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Technological Change and Technology Strategy

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ABSTRACT

This paper reviews both theoretical and empirical studies of technological change in developing countries. It assesses the contribution that these studies have made to technology strategy and offers suggestions for further economic research.

Our review of theoretical studies by economists concludes that most such studies have offered little policy insight. This is largely because of limited empirical verification. The older economic growth theories (of the 1950s and 1960s) did not treat technology as an economic activity. More recent "endogenous" growth theories, however, can be credited with reviving interest in technology and technology policy. Some empirical testing and verification of these models is now underway and with more empirical studies this line of research could be quite valuable. Search models and induced innovation models have made contributions to the extent that they have influenced empirical work. Most recent game-theoretic studies have yet to demonstrate policy relevance because of limited empirical verification.

The field of the economics of technology is thus primarily an empirical field. A great deal of the relevant empirical work in the field has been guided by the growth accounting framework developed in the 1950s. Total factor productivity calculations have served as the basis for statistical studies relating productivity to variables measuring inventive activity, infrastructure and policy environments. The agricultural sector has been extensively studied in this context and a large number of estimates of returns to investment in agricultural R&D have now been reported. These studies show that such investments have had a high payoff in both developed and developing countries. They also show that agricultural technology is subject to high levels of technological distance (i.e., location-specificity) and that the degree of simple transfer (spillover) of technology from developed to developing countries has been very low.

Empirical evidence for industrial technology in developing countries is much less complete. Rates of return studies for private sector R&D in developed countries show that privately captured returns are comparable to returns on other relatively risky investments but that "social" returns are much higher (roughly comparable to the high social returns for agricultural research). The few studies available for developing countries suggest that this is so for these countries as well.

The paper concludes that developing countries cannot expect to achieve technology- driven economic growth without significant investment in technology infrastructure and without developing a conducive environment for such investment and for accessing foreign origin technology. Of the approximately 100 less developed countries, only 25 or so have made sufficient investments in technology infrastructure to achieve rapid economic growth. And of these only ten or so have actually realized such growth because of adverse policy environments.

1. Introduction

Except with respect to agriculture, investments in technological change by less developed countries (LDCs) have not been emphasized in economic thought about the general design of development policy. Development textbooks do devote considerable attention to technological topics in nonagricultural sectors, such as the choice of techniques and technology transfer through direct foreign investment. And international institutions do engage in technological projects beyond the agricultural sector; supporting activities in the industrial sector to disseminate technical information and to upgrade production, for instance. But neither the topics nor the projects are generally perceived in relation to technological investments. Typically they are seen from other perspectives -- choice of techniques, in terms of generating appropriately remunerative employment; technology upgrading, in terms of assistance to structural adjustment following market opening; and so on. They are seldom brought together in a unified discussion of technology and development or in some nodal point within bureaucratic structures.

Why are the technological aspects of development usually considered as disparate elements? We suspect that part of the answer lies in the absence of a common conception of the role and nature of technological change in the context of economic development. Thus, in attempting to provide a more unified treatment, we find it necessary to devote some space at the outset to conceptual matters.

1.1. Concepts of Technological Change

In the past, many development economists have approached technological change from the vantage of structural change and technique choice. "Technological change" has meant the first appearance in local production of any novel process or product. It has been considered the result of an

endogenous process; the demand for new techniques is induced by other changes within the economy. And it was often thought that the supply of techniques was readily available from the "shelf" of techniques produced in developed countries. Perhaps most common has been the conception of dynamic comparative advantage, grounded in the tradition of Heckscher - Ohlin - Samuelson trade theory [Chenery (1967)]. New products are introduced into local production as the structure of production evolves in response to changes in the composition of domestic demand as well as in the balance of factor supplies and demands. And new processes are adopted as the allocation of resources adjusts to changes in relative factor prices. But, apart from the costs of searching for and acquiring new technical information, investments in technological change have had no meaningful role in this view.

The policy implications of this approach are straightforward. Technologically, it is sufficient if the policy regime simply insures the timely initial adoption of economically warranted techniques and their appropriate diffusion through the economy. Accordingly, the requisite policies are those required to achieve an efficient allocation of resources in the context of exogenously determined technological alternatives. Among these policies, the only ones explicitly focused on technology per se are those that address inefficiencies that may result where techniques are not freely available. One such commonly employed technology policy, justified as providing a public good, is government sponsorship of institutes that collect, process, and disseminate technical information. But technology policies per se are of secondary importance relative to the other kinds of policies that are conventionally associated with achieving efficient resource allocation in a static setting.

Two assumptions taken together would justify this inattention to endogenous elements on the supply side of technological change in the development process. One is an assumption that technology consists simply of a set of discrete techniques, each wholly described by its "blueprint." The other is that all techniques are created in the developed countries, from whence they flow to the technologically backward LDCs. On these assumptions, there is no place in development for investments in creating technology, in the form of either assimilating imported techniques or developing new techniques through adaptive invention. The first assumption implies that assimilation is costless. The second implies that there is little scope for LDCs to make useful adaptive modifications in technology.

If technology is perceived in more complex terms, consistent with empirical evidence, one is led to conclusions quite different from those based on the assumptions noted above. Most obvious is the evidence, reviewed later in this survey, that technology is in fact created in the LDCs. This and other important aspects of technological reality can only be fully comprehended by recognizing that technology is, most fundamentally, knowledge about how to do things. Techniques, defined as singular ways of doing particular things, are the result of choices made when applying technology in specific circumstances with respect to economic, physical, and social conditions. In effect, a technique is a solution to a problem of constrained maximization in which technology and circumstances form the constraints.

1.1.1. Tacitness and Circumstantial Sensitivity

No existing technique is completely expressed by the sum of the reproducible elements in which it is partially contained; that is, in the codified information about it and the material inputs that provide the

physical means for its accomplishment. This is because much of the knowledge about how to perform elementary processes and about how to combine them in efficient systems is tacit, not feasibly embodied and neither codifiable nor readily transferable. Thus, though two producers in the same circumstances may use identical material inputs in conjunction with equal information, they may nonetheless employ what are really two distinct techniques owing to differences in understanding of the tacit elements. In turn, currently existing techniques do not necessarily exhaust the potentially beneficial applications of technology. Even supposing that they represent optimal solutions for the circumstances in which they are respectively used, it does not follow that they must necessarily be optimal with respect to different circumstances where they have not been previously tested.

Tacitness and circumstantial sensitivity in the application of technology are often disregarded, being obscured by the tendency to think about techniques and circumstances in terms that are general rather than specific. Techniques are customarily identified in generic terms, typically with reference to key physical inputs -- variety of seed, for example. But technologies in use that are based on the same seed variety differ a great deal; planting and harvesting dates differ among locations, as do the optimal amounts of water and fertilizer used. In industry, machines can be calibrated to operate in different ways and can be used with distinct kinds of ancillary fixtures to achieve various effects. Circumstances are ordinarily identified with economic variables, which are frequently summarized very simply in terms of the wage-rental ratio, neglecting not only other economic variables but also physical and social conditions. Nontradeable inputs -- land, labor, utilities, and services -- vary greatly in characteristics and quality.

Similarly, ostensibly identical material inputs -- natural resources in particular -- are characterized by widely differing precise specifications. Among social institutions, labor-management relations are particularly variable.

1.1.2. Investments in Technological Change

Once technology is understood in these more complex terms, it is quite obvious that investments in technology are made whenever it is newly applied, regardless of the novelty of the application. Learning about technology and problem solving using the knowledge acquired in mastering technology are not costless, even if the choices made in realizing the technique to be used are identical in generic terms to choices previously made elsewhere. The magnitude of the warranted investment depends crucially on the circumstantial sensitivity of existing reproducible elements of technology. As will be discussed in detail later, there are pronounced sectoral differences in the circumstantial sensitivity of generic techniques and, correspondingly, in the scale of problem solving investments across sectors.

A stream of investments over time is typically required to overcome tacitness and thus achieve mastery. Not only is much technology tacit, so too is much knowledge about the specifics of local circumstances and about the ways that differences in circumstances affect the productivity of particular techniques. Tacit knowledge can only be acquired through investments in learning -- learning that is importantly grounded in purposeful analysis of information gained through practical experience. With learning comes increased understanding of technology and of circumstances, which typically results in changes away from the original solution, as techniques are adapted to local circumstances or otherwise modified to achieve higher productivity.

Learning is generally a sequential process, so that alterations in techniques usually take place through a progression of problem reformulations leading to new solutions.

Investments in learning lead either to assimilation, duplicating understanding that exists elsewhere without adding to the stock of reproducible technology, or to invention and innovation, adaptive or otherwise, creating novel elements of reproducible technology that yield higher productivity under local conditions.[1] To determine the relative frequencies of these outcomes in the experience of even one LDC would be an enormous undertaking because of the level of firm-level detail that would be required. Patent statistics and similar indicators, supplemented by case study research, clearly indicate that invention does occur in most LDCs, and that the advanced LDCs may be about on a par with developed countries in this regard. Moreover, case study research strongly suggests that internationally competitive levels of productivity are seldom if ever achieved through simple assimilation. It also suggests that the conventional measures fail to capture a great deal of the technological effort that underlies the attainment of competitive productivity levels.

Simple models of learning-by-doing [e.g. Arrow (1962b)] do not capture the essential elements of technological development even at the level of an individual firm that is pioneering the local introduction of some new technology [Bell (1984)]. They are not at all suited to comprehending the complexities of technological development among many interacting entities forming an economy. The essential elements are those that have been stressed by economic historians [Landes (1969), David (1975), Rosenberg (1976, 1982), among others] in writing about technological development in the now advanced

countries. Technological efforts to overcome tacitness and to adapt technology to local circumstances have figured importantly whenever technological followers have succeeded in effectively utilizing leaders' technology. From them have come many of the fundamental institutional and organizational innovations that have helped to make technological change an integral part of economic activity in the advanced countries.

The investment required to accomplish a particular technological change depends critically on two things: 1) the degree of external participation in its accomplishment; and 2) the internal technological capability (ability to make effective use of technology) that has been acquired through previous investments in technology. By substituting for internal technological capability through providing various technological services, external agents can substitute for current investment.[2] Accordingly, the management of technological change involves choices of both the changes to be made and the investments to be undertaken. The latter are essentially "make-buy" choices in which the decision to make results in the creation of technological capital. These choices raise important policy issues with regard to the sequencing of an LDC's investments in technological capital and to their phasing relative to other processes of economic development.

1.2. The Catchup Concept

The concept of catchup economic growth has been in the development literature for many years [Landes (1990)]. From Gerschenkron's (1962) discussion of the advantages of backwardness to the contemporary literature dealing with convergence [Barro and Sala-i-Martin (1992)], the proposition that technological followers benefit from the technology created by

technological leaders has been accepted as an empirical truth. A strong version of this proposition is that the scope for catchup growth is proportional to the difference in technological capabilities between a follower and the leaders. This version predicts an inverse relationship between technological capabilities at any point in time and subsequent productivity (as well as economic) growth.

The mechanism generally specified as underlying this process can be described as technology transfer. Followers, with appropriate policies and investments, are expected to learn about the leaders' technology, choose the best techniques for particular purposes, and then implement them. As previously indicated, the policies required for transfer are usually not seen to differ from those required for achieving economic efficiency. The investments entailed are usually thought to be investments in education, physical capital, and general management capability. In particular, R&D (research and development) and related activities that are considered essential to the maintenance of technological leadership are often not deemed to be important for success by follower countries.

