training—not only in educational and training institutions but within firms themselves.

Business Firms as Creators of Human Capital

The common perspective on human capital in economic growth gives primary emphasis to formal education and training in educational institutions; firms themselves are seen as the users, not the creators, of the human capital they require. This assumption understates the central importance of businesses in the process of technological learning. In fact, businesses have played an especially significant role in countries such as Japan and Germany, which have effectively exploited the dynamic gains of technological accumulation.[12]

However, educational institutions and firms are not substitutable alternatives: particular kinds of skills and knowledge can be acquired only in firms, through investment in learning by doing or training. But because firms are unable to capture the full returns to their investments (since trained workers can move to other firms), they are likely to underinvest in human capital, from both a social and possibly a private perspective. There are, however, significant differences in labor mobility among countries (notably, the United States and Germany or Japan) and hence in the incentive to provide on-the-job-training.

Although the formal education and training infrastructure has been extremely important in the East Asian NIEs, it has nevertheless accounted for only part of the total education and training effort that has contributed to technological accumulation in industry. Firms themselves have played an important role in this process. There is little information about the importance of their role during the rapid-growth phase of labor-intensive industries, but at that stage hands-on experience may be more important than more organized education and training within firms. In any case, the latter appear to have become increasingly important in Korea and Taiwan, China, as these economies diversified into knowledge-intensive industries.[13] Particularly significant has been the emphasis on training and the accumulation of experience in product and process engineering and project mana-gement (Enos and Park 1988; Amsden 1989). As in the industrialized countries, the East Asian firms are becoming increasingly important not just as employers but as creators of skilled human capital.

11. For example, see Mytelka (1978) and Vianna (1985) on some of the smaller Latin American countries; Farrell (1979) on Trinidad; Quazi (1983) on Bangladesh; Scott-Kemmis and Bell (1988) on India; Ng and Siy (1986) on the non-NIC Southeast Asian countries; and Mlawa (1983), Mytelka (1992), Ohiohenuan and Poloamina (1992), and Wangwe (1992) on a range of African countries.

12. See, for example, Prais (1981) for detailed and careful comparisons of the effects of investments in education and training on levels of and rates of increase in productivity in British and German firms.

13. Fragmentary evidence suggests that even in the 1970s in-plant vocational training was quantitatively more significant than similar training in public organizations. One study, for instance, notes that between 1967–71 and 1977–81 the total annual number of vocational trainees in Korea increased fivefold. The number of technicians trained in public organizations tripled, while the number trained in plants increased sevenfold (Kim 1994).

Iore recently, the role of firms in training has become more visible: the ıst electronics company in Taiwan, China, has set up its own university, 'atung Institute of Technology. In Korea, the Samsung Advanced Insti- of Science and Technology has been established. The Government of ıpore has been particularly skillful not only in mobilizing the financial ırces of multinational corporations to establish education and training ıutes but also in harnessing these corporations' own human resources ılp implement a range of education and training programs in technol- ınd management.

here is surprisingly little information from other developing countries t the role firms play in training. The available data suggest, however, this kind of complementarity between the public infrastructure and firm training efforts has been moderately significant. Only limited pri- initiatives have been undertaken in Latin America and India. Among in some southeast Asian countries, the prevalance of training pro- s seems to vary: in Indonesia, for instance, training has been signifi- in just one or two public sector enterprises; and despite some signi- t efforts in Thailand, intrafirm human resource development has been ıt even in companies involved in information technologies (Hobday 3aba 1990). In Africa, private intrafirm training has been almost com- ly absent (Mlawa 1983; Mytelka 1992; Ohiorhenuan and Poloamina Wangwe 1992).

Institutes

needs to be intimately associated with production. Specialized insti- can and do make important contributions to technical change, but links een these institutes and the production activities of firms depend ly on the strength of technological capabilities within firms themselves. ost developing countries have established separate government-sup- d institutes to undertake R&D for industry. In Korea and Taiwan, ı, the scale of government-funded R&D in the 1970s was somewhat er than in most other developing economies, but it was otherwise simi- that it accounted for the major proportion of total industrial R&D— ıd 80 percent (firms undertook the remaining 20 percent). Its innovative ties made only a limited contribution to technical change in industry.

owever, in two other key dimensions, the activities of the Korean and ınese institutes reflect activities common to the development experi- of industrial economies. In these respects, Korea and Taiwan, China, from other developing economies.