Studies of economic growth in the post-World War II era have shown that general convergence of income or productivity levels has not occurred [Easterlin (1981), Landes (1990), Barro (1991), Williamson (1991)]. True, several former LDCs, now typically classified as newly industrialized countries (NICs), have grown at very rapid rates and have, in fact, converged on the leading industrialized countries. And there has been convergence among the OECD countries. But most LDCs are not on a path of convergence toward the industrial countries.

Few studies have attempted to document carefully the sources of

initial divergence in levels of economic development. "Uneven development" studies [e.g. Hymer and Resnick (1970), Hymer (1972)] generally attribute it to political factors; economic historians [e.g. Ayres (1944), Landes (1969), Morris and Adelman (1989), Rosenberg et al (1992)], to a broader constellation of institutional and social factors. But it appears to be generally accepted that adverse institutions and deficient policy regimes are responsible for the failure by most LDCs to achieve catchup growth over the past four decades. This survey will conclude in addition that specific investments in technology over sustained periods are essential to the realization of technological catchup by followers. Institutions and policy regimes may explain why the investments have not been made, or why the investments made have been ineffective in many cases. But the investments are essential [Dahlman and Nelson (1991)]. No LDC has to date achieved rapid economic growth without continued technological investment.

1.3 Readers Guide

This chapter addresses questions that are primarily microeconomic in nature: What are the relevant varieties of technological investments? How large are the associated net returns? What factors motivate their being undertaken? Do private agents allocate adequate resources to the right kinds of technological changes? How can governments overcome likely market failures? What can be learned about probable government failures from the record of the past? Answers to these questions would provide the basis for gauging whether past technological investment has been insufficient or misdirected and, if so, for probing the causes and consequences.

As will be seen, answers are more nearly complete for agriculture than for other sectors. This reflects the disparity in the attention and funding

given by public authorities to promote technological change in different sectors. In turn, this survey includes work on developed countries where answers are at least partially available for them but not for LDCs. This is not done to imply that the issues and answers for both kinds of countries are necessarily the same, but instead to provide a meaningfully comprehensive overview of the topic at hand.

Several major themes that build on the tacitness and circumstantial sensitivity of technology are critical to an understanding of processes of technological change. These themes come primarily from empirical -- econometric and case study -- investigations of LDC experience. As will be argued in section 2, where pertinent theoretical work is reviewed, relatively few insights have been provided by theorists, most of whose work neglects key features of empirical reality in the LDCs. The themes are developed in sections 3 through 5, which collectively summarize the useful analytical structures that have been derived from empirical studies in the field.

The first theme is developed in sections 3 and 4: rapid economic growth that is importantly based on technological change can not be realized without technological development in the sense of creating technological infrastructure in the form of specialized institutions and capital stocks. And there are wide differences in levels of technological development among LDCs. Sections 4 and 5 articulate a second theme: technology flows from countries that are technological leaders to those that are followers in two distinct ways. One is through the direct transfer of techniques which are then typically adapted to local circumstances. The other is through the transfer of knowledge that is then used by the follower country to generate new techniques. A follower's technological capabilities are critical for both

modes of transfer, but in different ways. Section 5 also adds a related theme: differences in economic, physical, and social conditions coupled with the sensitivity of technology to these differences creates "technological distance" between any two locations. Distances are large in many fields of technology and critically affect the technological make-buy choices that confront entities in LDCs.

The final major theme, present throughout the chapter, is that effective technology transfer requires distinct activities and investments to minimize the cost of implementing the new technology and to maximize its productivity once in place. The optimal package depends on the field of technology as well as on the technological distance involved. It further depends on the behavior of technology suppliers and on the recipient's level of technological development. Policies affecting resource allocation and the availability of supporting infrastructure play a major role in determining whether the optimal package is actually chosen.

Sections 6 and 7 review the evidence from empirical studies of, first, the factors affecting the accumulation of technological assets in LDCs and, second, the returns to investments in such assets, including the growth and distributional implications of technological change. Policy issues are dealt with in section 8. It argues that the policy options faced by individual LDCs are significantly conditioned by technological development levels and, that for most countries, the building of technological capabilities should be a central objective of overall development strategy. Section 9 concludes the survey with a brief discussion of research priorities.

Theoretical Contributions

Economic development has been the focus of a large part of economic

growth theory. Much research was done in the 1950s and 1960s in the context of long-run equilibrium growth to model economies characterized by labor surplus and other conditions thought relevant to LDCs [Lewis (1954), Fei and Ranis (1964), Jorgenson (1966)]. This research produced a heightened appreciation for the important role of technological change in sustaining the development process and generated greater comprehension of the significance of sectoral differences in rates of technological change. But it contributed practically nothing to understanding how technological change is generated and maintained. The models simply treated technological change as an exogenous process, one occurring at a steady rate over time.

Techniques of development planning that evolved in symbiosis with growth theory embodied simple views of the sources of technological change. The most extreme view was that derived from socialist planning theory and practice. The capital goods sector, drawing on R&D performed in specialized institutes, was thought to be the singular driving force of technological change. Inspired by Mahalanobis (1955), India was one of several countries which put this view into practice through development planning in the 1950s and 1960s. As will be discussed in further detail below, the priority given to indigenous technology creation in the socialist approach proved to be highly counterproductive. So did the disregard for product innovation, which was thought merely to cater to frivolous tastes.[3]

A less extreme view, held by many Western advocates of development planning, saw technological change as being concentrated in the design and implementation of investment projects. It was thought to emanate from the activities of engineers who were responsible for selecting the best available techniques and plant designs as well as for seeing to their effective

implementation. As in the socialist approach, hardly any systematic attention was given to assuring continual processes of technological change within existing enterprises. Nonetheless, formal planning models often incorporated exogenous technological change parameters, yielding projections which generally turned out to be unrealistic. Regardless of its ideological underpinnings, the planning mentality of the 1950s and 1960s had a serious consequence. It stifled consideration of many forms of investment in productivity enhancement.

In this section we review those few bodies of theoretical analysis that do at least meaningfully incorporate some aspect of the processes of technological change. Included are the recently emerged body of endogenous growth theory, models of invention and discovery, as well as older models of induced innovation and technology diffusion. Our own conclusion is that the work in these areas has contributed useful insights to the analytical structures that we will later bring to bear on the analysis of technological change, but that most of our understanding of technological change comes from empirical studies.

2.1 Endogenous Growth Models

Endogenous growth theory [e.g. Romer (1986, 1990), Lucas (1988), Murphy et al (1989), Grossman and Helpman (1991), Barro and Sala-i-Martin (1992)] differs from its precursor in the explicit introduction of activities which can affect the long-run growth rate. Human capital formation and/or R&D investment are modeled as being subject to increasing returns, with various arguments being given about the source of the non-convexity, which is generally found in some form of externality or spillover phenomenon.[4] The presence of increasing returns (or, more accurately, a lower bound on

diminishing returns to capital) is responsible for the possibility of per capita income growth in the long run (asymptotically). By exploring the implications of the properties of technology as knowledge, the theory has increased the general understanding of the importance of technological investment.[5]

To date, endogenous growth theory has achieved few robust policy generalizations. Moreover, development economists who grew up arguing about the merits of Rosenstein-Rodan's (1943) "big push" and debating balanced versus unbalanced growth are prone to find much that is not really new in endogenous growth theory. The vocabulary is new, but many of the insights that are today considered novel were the staple of development economics in the 1950s and 1960s. Indeed, as is relatively well known, the basic insights on which much endogenous growth theory is built are present in Adam Smith's (1776) discussion of pin making technology.

Translation of the theory into empirically testable models is confounded by using steady-state conditions as guides to specification. While these conditions do offer insight, it is not at all clear that they provide directly applicable guides for empirical work. Economies may require long periods to reach steady-state, particularly if the incentives for appropriate investments are not in place or are endogenously established. Moreover, technology spillovers are not well specified in these models, and indivisibilities in processes of technology creation are not fully captured.

Most of the empirical work [e.g. Lichtenberg (1991), Kortum (1992), Mankiw et al (1992)] so far spawned by the theory has produced some findings of consequence for attempting to understand technological development. Particularly noteworthy in this respect is Lichtenberg's (1991) work

demonstrating the importance of distinguishing among different asset accumulation processes; in particular, R&D versus schooling. Also promising is work like that done by Coe and Helpman (1993), which investigates the relationship between total factor productivity (TFP) growth in OECD countries and domestic as well as foreign R&D expenditures, with the latter being included to capture international technology spillovers. Additional research of this kind is discussed in sections 5 through 7.

Endogenous growth theory has made a significant contribution through the disciplined rigor that it has introduced into the analysis of the technological underpinnings of long-run growth. No less important, it has brought issues of long-run growth back into mainstream discussion, making development again a matter of interest to many economists. Additionally, the incorporation of endogenous growth considerations into international trade theory has greatly increased its relevance in the context of technological development. The most important work here is that of Grossman and Helpman (1991). Their models treat inventive activity and related investments in a systematic fashion to derive a number of new insights centered on the distinctive roles of these investments in generating trade between technological leaders and followers. But the comments made above in relation to endogenous growth theory generally apply here as well. Moreover, these models do not fully come to grips with the disparities in technological capabilities among countries at widely different levels of technological development.

2.2. Models of Invention

Growth theory is concerned with the implications of particular properties of technological activity rather than with comprehending the

activities per se. Early work on invention did not consider international dimensions but it did establish the basic rationale for intellectual property rights (IPRs) and clarified their value. Machlup (1958) reviewed the effectiveness of existing IPR systems. Arrow (1962a) and Nordhaus (1969) developed the basic model for analyzing the incentives to engage in R&D that are afforded by IPRs. In later studies within the industrial organization tradition, Barzel (1968), Dasgupta and Stiglitz (1980), Gilbert and Newbery (1982) and Dasgupta (1986) developed models of patent races which demonstrated the possibility of excessive duplication of R&D activity (due to overfishing in the pool of latent inventions).

None of these studies paid attention to the peculiar circumstances of LDCs, nor did they foster much work to verify their propositions empirically. Even so, some theorists consider that this work has weakened what was once an overwhelming case for IPRs. In the realm of developed country policy, however, there is a clear trend toward stronger IPR protection, both in case law and in legislation. This trend has an obvious international thrust, with trade law increasingly being used to achieve IPR compliance by other countries. The just concluded GATT negotiations attest to the importance that is attached to IPRs by the developed countries.[6]

2.2.1. Search Models

The invention process differs considerably across fields of technology. In each field, the pre-invention sciences (see section 3.2) have devised procedures for discovery and invention -- a kind of technology for the discovery of technology. Scientific instruments, for example, are part of this technology. Well developed experimental design structures are another. Animal and plant improvement sciences rely on models of genetic improvement.

Industrial engineering uses design principles grounded in both theory and practical experience. And so on.

Thus it is incorrect to say that the invention process is not amply understood by the researchers working in most technological fields. Models of genetic selection, for example, can explain animal and plant improvement quite well. Nonetheless, each invention entails an "inventive step" that goes beyond the known and conventional. Trial and error, or search, along with an element of boldness and risk-taking is involved. Important pioneering, or "macro" [Mokyr (1990)], inventions are characterized by large inventive steps. They are typically followed by commonplace, or "run-of-the-mill" [Nordhaus (1969)], inventions that come in a reasonably obvious (to those familiar with invention in the field) sequence. Lower down the scale are the frequent minor, adaptive sub-inventions characterized by a low inventive step.[7] These are the predominant inventions in LDCs, which rarely produce pioneering inventions and, except for the more advanced among them, contribute relatively few commonplace follow-on inventions.

Several authors have applied search concepts to examine the general nature of the invention process [Schmookler (1966), Nordhaus (1969), Scherer (1972), Evenson and Kislev (1975, 1976), Binswanger and Ruttan (1978), Lee (1982)].[8] The basic search model has two elements that are particularly relevant to the invention of improved technology for LDCs.[9] It provides for changes over time in the pool of knowledge from which inventions are drawn (invention potential). Such changes do not only flow from upstream, basic research; they come as well from the search process itself and from similar research activities elsewhere. The model also provides for diminishing returns within a period of research while allowing for diminishing, constant,

or increasing returns over periods depending on changes in the pool of potential inventions.

The search process is modeled as a sequence of experiments, each composed of n trials or draws. A single draw can be a new crop variety, a certain dose of fertilizers, an alternative planting date, etcetera. At the beginning of a research period, a distribution of potential inventions exists. This distribution is determined by factors which are importantly influenced by the country's level of technological development within a particular field: the design of the research project, the skills and inventiveness of the R&D personnel, the results of research in previous periods, and the stock of inventive "germplasm" available from science and from practical experience. In the case of biological inventions, germplasm applies literally in the form of biological parent material. But the concept of parental material applies to other fields of invention as well, since inventions tend to build on inventions in what Rosenberg [(1976), ch. 6] has termed "compulsive sequences"; in other words, inventions tend to be the progeny of prior inventions, with important pioneering inventions being an exception.

The search model treats the uncertain outcome of a research project as a random draw from the distribution of potential inventions. Evenson and Kislev (1975) employ the exponential density function in their model, which yields the result that research within a single period is subject to diminishing returns -- the expected value of the research objective changes in proportion to the log of the number of trials.[10] The optimal extent of search is given by the condition that the expected value of the marginal gross benefit should be equal to the marginal cost of extending the search by one trial. Associated with the optimal search are an expected maximum value and,

at the end of the period, a realized maximum value.

In the following period the research system faces a new set of conditions. If the preceding research was successful, the way to achieve a better than previously realized outcome has been discovered. But the last period's research findings will generally also enable the researchers to identify avenues of search that should no longer be considered promising, leading to a rightward shift in the mean, though not necessarily in the all important righthand tail, of the distribution of outcomes relative to the previous distribution. However, the entire distribution may be shifted to the right by the introduction of new elements. New skills, methods, and knowledge may have been discovered by additional activities undertaken in the previous period, including the monitoring of developments in science and in other R&D programs in the same field. New germplasm in the form of new materials or potentially adaptable inventions from domestic or foreign sources may also have become available.

Thus in the following period the researchers face a greater challenge insofar as they must improve on their previous success. But they also confront a changed distribution of potential discoveries. Continued search is optimal only if the new distribution offers sufficient additional inventive potential relative to the result of the preceding period's research. Absent the introduction of new elements that go beyond the results of the formal search process, there will quickly be insufficient additional potential to justify continued search. Thus the introduction of new elements leading to sufficiently large rightward shifts in the distribution over time is the necessary condition for sustained inventive search. Without these elements, there will be falling R&D activity and invention as the corresponding field of

technology becomes subject to exhaustion.[11]

Within any given field, advanced countries are more dependent on scientific progress to avoid exhaustion than are their technological followers. There are several reasons for this. The germplasm available to a follower is effectively increased or renewed as more is learned about its peculiar circumstances. In turn, a follower's technological development within any field enables additional elements of technology to be effectively transferred to serve as germplasm for new avenues of adaptive invention. Moreover, individual followers can benefit from inventions and research results emanating from other followers' technological efforts. The search model not only embraces these means of overcoming local exhaustion, it more importantly highlights their critical importance, which is supported by ample empirical evidence.

2.3. Induced Innovation Models

Models of induced innovation are less concerned with the search process per se than with the determinants of the direction of search; for example, whether the search is for more labor-intensive or for more capital-intensive techniques. These models posit what is essentially a transformation frontier -- or "invention cum innovation possibilities frontier" (IPF) -- among factor augmenting and/or saving reductions in cost:

(1) $I(dL, dK, E) = 0,$

where dL (dK) is labor (capital) augmenting or saving productivity or technological change relative to the unit isoquant and E is R&D expenditure. Thus, for a given R&D budget, various combinations of dL and dK can be achieved. Relative factor prices determine the combination yielding the largest cost reduction. Binswanger [ch.s 4 and 5 in Binswanger and Ruttan

(1978)] discusses the specification of an IPF based on search processes. His model overcomes the seriously objectionable characterization of invention as a deterministic process that is found in other IPF models.

Applied to the advanced countries, to technological change at the global frontier, induced innovation models suffer from a lack of evidence about the character of the IPF. In this context, the most complete evidence supporting the induced innovation hypothesis, assembled in Binswanger and Ruttan (1978), is drawn from agriculture. Applied to LDCs, the hypothesis that expected factor prices affect the direction of search activity has greater plausibility insofar as there is less uncertainty about outcomes behind the global frontier. There is, in fact, a good deal of case study research that is at least consistent with the hypothesis. This research generally supports the view that "getting factor prices right" is important not only for choice of technique reasons but also in relation to incentives affecting the nature of technological activity. But there is an important respect in which induced innovation models are fundamentally misleading, particularly in the LDC context. These models take the exploitation of invention potential for granted. However, cross-country evidence (discussed in section 4.3) clearly indicates that the mere existence of potential inventions is insufficient to motivate investments to realize them. In most countries, the fundamental problem concerns the absence of invention, not its direction.

2.4. Diffusion Models

Diffusion models focus on the spread of innovations across firms engaged in similar activities. They relate to the evaluation and adoption of a well specified technology by individual producers operating in relatively

homogeneous production conditions. The classic statements of the diffusion
model are given by Griliches (1957) for agriculture and by Mansfield (1961)
for industry.

The general diffusion model assumes that the probability of a
particular firm's deciding to adopt an innovation at a particular point in
time depends on three things: the proportion of the firms in the industry
that have already adopted the innovation; the benefits from adopting it; and
the costs of its adoption.[12] In the standard implementation of the model, the
derived functional form is a logistic equation:

(2) $p(t) = 1/[1+ae^{-bt}]$

where p(t) is the proportion of firms that have adopted the innovation by time
t, a is a constant, and b is an equation expressing the dependence of the
diffusion rate on the benefits and costs of adoption.[13] The model has
traditionally been applied to analyze the determinants of differences in
diffusion rates across distinct innovations or groups of firms.

Results from applying the diffusion model are generally interpreted to
signify that adoption decisions are economically motivated.[14] Inventions that
have higher costs and lower benefits diffuse more slowly; conversely, lower
costs and higher benefits lead to faster diffusion. Some studies have found
that skills related to adoption also matter. In agriculture, diffusion rates
are higher among educated farmers and are accelerated by extension
prpgram.[15] In industry, higher diffusion rates are found in industries that
spend proportionately more on R&D. Market structure is also sometimes found
to exert a significant influence.

The basic insights of the diffusion model are supported by empirical
research in both developed and less developed economies. But the standard

empirical specification has not been successfully applied to the spread of technology across widely differing conditions of production, either within or between countries. This is because it does not provide a straightforward means to incorporate the circumstantial sensitivity of technology, which often acts as a barrier to the simple diffusion of well specified techniques. Other approaches that embody the basic insights in a framework that directly accommodates circumstantial differences have proven more fruitful. Vernon's (1966) model characterizing the international product cycle is the seminal case in point for manufacturing activities. Recent work, discussed at length later in this survey, has used econometric methods to measure and incorporate technological distance in models of technology transfer.

2.5. Growth Accounting

The development of growth accounting methods and their application to developed countries has had a profound effect on economists' thinking about development. Following the discovery [Solow (1957), among others] in the 1950s of the large "residual" in the growth of per capita output that could not be attributed to the growth of per capita capital service flows, economists embarked on two related lines of empirical research to comprehend its basic nature. Both lines of research have been relevant to understanding technological development.

The first, starting with Griliches (1957, 1963) and Denison (1962), sought to explain the residual by more carefully and properly measuring inputs. Capital, labor, and output measures were disaggregated into distinct types to take account of changes in their quality. Early work on labor quality, adjusting for increases in schooling and changes in occupational composition, "explained" a considerable part of the residual. Denison, in

particular, made further adjustments to account for changes in such things as the composition of economic activity, market structures, and public infrastructure. Encouraged by the initial work, Jorgenson and Griliches (1967) attempted a full explanation. But the attempt was not generally considered to be persuasive [see Denison (1969)]. In subsequent work, Jorgenson and his colleagues [Jorgenson et al (1987)] have continued refining the measurement of input quality and the estimation of substitution parameters, leading to the identification of a residual "cleansed" of the impact of quality changes.[16]

The second line of research has used statistical methods derived from hedonic regression approaches to identify sources of economic and TFP growth. Many studies in this tradition first compute TFP measures and then examine their statistical association with various forms of investment and different policy variables. In this work, Griliches and others have directly focused on the variables that determine input and output qualities as well as contribute to the cleansed residual, variables like R&D, schooling, infrastructure, and the policy regime. Much of their work has been concentrated on developing measures of the determining variables, distinguishing between investments in stocks and flows of services. Section 7.1 of this chapter surveys research within this vein to estimate returns to R&D and to investigate spillovers of the results of research in one location to other locations.

3. Technological Infrastructure

Developing countries have not realized rapid economic growth without also having experienced significant technological development. Technological development involves both institutions and organizations which together constitute a country's technological infrastructure. The principal

institutions take the form of IPRs and contract laws that provide incentives to develop technology and facilitate its exchange among economic agents. The organizations are those where the scientific and technical competence of significant numbers of people are combined to achieve the advantages of specialization and exchange. Such organizations may be private or public; they may exist as separate bodies or as constituent elements of larger entities. In them resides a substantial share of any society's accumulated stock of technological investment.[17]

3.1. Intellectual Property Rights

IPRs are generally considered to be elements of a social contract rather than "natural" rights. The United States and some European countries have long experience with them, while international agreements (or conventions) providing IPRs for foreigners have been respected in most developed countries for more than a century. Many LDCs possess operating IPR systems and have subscribed to the international conventions. But there is a good deal of controversy about the effectiveness of IPRs and their role in technological development. In the 1970s IPRs became part of the North-South debate over the terms of technology transfers. LDCs saw IPRs as primarily protecting advanced country interests and as being partially responsible for what was perceived as "unfair," or at least inappropriate, pricing of technology. Most LDCs actually weakened their IPR systems during this period. The debate shifted sharply in the 1980s as the North, led by the United States, began to use trade law to push for stronger IPRs for technology originating in the North.

Several major kinds of intellectual property are distinguished in laws governing the rights to them.[18]

o   patents, for conventional inventions;
o   utility models, for minor or "petty" inventions;
o   plant breeders rights, for new plant varieties;
o   copyrights, for creative works (writing and music, for example);
o   trademarks, for identifying names or symbols;
o   trade secrets, for proprietary information; and,
o   industrial designs, for designs and shapes.

The laws of most relevance to technological development pertain to patents, utility models, and plant breeders rights, all of which relate to inventions broadly conceived. However, copyrights have been used to protect inventions in the form of computer software. Trademarks and industrial designs protect products, which may or may not embody new technology. Trade secrecy law provides a distinct form of protection because it does not require the disclosure of proprietary information. But not all privately held information is eligible for such protection.