First, especially since the 1970s, many of the R&D institutes in the East Asian NIEs have emphasized both innovation and the learning or technology absorption aspects of R&D (Cohen and Levinthal 1989). In emphasizing the role of learning rather than concentrating solely on the generation of technological innovations, these institutes undertook activities that differ from those typically undertaken in developing countries. This difference has been especially evident in those institutes set up to support the electronics industry. In Taiwan, China, the Electronic Research and Service Organization of the Industrial Technology Research Institute has acted less as a generator of state-of-the-art technology for industry than as a focal point for acquiring existing foreign technology, assimilating it, training people to use it, and then diffusing both the technology and the trained operators to firms. Naturally, it has also undertaken its own activities, which imitate R&D activities in industrial economies, in order to keep up with the latest technology. A similar emphasis on acquisition, absorption, training, and diffusion (as opposed to generating innovation) has characterized the activities of electronics-oriented R&D institutes established in Korea in the early and mid-1980s and more recently in Singapore.

Second, the apparent dominance of R&D in infrastructural institutions (compared with firms) in the East Asian NIEs in the 1970s is misleading in two ways. Surveys take little or no account of the engineering and related resources that play a major role in generating and managing technical change in industry. If these resources are included alongside R&D activities, the balance between infrastructural and intrafirm technological capabilities tips substantially towards the latter—the typical pattern shown by R&D data for the advanced industrial economies. In any case, even for R&D alone, the balance changed considerably during the 1980s. This change has been most striking in Korea, where, within a rapidly growing total, the 20/80 percent distribution of R&D activity between intrafirm and infrastructural institutions in the 1970s was reversed to 80/20 percent in the early 1990s.

Most other developing countries have continued to maintain a large proportion (80 percent or more) of their R&D capabilities in infrastructural institutions—even countries such as Brazil and Argentina, where substantial industrial expansion began in the early decades of this century. However, more important for many countries is the limited intrafirm accumulation of a much wider range of (non-R&D) engineering and other change-generating capabilities. Even if these are taken into account, however, the distribution of overall technological capabilities between infrastructural institutions and firms frequently remains heavily weighted oward the former, in comparison with the historical experience of the ndustrial countries or the contemporary experience of the East Asian NIEs.

;umming Up

'his chapter has argued that competing in the world market requires not nly that firms achieve international benchmarks of productive efficiency ut that they make steady technological improvements over time. This proess starts, rather then ends, with investment in new industrial plants and roductive capacity. Thus, a nation's capability to foster and manage techological change is crucial to its firms' ability to survive and grow in the nternational marketplace.

While firms in developing countries tend to depend on imported techology in the initial stages or when they are entering new lines of producion, there is considerable variation in the gains they derive from adopting nd using this technology. In particular, the intensity with which firms ccumulate their own capabilities to generate and manage technical change nfluences a range of important performance variables, including:

- the efficiency of investment in new production capacity—including the economic efficiency of input combinations chosen in the light of local prices, the level of process technical efficiency initially attained, and the initial competitiveness of product quality and specifications;
- the subsequent rate of productivity growth in existing lines of production; and
- the sustained competitiveness of product specifications and designs.

Over longer periods, the intensity with which the change-related esources are accumulated and applied in the process of technical change vill influence other variables:

- the strength of both backward and forward linkages to suppliers and customers;
- the ease of structural change toward more technology-intensive lines of production; and
- the ability to enter new product markets successfully.

Technological capabilities are not acquired as an automatic byproduct of nvestment and production activities. They are accumulated through concious and continuous investment by firms in specialized, change-generatng activities, comprising product design, production engineering, quality

The volume and effectiveness of these largely firm-specific investments depend in turn on the technological competence of senior management, the skills of the labor force, the incentives for firms to invest in technological accumulation, and the effectiveness of specialized support institutions (especially R&D laboratories) in providing technological knowledge and training. These conclusions have clear implications for industrial policy that are taken up in the next chapter.