In these laws, the term "protection" essentially means "a limited right to exclude" others from making or using the designated property without the permission of the holder of the right. The right is limited to a fixed term of years (17 to 20 years for patents, 4 to 7 years for utility models, and so forth) and by its scope of coverage, discussed below. Moreover, the right applies only in the country granting the right. However, international agreements provide "national treatment" to foreigners from signatory countries. The major such agreements are the Paris Convention for patents and the Berne Convention for copyrights.

The scope of protection is implicitly defined by the accepted standard for obtaining the particular right. For patents these standards include:

o   novelty: the invention must be new in prescribed terms;
o   usefulness: it must useful and practical or operational in form;
o   inventive step: it must not be obvious to a person skilled in the art.

The patent document must also provide an "enabling disclosure" that

serves to reveal the true nature of the invention to the public. Weaker standards, designed to protect minor national inventions, are applied in the case of utility models. Novelty is sometimes judged against a national standard -- the invention need only be new in the country in question. Additionally, the inventive step may be lower than is required for a patent. When properly administered, utility models provide protection for adaptive inventions of a minor nature. In this regard they are similar to industrial designs.

Multicellular plants and animals have in the past been excluded from the scope of patent protection because they are naturally occurring and, as with concepts, are considered to be the common heritage of mankind [see, e.g., Persley (1990)]. Plant breeders rights were developed as an alternative to patents to provide incentives to private plant breeding activities. With the emergence of biotechnology has come renewed controversy over the protection that should be afforded to living organisms. In the United States, patent protection has for some time been provided to new plant varieties; more recently, administrative decisions by the U.S. Patent and Trade Mark office have extended patent protection to multicellular animals.[19]

In granting property rights to inventors, societies give legal sanction to monopolies that might otherwise be sustained through de facto (not de jure) trade secrecy. But this is done in exchange for public disclosure, which is important in providing germplasm for subsequent inventions. An offsetting cost is associated with the monopoly power that is bestowed by IPRs, but this cost has to be assessed as well in relation to the likelihood that inventive activity is stimulated by the presence of IPR protection.[20] In principle, the scope -- breadth and length -- of the monopoly right can be adjusted to

maximize the expected net benefits provided by a country's IPR system.[21]

The economic case for international agreements to recognize the rights of foreigners by treating them on a par with nationals is clear for countries at similar levels of technological development. Such agreements broaden the markets for inventions and strengthen the incentives to inventive activity in the subscribing countries. They also provide protection for direct foreign investment and incentives to sell technology abroad. The experience of recent decades has shown that international conventions, which do not include enforcement sanctions, work effectively among countries which both buy and sell technology. But they do not work well between industrialized countries and others that are primarily buyers of technology, as are most LDCs. This point is elaborated in the concluding section on policy, in the context of a more general discussion of the LDCs' failure to use IPRs to their advantage.[22]

3.2. The Structure of Knowledge Generating Activities

Agricultural research and extension systems adhere to a common design and afford the most transparent example of the structure of technological activities. For this reason, and because of agriculture's importance in the economies of the poorest countries, the general design of these systems is worthy of particular attention.

The agricultural sector is subject to three phenomena that differentiate it from most other sectors:

> o The predominance of small family farm units in producing most agricultural products in most countries;
> o The limited scope for intellectual property protection for biological technology, particularly for plant varieties and animal types; and,
> o The high degree of sensitivity to the physical environment for much agricultural technology.[23]

These conditions have led the public sector to take on the principal

responsibility for developing agricultural technology in most countries, even in highly market-oriented economies.

They have additionally motivated a hierarchical structure of specialized R&D organizations, with regionally focused experiment stations at their base and various supporting laboratories at supra-regional levels.[24] This structure extends globally to a number of international agricultural research centers which operate under the aegis of the Consultative Group for International Agricultural Research (CGIAR). The hierarchical structure is loosely paralleled by the boundaries that define the many interlinked fields of specialized knowledge that contribute, directly or indirectly, to the development of agricultural technology. These boundaries are the result of institutional evolution over many decades.

Figure 1 identifies the specialized fields of knowledge in a hierarchical ordering that depicts the flows of knowledge among fields and the relationships to various agricultural activities and branches. It is based on the present-day agricultural research system in the United States, one of the world's most advanced. The primary objective of the system is to yield innovations at level IV. These are the products of R&D taking place at level III, which is conducted in both private firms and public sector programs.

Three vertically interrelated levels of R&D activity are present in the figure. Upstream from inventive activity at level III are the pre-technology sciences (level II), which are differentiated in their objectives and incentive structures from the general sciences (level I), but which employ the same language and scientific methods. The general sciences (more often referred to as basic sciences) do science for scientists. In contrast, the pre-technology sciences do science for inventors; that is, they

Figure 1
Hierarchical Specialization in R&D Systems for Agriculture

THE R&D SYSTEM

Layer/Activity	Mathematical Sciences	Physical Sciences	Biological Sciences	Social Sciences
I. GENERAL SCIENCES (University and public agency research primarily)	Mathematics Probability & Statistics	Atmospherical & Meteorological Sciences Chemistry Geological Sciences Physics	Bacteriology Biochemistry Botany Ecology · Genetics Microbiology Molecular Biology Zoology	Economics Psychology
II. PRE-TECHNOLOGY SCIENCES (University and public agency research primarily)	Applied Math Applied Physics Engineering Computer Science	Climatology Soil Physics & Chemistry Hydrology & Water Resources *Environmental Sciences*	Plant Physiology Plant Genetics Phytopathology · Animal & Human Physiology Animal & Human Genetics Animal Pathology Nutrition	Applied Economics Statistics & Econometrics Political Science Sociology
III. TECHNOLOGY INVENTION (Public and private research)	Agricultural Engineering & Design Mechanics Computer Design	Agricultural Chemistry Soils & Soil Sciences Irrigation & Water Methods *Integrated Pest Management*	Agronomy Horticulture Plant Breeding Applied Plant Pathology · Animal & Poultry Science Animal Breeding Animal & Human Nutrition Veterinary Medicine	Farm Management Marketing Resource Economics Rural Sociology Public Policy Studies Human Ecology
IV. PRODUCTS FROM INNOVATION (Agro-industrial development)	Farm Machinery & Equipment Farm Buildings Computer Equipment/Software	Commercial Fertilizers Agricultural Chemicals Irrigation Systems Pest Control Systems	Crop/Plant Varieties Horticultural/Nursery Species Livestock Feed · Animal Breeds Animal Health Products Food Products	Management Systems Marketing Systems Institutional Innovations Health Care Child Care
V. EXTENSION (Public and private)	Resources & Environment	Commodity Oriented	Management & Marketing · Public Policy	Family & Human Resources
VI. FINAL USERS/SOURCES (Clientele problems)	Producers		Governments	Consumers

Source: Huffman and Evenson (1993)

anticipate or perceive inventors' demands and respond accordingly, just as inventors anticipate or perceive users' demands for their inventions. Downstream from levels III and IV are extension activities (level V) which support the implementation of new technology by the users of inventions. Public agricultural extension programs serving farmers are an integral part of the system of research, teaching, and extension among the American "land grant" institutions. Private firms supplying farm technology also invest in extension to aid them in their testing and experimental activities as well as to inform farmers about the use of their products.

Extension services are located spatially close to the users. In the United States, each county (jurisdiction below the state level) has an extension program whose agents are supported by specialists working in agricultural experiment stations (level III applied R&D units). Typically, a number of such stations are distributed geographically throughout a state, with a central unit at the apex, most often located at a state university where it is closely integrated with teaching. The federal government also operates a number of separate, specialized experiment stations, some of which have close ties to state universities. Level II pre-technology sciences are well developed only in the larger university systems (Cornell, Minnesota, and Wisconsin, among others). In the course of doing science for inventors, they serve as the training ground for most agricultural scientists (especially those who will be engaged in invention).

The structure of scientific and technological effort in agriculture is rather unique insofar as it is organized around the public sector's large role in invention and extension, though it does have a reasonably close counterpart in medicine and public health in most countries. But not all biological

research for agriculture is public. Private firms have long been active in those areas where the biological technology provides inherent protection to inventors, as it does for hybrid crops such as corn and sorghum.[25] With rice becoming a hybrid crop in some regions, private firms have begun to undertake rice research as well. More generally, the private sector is growing in importance as a supplier of technology to farmers in both developed countries and more advanced LDCs. In part this follows the strengthening of IPRs for plant varieties (and, to some extent, animal breeds), which has led to an expansion of plant breeding programs in the seed industry [Pray (1987)].

There are very few extensive systems of public sector invention for the industrial sector; among LDCs, India has had the largest -- the network of laboratories associated with India's Council for Scientific and Industrial Research. More generally, most LDCs invest very little in level III activities regardless of sectoral orientation; they publicly invest virtually nothing in extension outside of agriculture. In the developed countries, except in agriculture, most level III efforts are carried out by private firms with the encouragement of well developed incentive systems. Private firms also engage in extension through various consulting and engineering activities as well as though services related to the sales of producer goods, but these activities are seldom referred to in terms of extension.

3.2.1. Empirical Evidence of Structural Linkages

Evidence for the hierarchical structuring of related scientific and technological activity comes from studies of citations in journal articles as well as in patents. To examine article citations within and between fields, Huffman and Evenson (1993) classified some 300 journals dealing with research on animals, crops, forestry, nutrition, and agriculturally-related social

science according to their levels. For the first two of these areas, they found that articles pertaining to the pre-invention sciences formed the link between the general sciences and technology invention. In relative terms, few citations were found directly linking levels I and III, while many were found in both directions between levels I and II as well as between levels II and III. Moreover, from examining the impact of agricultural research on American farm productivity, they concluded that the pre-invention sciences yielded the highest social returns per dollar spent on research.[26] Their findings are consistent with the view that research at level II plays a vital role in some technological fields through augmenting the pools of knowledge from which level III inventions are drawn. Further evidence of the importance of knowledge upstream from level III comes from cross-country comparative research by Evenson (1993c) that examined factors responsible for differences among LDCs in the productivity of agricultural research.

Patent documents in many countries, including the United States, give citations of relevant precursors, which often include scientific publications. It does not necessarily follow in such cases that a scientific discovery was the initiating factor behind the invention. In fact, there is a good deal of research to show that inventions are primarily motivated by demand factors [Rosenberg (1974)]. Nonetheless, the citation of a scientific reference does signify its importance as a facilitating factor. Correspondingly, such references can be used to identify differences among technological fields with respect to their dependence on scientific knowledge as opposed to the results of practical experimentation. Evenson (1990) studied patent citations in six fields: dentistry, animal husbandry, general medicine, genetic engineering, molecular biology, and plant agriculture (patents here largely pertain to

chemical and mechanical technology). Molecular biology exhibited the highest linkage to science, with 70 percent of the sampled patents citing one or more scientific publications. Next were animal husbandry and genetic engineering, with citation ratios of 61 and 50 percent respectively. Inventions in plant agriculture, general medicine, and dentistry had the least linkage to science, having citation ratios of between 15 and 8 percent. For most mechanical invention, the linkages to science would be even less.

3.3. Intersectoral Interdependencies

Just as there are multiple and variable linkages between scientific areas and technological fields, so too there are technological interdependencies among sectors of economic activity, such that no sector is wholly self-sufficient in generating its own technology. Inventions generated in one industry may be used in the same industry or in other industries. Typically, apart from those embodied in machinery, process inventions have the same industry of manufacture (IOM) and sector of use (SOU).[27] But for most product inventions, IOM and SOU differ. Thus, distinct from a conventional input-output matrix of product flows, there is an implicit technological input-output matrix mapping invention flows from IOM to SOU. This technology matrix is critical to measuring and understanding the relationship between R&D, inventions, and productivity change.

Evenson et al (1989) used information generated by the Canadian Patent Office to develop an IOM-SOU concordance, which gives the frequency distributions of IOMs and SOUs for each of more than six thousand (aggregated) International Patent Classification (IPC) categories; that is, technological fields. Canada's Patent Office has assigned IPC categories along with IOM and SOU categories (4-digit level) to all patents granted since 1972. By 1990,
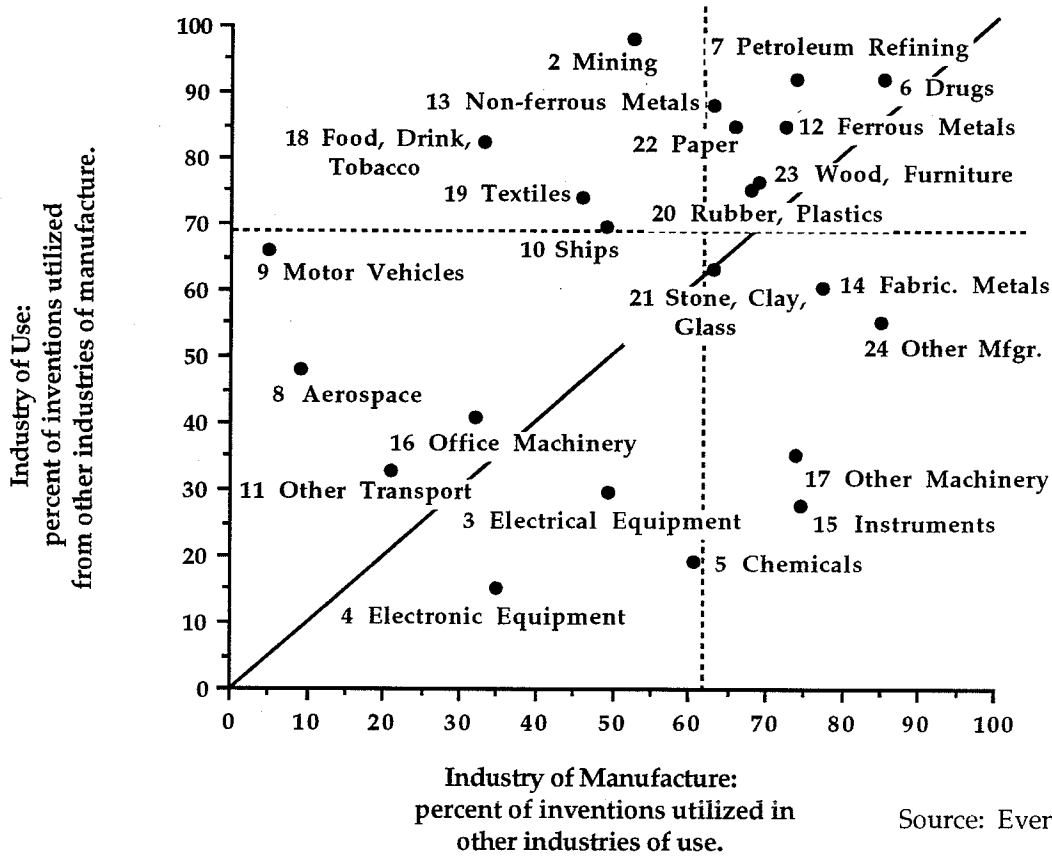
more than two hundred thousand patents had been so assigned, yielding a large sample from which to determine the concordance frequency distributions. Since most of the world's important inventions are patented in Canada (only 12 percent of the patents are to Canadian inventors), the concordance is a plausible estimate of its global counterpart.

Using the concordance, any set of patents can be distributed into IOMs and SOUs to obtain an estimate of the corresponding technology matrix.[28, 29] Figure 2 demonstrates the basic nature of inter-industry technology flows. Based on all patents registered in Canada between 1972 and 1990, for each 2-digit SIC industry, it shows the proportions of total inventions originating in (vertically) other industries and utilized by (horizontally) other industries respectively. Industries above the diagonal are net users in proportionate terms; those below, net suppliers. The dashed lines in the figure show the sample means. Industries in the southwest quadrant with respect to these lines are correspondingly self-sufficient in relative terms, while those in the northeast quadrant exhibit relatively high interdependence. Consider the drug industry as one example. Most of the inventions used by it originate in the chemicals sector; most of its inventions are used in the health sector.

It is clear from Figure 2 that manufacturing industries are substantially dependent on one another for technology. Not obvious from the figure is the fact that most non-manufacturing sectors -- including agriculture, forestry, fishing, construction, communications, health, finance, and trade -- depend on manufacturing for much, in some cases most, of their technology. [30]

4. **Technological Assets and Development**

Figure 2
Inter-industry Invention Flows

Industry of Use: percent of inventions utilized from other industries of manufacture.

Industry of Manufacture: percent of inventions utilized in other industries of use.

Source: Evenson et al. (1989)

Most technological development in LDCs in some way or another starts
with and builds on transfers -- of various kinds, including spillovers -- of
technology from technologically more advanced countries.[31] Indeed,
technological development can not be understood apart from various forms of
international trade that importantly involve technology. Consider the two
extremes by which a particular sector can be established in an LDC. One is
the virtually autarchic creation (or re-creation) of technology by locally
providing all of the necessary elements through developing the corresponding
technological capabilities. This approach is likely to be very costly and
time consuming even if extensive use is made of readily available foreign
knowledge that spills over through documentary sources and imported
"protypes." But it does guarantee the achievement of at least rudimentary
proficiency in the associated capabilities. The opposite extreme is the
establishment and operation of an industry using only foreign capabilities
with no local technological development whatsoever. This sometimes happens,
for example, with direct foreign investment in an enclave when indigenous
involvement is limited to the employment of unskilled labor. It can be an
effective way of generating employment and foreign exchange, at least over the
short to medium term, but in the absence of appropriate policies it need not
contribute to the development of local capabilities.

As the foregoing extremes illustrate, trade possibilities involving
technology are such that there is no necessary relationship between the
sectoral composition of a country's economic activity and the extent of its
technological development sector-by-sector. Individual sectors can be created
and developed through many alternative combinations of local and foreign
capabilities. Thus various paths of technological development can be followed

to reach the same level of economic development. To comprehend technological development in these terms, one needs an analytical framework that integrates investment choices among technological assets with trade choices among transactions involving elements of technology. This section develops such a framework and then examines differences in levels of technological development among LDCs.

4.1. Technological Assets

The critical technological assets are human and organizational capital, the latter being the knowhow used to combine human skills and physical capital into systems for producing and delivering want-satisfying products. Corresponding to the wide variety of technological fields and elemental activities through which knowledge is applied, there are a vast number of differentiated technological capabilities. They can be classified in various ways, each of which corresponds to a different approach to distinguishing among the aspects of technological knowledge and its practical application.[32] For analyzing technological development in general terms, it is most useful to separate technological capabilities into three broad categories according to whether they are related to production, investment, or invention:

> o Production capabilities: pertain to the operation of productive facilities; they encompass various activities involved in product design, production management and engineering, repair cum maintenance, input sourcing and output marketing, and so forth.
> o Investment capabilities: relate to the expansion of existing capacity and to the establishment of new production facilities; they embrace the many activities related to project selection, design cum engineering, and execution as well as extension services and manpower training.
> o Invention capabilities: concern indigenous efforts to adapt, improve, and develop technology.

The grounding of proficiency in experience limits the scope for transferring capability gained in one activity to other activities. The highly differentiated nature of technological knowledge also establishes a

strong association between capabilities and activities. The boundaries

created by experience and knowledge differentiation are often fuzzy, but their

existence nonetheless means that specific investments are required to develop

distinct capabilities. One shouldn't, however, think that all capabilities

are specific to particular sectors. Some, like the ability to mix iron ores

to achieve the best blast furnace charge, are highly sector specific. But

many, such as the basic knowhow involved in the adhesive properties of

different materials, are more generally applicable. Others -- such as those

related to information and control systems or to aspects of project execution

-- find even more widespread application.

Investments in technological capabilities, whether to strengthen

existing ones or to add new ones, are often associated with changes that alter

patterns of specialization and exchange. These changes occur through

investments embodied in organizational structures, codified knowledge and

procedures, and less formalized customs that govern behavior within and among

entities. They are fundamentally important because they are the means by

which transactional modes involving technology are changed. Indeed,

technological change can occur solely as the result of such changes, as when

the creation of new modes of distributing products leads to lower transactions

costs.

The potential benefits of technological development can often not be

fully realized without changes in transactional forms. The changes are

typically in the direction of increasing specialization on the basis of

technological capability, either through the creation of new units within

existing entities or the establishment of new entities. For example: In

manufacturing, young firms often carry out activities like quality control,

project engineering, and R&D in a generalized production management cum

engineering department; but as the capabilities and their uses increase over

time, these activities are separated into specialized departments, which

sometimes then evolve into separate entities [see, for example, Katz (1987)].

4.2. Trade and Technological Development

With specialization and exchange, technological capabilities are

deployed across entities through market transactions involving elements of

technology. These transactions occur between countries as well as within them

and take many forms which involve -- singly or in combination -- goods,

services, and information. In terms of broad categories, the transactional

elements of technology include:

> o Information: about physical processes and social arrangements that
> underlies and is given operational express in technology.
> o R&D: activities of generating new knowledge or inventive germplasm
> with the ultimate objective of practical use.
> o Technical services: activities, such as engineering, of translating
> technological knowledge into the detailed information required to
> establish or operate a productive facility in a specific set of
> circumstances.
> o Embodiment activity: activities of forming physical capital in
> accord with given and complete design specification.
> o Training services: activities of imparting the skills and abilities
> that are used in economic activity.
> o Management services: activities of organizing and managing the
> operation of productive facilities, the implementation of investment
> projects, and the development of process and product innovations.
> o Marketing services: activities of matching the capacity of
> productive facilities to existing and latent market demands.

Trade involving elements of technology has many transactional modes that

serve numerous objectives.[33] Licensing, subcontracting, technical agreements,

management contracts, marketing arrangements, turnkey project contracts,

direct foreign investment, and trade in capital goods are only a few of

them.[34] Some of these modes provide complementary services without any real

flow of technology. Marketing services provided under international

subcontracting are an example, but they are often combined with technical services which do provide technology. Other modes bundle information together with services required to translate it into useable form. Direct foreign investment, turnkey project contracts, and trade in capital goods are obvious examples.

Technology trade can be used to supplement -- as a substitute for or a complement to -- local capabilities as well as to augment them.[35] Implicit in the import of any technological element is a decision to rely on foreign rather than local capabilities. Where the capabilities do not exist locally, the decision is a choice not to develop them through means that involve indigenous effort. A great deal of technological development is import substitution to replace foreign capabilities with indigenous ones. The benefits extend beyond simple import replacement to include dynamic economies of various forms. But technological development can not reasonably be seen as having the objective of progressive import substitution for all of the elements of technology. Even the most advanced countries are far from technological autarchy. Notions of efficiency and comparative advantage are as important to technological development as they are to other kinds of development.

It is economically appropriate to develop the capability to supply some elements of technology -- or to make rather than buy it -- only if the net benefit of doing so is positive. The difficulty here lies not in the principle of make-buy decisions but in the practice. Costs of developing a capability can often be determined with some precision; they are the investment expenditures needed to create the capability, including the higher expenses and greater risks relative to imports which may be incurred as

initial experience applying the capability is acquired. Benefits can not so readily be determined. The direct benefit of import replacement in terms of foreign exchange savings is no harder to determine for technological development projects than for those of other kinds. The problem is in assessing the other, indirect but potentially more important, benefits. Technological development is a cumulative process in which capabilities acquired during the present can provide important foundations for making technological changes of acquiring other capabilities in the future. It is difficult at best to foresee all of the consequences that may follow from foundations presently being laid, and to evaluate the corresponding benefits.

Technology trade contributes to technological development when it augments local capabilities. But, sometimes overlooked is a simple fact -- trade involving elements of technology is meant to provide the elements, not the capabilities to supply them, certainly not as a direct or immediate consequence of their being provided. Nonetheless, the relationship of elements involved to capabilities enhanced is complicated because capabilities that are ostensibly meant to be developed are often not. Plants established under turnkey projects, for example, often continue years later to produce well under their design capacity owing to insufficient local effort to develop the requisite production capabilities. But just as intended results are often not achieved owing to insufficient effort, so too others can be achieved on the basis of atypical effort. Trade of any form can provide wherewithal for at least some forms of learning given sufficient will and capacity to learn.

4.3. Indicators of Technological Development

In analyzing technological development, one ideally wants to know how much has been invested in what kinds of capital with what rates of return.

Unfortunately, such information is not generally available and is exceedingly difficult to obtain on an aggregate basis for some important forms of capability acquisition, like those which occur in connection with initial efforts to attain increased mastery over newly acquainted industrial technology. Available instead are data for various indicators related to distinct aspects of technological capability. These indicators offer a limited, but meaningful for the corresponding aspects, way of gauging levels of technological development across countries. Together with indices of overall economic performance, Table 1 displays several indicators for eight levels of technological development.

The typology of levels shown in Table 1 is taken from Weiss (1990), which may be consulted for qualitative details about the various attributes of each level. The concern here is with a few illustrative quantitative indicators.[36] In general terms: Level 1 countries have not yet achieved what might be considered"basis" levels of technological capabilities in at least some important sectors. Basic capabilities are possessed by all of the level 2 countries, but not all have been expanding and improving their capabilities.

Level 1 includes 75 countries having a combined population of one billion persons. One tenth of them reside in 16 level 1a countries (all small, except Zaire), which have little or no technological infrastructure. Roughly 20 percent live in 19 level 1b countries, where there is some research capacity in agriculture but virtually none in other sectors. Countries at level 1c, which account for the rest, have good agricultural research capacity and undertake some industrial research in the public sector. But they, like the other level 1 countries, have no industrial R&D capacity in producing firms.

Table 1
Selected Technological Capability Indicators for Eight Synthesized Levels of Technological Development

Indicators	Level 1 Developing Countries			Level 2 Developing Countries			Recently Industrialized	OECD Industrialized
	1a Traditional Technology	1b First Emergence	1c Islands of Modernization	2a Mastery of Conventional Technology	2b Transition to NIC-Hood	2c NIC-Hood		
REAL GROWTH (1965-90)								
GDP per Capita	.5	.5	1.5	2.4	2.5	7.1	2.8	2.5
GDP: Aggregate	2.5	2.6	2.8	4.7	5.3	8.1	4.0	3.5
Agriculture	2.5	2.5	2.6	3.8	3.0	3.1	2.5	1.5
Industry	5.0	5.0	4.5	5.1	6.0	9.1	3.1	3.1
Services	5.0	5.0	4.8	5.0	6.0	10.0	3.5	3.5
II. R&D INTENSITY								
R&D/GDP (1990)								
Aggregate:								
Public	.2	.2	.3	.4	.6	.6	.7	.7
Private	0	0	.02	.05	.2	1.0	1.2	2.3
Agriculture:								
Public	.4	.4	.5	.6	.7	.8	.8	1.5
Private	0	0	.01	.05	.1	.2	.5	1.5
Industry:								
Public	.05	.05	.1	.2	.4	.3	.3	.3
Private	0	0	.02	.05	.05	1.0	1.2	2.3
Services:								
Public	0	0	0	.01	.05	.05	.1	.3
Private	0	0	0	0	.05	.1	.2	.5
Science/GDP (1990):								
Public	.02	.02	.03	.04	.10	.20	.25	.40
Private	0	0	0	0	0	.02	.04	.05
III. S&E INTENSITY								
S&E/GDP (Index)	.2	.2	.4	.6	.8	1.3	1.0	1.0
IV. INVENTION INDICATORS								
Inventions/S&E*	0	0	0	.05	.1	.5	.3	.2
Invention Import Share	0	0	.9	.95	.81	.64	.80	.31
Invention Export Share	0	0	0	0	.05	.10	.20	1.70
V. INTELLECTUAL PROPERTY RIGHTS								
International Recognition	0	0	1	2-3	2-3	2-3	4-5	5
Domestic Use	0	0	0	1	2	4	4	5

* Number of inventions per scientist and engineer engaged in R&D, in 1989.

Typical Countries:

1a: Yemen, Laos; 1b: Nepal, Ethiopia; 1c: Sri Lanka, Kenya; 2a: Malaysia, Turkey, Colombia; 2b: India, Thailand, Mexico; 2c: Korea, Taiwan. Recently industrialized Greece, Portugal, Spain.

Source: authors' estimates.

Twenty countries are found at level 2. Among them, only four [Hong Kong, (in truth, a colony), Korea, Taiwan, and Singapore] achieved full NIC (newly industrialized country) status by the 1980s. Several more countries [China, Indonesia, Malaysia, and Thailand (plus, possibly, Chile)] are currently experiencing development sufficient, if maintained, to qualify as NICs in the near future. All of these countries have adopted the macro and micro economic policies that are required to achieve rapid, technologically driven growth. In most of them, public policy explicitly promotes technological development through the accumulation and utilization of technological infrastructure.

The figure in the table illuminate several aspects of technological development; this is notwithstanding various caveats, that go unstated here, regarding the comparability of such indicators across countries. Consider first the aggregate figures. Public sector investment in applied R&D as a percent of GDP increases roughly threefold from level 1a (reliance on traditional technology) to level 2c (NIC-hood). Private sector R&D investment is effectively nil in level 1 countries; it is quite substantial in the NICs, though well below the OECD country standard. The availability of scientists and engineers (S&E) relative to GDP rises in an even more dramatic fashion across the levels, being greater in the NICs than in countries more developed than they. Expenditures on science relative to GDP show a yet even more pronounced change, as does the domestic patent indicator.

Patent indicators are used to express cross-country differences in the extent of inventive activity, but they also indirectly reflect differences in laws governing IPRs. The IPR indicators appearing at the bottom of the table are qualitative indexes (using a scale of 0 to 5) developed by Evenson (1990).

Countries at levels 1a and 1b do not have functioning IPR systems; moreover, many of them lack systems that would support an IPR system. Level 2 developing countries generally have IPR systems of intermediate strength from the perspective of foreign inventors. Most of these countries have been accused of pirating inventions patented abroad, with the NICs having been regarded as the most serious offenders. The domestic use indicator demonstrates the failure of most LDCs to give adequate support to domestic inventive activity. Only the NICs use IPRs aggressively as a means of encouraging domestic R&D.

Virtually no patents are awarded to domestic inventions in level 1 countries; in the NICs, more patents are awarded to domestic inventions relative to the number of scientists and engineers than in the more advanced countries. Nonetheless, as shown by the invention import share figures, which give ratios of patents granted to foreigners relative to total patents granted, patents awarded to foreign inventions exceed those granted to domestic inventions in all LDCs, NICs included. In turn, the invention export share data, which give ratios of patents obtained abroad to total patents awarded domestically, indicate that exports of inventions from LDCs are practically nil until they come close to achieving NIC status, and that only the industrialized countries are net exporters of inventions.

The magnitude of the difference in indicators between the lowest and the highest levels of LDC technological development, particularly in industry, suggests that a great deal of investment in technological development is required to achieve NIC-hood. Much other evidence, some direct and some indirect, confirms that this is so. As the NICs' (and, before them, Japan's) track record reveals, LDCs can grow faster than the advanced countries. Being

able to use modern technology without having to expend resources creating it from scratch, LDCs can -- it appears -- catch up to advanced country levels of economic development. But convergence through catchup growth can not happen in the absence of substantial investment in technological development. It is simply not the case, therefore, that LDCs can enjoy a technological free ride on the road to NIC-dom.

It can be seen from Table 1 that technological development is quite different in the agricultural and industrial sectors. There is a rather sizeable amount of agricultural R&D (in proportion to agricultural GDP) in the level 1 countries, most of it in public sector experiment stations that develop new seed varieties and the like. These research units, which also exist in the level 2 countries, are linked in a two-way exchange of biological materials, new knowledge, and R&D personnel to a network of international research centers; R&D expenditures by the international centers for the benefit of LDCs (not shown in the table) amount to roughly ten percent of national expenditures. Private sector agricultural research is of some importance in level 2 countries, although it is only in the advanced OECD countries that private sector R&D is as important as public sector R&D.

In comparison with public sector spending on agricultural R&D, public expenditure on industrial R&D is low, being greatest -- roughly half as much (relative to industrial GDP) -- in level 2b countries.[37] Private sector industrial R&D assumes significant proportions in level 2 countries; among the NICs, it is roughly three times the value of public sector expenditure -- the difference is sevenfold in the advanced OECD countries. However, as will be discussed below, data on industrial R&D do not capture many related kinds of technological effort that are disproportionately important at lower levels of

technological development. Comparatively little R&D is performed in the service sector at all levels, though industrialized countries do engage in considerable health sector R&D.

Table 2 provides data on industrial R&D and IPR utilization in India and Korea to portray some typical patterns in technologically advanced LDCs. Korea (level 2) performs more R&D in relation to sales than does India (2b), but both countries exhibit a roughly similar structure of relative R&D intensities across industries. There is little difference between the countries in their reliance on foreign patents (IOMF, by industry of manufacture), which are 65 percent of total patents granted in India and 62 percent in Korea. The number of patents granted to domestic investors (IOMD, by industry of manufacture) in different sectors demonstrates the relative strength of chemical and machinery sector research in India; in Korea, it is the electronic sector that stands out.

Industry of manufacture - sector of use (IOM-SOU) comparisons show that more than 20 percent of domestic patents in both countries, and more than 48 percent of utility models in Korea, are used in non-manufacturing sectors where little R&D is performed and few inventions are generated. This is especially noteworthy owing to the great technological distances that characterize many activities in these sectors (see section 5.4). The chemicals and machinery industries contribute disproportionately to other sectors. Utility model protection, not available in India, is widely used in Korea, with the number of utility models being 3.7 times the overall total of patents. Very few utility models are granted to foreigners in Korea, as in other countries where they exist. Utility models are extensively used by the electronics and machinery industries, but are comparatively little used by the

Table 2
Industrial R&D and Patents in India and Korea

Sector	R&D/Sales*		Inventions (1986-88)**						Utility Models Korea (1986-88)	
	India (1989)	Korea (1989)	India			Korea				
			IOMF	IOMD	SOUD	IOMF	IOMD	SOUD	IOMD	SOUD
Agriculture	na	2.16	-	-	46	-	-	73	-	763
Food and Beverage	.50	.52	53	42	91	46	165	227	116	411
Pulp and Paper	.35	.77	31	14	38	28	24	65	145	199
Textiles	.35	.99	56	31	85	121	130	299	458	655
Chemicals	.97	1.37	877	559	352	1309	504	227	137	155
Drugs	1.60	2.19	73	40	118	180	75	174	21	27
Basic Metals	.39	1.11	401	213	171	213	165	193	1590	615
Electronics and Computers	1.01	4.80	721	284	194	975	682	569	3294	2491
Machinery	.25	2.36	1174	658	308	1002	634	245	3012	1600
Construction	.25	.51	-	-	129	-	-	100	-	1041
Utilities	na	.34	-	-	131	-	-	101	-	590
Trade and Finance	na	na	-	-	47	-	-	81	-	652
Health	na	na	-	-	108	-	-	86	-	358
Government and Education	na	na	-	-	55	-	-	67	-	852

* Ratio times 100.

** IOMF: Industry of manufacture, foreign inventors; IOMD: Industry of manufacture, domestic inventors; SOUD: Sector of use, domestic inventions.

Source: Computerized patent database, International Patent Documentation Center, Vienna.

chemical and drug industries.

4.4. Sectoral Trajectories

The substantial difference in patterns of R&D expenditures between agriculture and industry across levels of technological development reflects inherent differences in the underlying logic of technological development in the two sectors. As indicated previously, two fundamental phenomena lie behind the empirical observation that catchup economic growth can not be achieved without the simultaneous development of technological capabilities. The first is the circumstantial sensitivity of much technology, which provides the rationale for the spatial organization of technological effort in agriculture. The second phenomenon is the tacitness of much technology. Agricultural and industrial technology are alike in being characterized by both circumstantial sensitivity and tacitness. But the dominant feature, the one which has exerted the greatest influence in shaping the course of technological development in the LDCs over the past four decades, has differed between the two sectors.

Circumstantial sensitivity has played the major role in agriculture. Strong interaction between the environment and biological material makes the productivity of agricultural techniques, which are largely embodied in reproducible material inputs, highly dependent on local soil, climatic, and ecological characteristics. Industrial technology is not circumstantially sensitive in the same way as agricultural technology. Nonetheless, industrial processes must nearly always be specifically tailored to the particular circumstances in which they are being used to achieve economic levels of productivity. This is readily comprehensible in cases where the chemical and physical properties of inputs vary across alternative sources, or where

product characteristics differ owing to differences in finely-grained preferences. Other, not so obvious but still significant, circumstantial differences relate to matters of scale and scope as well as to established labor and management conventions. Investments to adapt technology to local circumstances are therefore just as warranted in industry as in agriculture. But industrial adaptation largely involve changes in the design and operation of capital goods or in ancillary processes rather than changes in primary material inputs.

The archetypal adaptive efforts in agriculture are undertaken by scientists using established R&D principles to fashion new inputs; those in industry are performed by engineers carrying out conventional measurements and computations to customize new processes and products. Newly engineered processes and products in industry are no less inherently "new" than newly developed inputs in agriculture. Moreover, the distinct locations of adaptive effort -- closer to science in agriculture; to engineering in industry -- are largely a reflection of the language used in the respective sectors. The efforts entailed are neither more nor less inherently routine in one sector than the other. The significant differences between the sectors as regards adaptive efforts are found elsewhere; in the first instance, in the scale of the circumstantially specific effort and in the scope of its application.

Important forms of adaptive agricultural R&D require a substantial commitment of resources dedicated to developing techniques for a particular set of agronomic conditions. The users of the newly developed techniques are as numerous as the farmers who work subject to those conditions. In contrast, adaptive industrial engineering can be accomplished using resources that are not circumstantially dedicated. Furthermore, it is a commonplace activity in

any well executed project to establish industrial facilities. And most, if not virtually all, of the adaptations made in the course of designing a project are highly specific to that project.

Seen comparatively, industrial technology is readily transferable but not so easily mastered. Thus tacitness has been the principal factor conditioning the trajectory of technological progress in industry. None of the indicators shown in Table 1 captures the kinds of technological investments that dominate in the early stages of an industry's development, when the tacitness of production technology is initially being overcome. Even in the technologically most advanced countries, many important innovations come from sources other than what is formally classified as R&D; the system of "just-in-time" production scheduling is a notable example. In other words, R&D is only one form of technological effort, or activity to improve technology. Other forms of technological effort leading to technological change are the crucial ones as newly established industries begin to progress beyond rudimentary levels of mastery.

Case study research on infant industries reveals that significant increases in productivity, where they occur, come initially from technological efforts related to raw material control, product and process quality control, production scheduling, repair and maintenance, changes in product mix, as well as others including episodic trouble-shooting to overcome problems encountered in the course of operations. Additional sources of productivity change are found in many of the distinct tasks related to investment; that is, related to expanding existing production facilities and establishing new ones. Infant industries rarely achieve international competitiveness without having realized productivity gains from such technological efforts [Bell et al

(1984)].

Even though the returns to forms of technological effort often appear -- from qualitative, case study evidence -- to be quite large, they seldom are associated with inventions that are patentable abroad. They do not yield improvements that are sufficiently inventive relative to the known state of the art. Nonetheless, the improvements are not infrequently sufficiently novel and useful to qualify for petty patent (or utility model) protection in countries having this form of IPR. In turn, formal R&D activities typically commerce only after a substantial degree of capability has been acquired in production and in at least some aspects of investment. This is in large part because of their differentiated nature, but it also reflects some redefinition of pre-existing technological activities when they are incorporated into the R&D departments that emerge from the increasing division of labor within firms among specialized units.

A great deal of costly and purposeful effort must be expended to master any newly acquired technology, and therefore to achieve its potential productivity. This fact is equally relevant in agriculture and in industry. But the central locus of effort differs in the two sectors: in industry, it is found within individual firms; in agriculture, it resides in the complex of institutions that are engaged in research and extension. This follows from the difference between the sectors in what is directly transferable; production methods in the former, and R&D and extension methods in the latter. Effective mastery of transferred agricultural R&D methods has entailed substantial costs and has been no less problem ridden than have been the ventures to establish large scale, sophisticated plants in the industrial sector.

5. International Flows of Technology

It is important to distinguish between the fact that technology developed for one location can generally be employed, given enough resources, in another location and the fact that its relative economic value in another location may not be the same as in its original location. Few models of technological discovery and diffusion incorporate this distinction, in part because few are internationally focused. Models of discovery do recognize knowledge as a form of inventive germplasm, but they typically fail to include any meaningfully specified form of knowledge transmission. Diffusion models recognize knowledge transmission but generally incorporate little insight into the adaptive process. This section examines how technological distances in agriculture and industry condition the international flow of technology.

5.1 Factors Determining Technological Distance

As noted above, a given technique or technical change does not have the same relative value in every circumstance. This is generally understood insofar as the effects of factor price differences on the choice of technology are concerned. Less generally understood, at least outside of agriculture, is the effect of physical and social differences across circumstances. These differences can also reduce the value of technology as it flows from one location to others. Two factors are relevant when assessing disparities in the value of a technique (or a particular element of knowledge) between locations. One is the circumstantial difference between the locations. The other is the sensitivity of the technique to circumstantial differences. Together they determine the technological distance between locations.[38]

Circumstantial differences include those in physical (soil, climate, and length of day, for instance), economic (relative prices, infrastructure,

and so on), and social (legal systems, transactions costs, and the like)
factors. Disparate fields of technology exhibit distinct sensitivity
gradients with respect to these factors. Biological technologies are perhaps
the most highly sensitive to physical factors; crop agriculture is
particularly affected, with some crops (corn, or maize) being more sensitive
than others (wheat). Mechanical technologies in agriculture exhibit similar
sensitivity, which is reflected, for example, in the existence of myriad types
of plows, cultivators, and harvesting equipment, each suited to a particular
set of soil conditions.

Nearly all technologies are sensitive to relative factor prices, with
the degree of sensitivity being greater the higher is the elasticity of
substitution between capital and labor. Peripheral activities in
manufacturing, activities such as packaging and in-plant materials conveyance,
are particularly sensitive to the wage-rental ratio. Most technologies are
also sensitive to what is available from the existing infrastructure, though
infrastructural deficiencies can often be overcome by complementary
investments to alter circumstances, as when manufacturers invest in auxiliary
power generators to offset frequent disruptions in electricity distribution.
Some technologies, construction being one example, are particularly sensitive
to social factors [see, for example, Sud et al (1976) or Green and Brown
(1976)]. Technology requiring delicate maintenance will perform differently
in different institutional and infrastructural environments. In short, most
technology is circumstantially sensitive in some way.

It is, therefore, fundamentally important to consider both
circumstantial difference and technological sensitivity when considering
whether and how technology may flow from one location to another. Little

adaptation is required if circumstantial differences are small or the sensitivity gradients are flat, but there is still need for investments in technology in order to accomplish the transfer and master the technology. If circumstantial differences are considerable and the sensitivity gradients are steep, there may be no effective transferability. In intermediate cases, where transfers require adaptation to be realized effectively, investments in creating technology are necessary. In these cases, foreign technology serves as parental germplasm which has value only insofar as there is the capability to invent appropriate offspring and the incentives (IPRs and otherwise) to do so.

Positive technological distance between advanced and developing countries is often optimally overcome by adaptive technological effort. Two distinct forms of adaptation can be distinguished. Minor adaptations involve changes in the technique but leave its core unaffected; for example, running a loom at higher speed, or replacing an automatic filling mechanism with hand labor. In turn, inventive adaptations make use not of the technique but of the knowledge that underlies it. Here knowledge from the source serves as inventive germplasm. Producers are often observed to undertake minor adaptations without formal R&D activity. But inventive adaptations typically require some kind of formalized R&D capabilities. As a general rule, minor adaptation can not overcome great technological distances, only inventive adaptation has the potential of doing so.[39]

National research programs in the public sector, in research institutes as well as in universities, have recognized knowledge spillovers in the form of nonrival public goods. Programs in non-defense related areas, for example those in agricultural experiment stations, do not seek to withhold

proprietary information. On the contrary, they usually endeavor to "extend" research findings to as many users as possible. Moreover, in agriculture, research findings -- new plant varieties, for instance -- developed in one location are freely transmitted to researchers in other locations, nationally and often internationally as well. The international agricultural research centers were established to facilitate international spillovers of germplasm and of results from pre-technology science more generally. In recent years, scholars have increasingly recognized that R&D conducted by private firms may have significant spillovers. Jaffe 1986, Romer (1986, 1990), Grossman and Helpman (1991) others distinguish between firm-specific proprietary knowledge and public good information that is not proprietary and is valuable to other firms because it provides inventive germplasm.

5.2 Inventive Adaptation in Agriculture

Technological distance in biological technology can often be surmounted only through inventive adaptation. Griliches (1957), in his pioneering study of the diffusion of hybrid corn in the United States, made this point forcefully. He noted that long after farmers in Iowa and Illinois had adopted hybrid varieties suited to these Corn Belt states, farmers in Alabama (outside of the Corn Belt) had not yet adopted any hybrid varieties. This had little to do with the farmers' capabilities. Rather, differences in climate and soil between the Corn Belt and Alabama, along with the sensitivity of hybrid corn to these differences, resulted in there being a large technological distance between these areas. Thus, as Griliches noted, Alabama farmers could not benefit from hybrid varieties until hybrid research took place in Alabama, using knowledge acquired in the Corn Belt as inventive germplasm. The same lesson applies to most LDCs. Corn farmers in the

Philippines got no direct benefit from the 75 years of American hybrid corn research that produced a tripling of U.S. corn yields. They indirectly benefited from previous hybrid research in the U.S. only after the capacity to undertake inventive adaptation was created in the Philippines.

Technological distance in biological technology is related to Darwinian processes of natural selection. Animals and plants evolved into numerous variegations of species, each suited to a particular environmental "niche." The domestication of some animal and plant types led to centuries of selection by farmers, producing further differentiation within species. In rice, for example, more than one hundred thousand "landrace" types within the O. Sativa species have been selected by farmers since rice was first cultivated for food. Each of these landraces had some form of comparative advantage in the particular niche where it was selected. Modern plant breeding has consisted of crossing and selection programs to find improved genetic combinations. In rice, virtually all of this work has been undertaken in publicly supported experiment stations.

The earliest rice improvement research activities were in Japan, where major gains were made early in this century through improving Japonica landraces suited to subtropical regions. It was not until after World War II that concerted efforts were made to improve the Indica landraces. As of that time, rice producers in Japan, Korea, Taiwan, and parts of mainland China had achieved a 50 year technological lead over the tropical rice producing areas. In the 1950s, an Indica-Japonica crossing program sponsored by the Food and Agricultural Organization of the United Nations, coupled with the creation of the International Rice Research Institute (IRRI) in the Philippines, gave major impetus to rice improvement for tropical conditions. By 1965, many

national rice breeding programs had been established in tropical countries. India, for example, had 23 programs in various locations. Around 200 rice breeding programs existed in some 40 countries by 1970. Most had, and have maintained, a close association with IRRI, which has served as a nodal point in the transfer of inventive germplasm.

IRRI achieved a breakthrough in 1964 leading to the release of the semi-dwarf variety IR-8 which, along with other modern varieties (C4-63, Masuri, TN-1), ushered in the "green revolution" in rice [Hargrove (1979)]. IRRI's IR-8 variety was widely planted after its release in 1966, but by 1970 its yields were severely diminished owing to Darwinian processes of disease and pest evolution in reaction to its introduction. The various breeding programs led by IRRI were able quickly to develop new varieties, comparable in yields to IR-8's initial levels, but having genetic resistance to the then common diseases and pests. By 1975, high yielding semi-dwarf varieties were planted in 30 percent of Asia's rice area. Continued varietal development to incorporate additional pest and disease resistance, cold tolerance, and other improvements have, in effect, produced a second green revolution leading to further diffusion of the high yielding varieties, so that they were planted in roughly 70 percent of Asia's rice area in 1990. Rice varieties suited to upland conditions (where irrigation is absent) and to deep water conditions (prevalent in parts of Southeast Asia) have not yet been developed [Chang (1989)].

A recent study of varietal development in rice by Gollin and Evenson (1991) analyzes more than 90 percent of the varietal releases (that is, successful inventions of improved varieties) of Indica rices since 1965. It shows that IRRI has played a relatively small role as a producer of varieties

-- it accounts directly for only some 17 percent of the varieties released. Roughly 10 percent of the varieties that were developed in national programs were released in other countries. Of more policy relevance are the findings in regard to parent varieties (the germplasm from which planted varieties are derived). IRRI contributed 65 percent of all parent varieties. National programs (particularly India's) have also contributed parent material that has crossed borders.

Studies of wheat technology, where a similar green revolution has occurred, show a very similar history to that of rice. Maize (corn) technology exhibits greater circumstantial specificity than either rice or wheat. Most other crops are similar in this regard. Fewer studies have been undertaken on livestock. Huffman and Evenson (1993) report evidence that circumstantial sensitivity for livestock is less than for crops.

5.3 Measuring the Effects of Technological Distance in Agriculture

We are aware of only one attempt to measure technological distance directly in order to show its impact on the value of technology transfers. Evenson (1992) used the following measure technological distance between locations i and j with respect to all of the techniques that may be used individually to conduct some given activity:

(3) $$D_{ij} = C_{ij}/C_{ii}$$

where the denominator, C_{ii}, is the unit cost of carrying out the activity in location i using technique i, the optimal choice of technique for that location; and the numerator, C_{ji}, is the unit cost in location i using the technique that is optimal for location j.[40] This distance measure reflects both differences in circumstances and sensitivity to those differences. If circumstances were identical, or if technology were insensitive to differences

in circumstances, the optimal choice of technique in both locations would be the same, and D_{ij} would equal one. Values greater than one indicate a positive technological distance.

This measure is based on existing technology and reflects prior technological development in the two locations. But it may also serve as an indicator of the proximity of their future technological development. Thus, it may show the value in location i of research conducted in location j, since new technology developed for location j must overcome the existing distance if it is to be useful in location i. If D_{ij} equals one, it may be considered highly likely that inventions in location j will have immediate application in location i. More generally, it may be expected that higher values of D_{ij} imply lower probabilities of direct transfer and lesser gains from any indirect transfers that might take place. However, the use of the measure in this way may be confounded if research in either location is circumstantially specific, causing D_{ij} to increase over time. But even with such divergence, inventions in one location may serve as parental germplasm to others as illustrated above in the discussion of rice technology.

Evenson (1992) applied the measure to data generated from rice yield trials in India. In such trials, common sets of culitvars are planted in each of many locations, with all varieties being subject to the same experimentally controlled production conditions in each production location. The values for rice across regions of India range from 1.05 to 1.67.[41] They exceed one entirely because of differences in soil and climate conditions. They reflect the fact that farmers may choose among many rice varieties, each having a comparative advantage in a distinct set of soil and climate conditions.

The distance measures just discussed were used to estimate the

relative value of rice research conducted elsewhere within India. The basic specification was as follows:

(4) $T_i = \sum (D_{ij})^\alpha R_j + \gamma Z$

where T_i is a TFP index for district i, D_{ij} is the distance measure, R_j is the depreciated stock of research expenditure in district j, and Z is a vector of other productivity affecting variables, including irrigation, weather conditions, and the like. The estimated value of the alpha parameter is -5.0. For D_{ij} equal to 1.1, the benefit to region i of one dollar's worth of research in region j is 0.62 times the benefit of spending a dollar in region i's own research program; for D_{ij} equal to 1.5, the relative benefit of research in region j drops to 0.13. Thus, even when knowledge spillovers are considered, technological distance greatly affects technology transfer possibilities.

As will be discussed further below, a number of studies -- in both agriculture and industry -- have attempted to incorporate technological distance by utilizing various circumstantial variables when investigating the value of spillovers [Jaffe (1986), Griliches (1991)]. One line of empirical research relates productivity measures to, among other variables, separate research stock variables, one for the region's own R&D and the other for R&D conducted in regions that are circumstantially close neighbors. Another line of research utilizes patent statistics in place of R&D expenditures. These studies have shown that individual regions generally do benefit from research in other regions that are circumstantially not too far distant. But they have equally demonstrated that local research capacity is required in order to gain spillover benefits from research done elsewhere.

5.4 Technology Transfer in Industry

In substantial contrast to policy makers dealing with agricultural technology, many policy makers concerned with industrial technology appear to believe that technological distance depends solely on economic circumstances; that is, that industrial technology is not sensitive to physical and social circumstances.[42] Following from this belief is their view that the only issues of consequence with respect to industrial technology relate to the dependence of choice of technique on factor prices. Often implicit is the corollary notion that LDCs can simply free-ride on industrial technology created in the advanced countries, thereby avoiding the cost of creating technological capabilities. But, as argued previously, developing countries do not obtain industrial technology as "manna from advanced countries" even if the technology is insensitive to circumstances. Owing to the tacitness of technology, substantial investments in acquiring production capability are always required to master a new technology.

There are, as yet, no direct estimates of technological distances for industrial technologies. Nonetheless, there is a great deal of evidence that product and process designs alike are sensitive to differences in circumstances in virtually all industries. For example, observers of invention in India conclude that much of it consists of adapting foreign technology to local circumstances [see, for example, NCAER (1971), Bhagwati and Srinivasan (1975), Desai (1984), and Lall (1987)]. Such adaptation is motivated by differences between developed and developing countries in things like income levels, consumer preferences, factor costs, climatic conditions, and material input characteristics. Sometimes these differences are artificially created by import-substitution policy regimes, which force producers to purchase particular inputs from domestic sources that supply

inputs of inferior quality relative to their foreign counterparts. To make the most effective use of such inputs, firms are often forced to undertake a form of policy-induced technological effort, with low social returns [Teitel (1987)].

Important evidence of adaptation in response to significant circumstantial differences comes from the engineering activity that occurs whenever new production facilities (or additions to existing facilities) are being established. It is hidden from casual observation which fails to recognize that engineering design involves tailoring technology to local circumstances. Additional evidence comes from case studies of the use of industrial technology in LDCs. As noted previously (section 4.4), these studies demonstrate that production capability is in large part acquired through a variety of technological efforts which lead to productivity enhancing technological changes. Many of the numerous changes uncovered can only be described as having been intended to adapt the technology to local circumstances [see, for example, Mikkelsen (1984)]. Not always clear from the information provided is whether the adaptions are motivated by differences in physical, social, or economic circumstances. Some of them are obviously related to differences in relative prices. Otsuka et al (1988) provide a notable study of adaptations to economic circumstances in the development of Japan's textile industry. But there are also obvious cases of adaptations to differences in physical circumstances. For instance, producers of cement, steel, and other natural resource-intensive products have often been found to alter their processes to adapt them to peculiar raw material characteristics [Dahlman (1979)].

Dahab's (1986) study of farm machinery producers in Brazil is

instructive in this regard. The industry was established by multinational firms that progressively lost market share to indigenous producers who first imitated and subsequently adapted the multinationals models, making them better suited the local circumstances. Within 20 years the indigenous producers dominated the markets for all but the most complex models.[43] Patent and utility model protection appears to have given the indigenous producers important incentives in this process.

There is very little direct evidence about sensitivity to social circumstances. In some cases it is thought that they can preclude the use of labor-intensive methods that would otherwise be the optimal choice. Pack (1987), for example, argues that labor-intensive weaving techniques which were used effectively in Korea can not be used in some African settings because of social factors which preclude sustained accumulation of the necessary skills.

Indirect evidence of sensitivity to circumstantial differences comes from international patent data. If technological distances were nil, one would not observe much domestic invention in LDCs, since they could simply free-ride. But, as reported in Evenson (1990) and reflected in data provided for India and Korea in Table 2 (in section 4.3), there is domestic invention in a number of LDCs. Reflecting perceived invention opportunities, ratios of R&D to sales differ among performing industries in a roughly similar pattern in India and Korea. In turn, reflecting inherent differentials in technological distance, proportions of patented inventions having foreign and domestic origins also differ among industries in both countries. If there were no differences in technological distances across industries, one would expect to find similar ratios of imported to total inventions in all industries.

Table 3 provides complementary evidence of sectoral differences in technological distance. The indices reported there are average ratios, among eight OECD countries, of patents obtained by domestic inventors in their home country to patents obtained by them in the other countries. A value of 7.0, for example, would indicate that inventions originating in any one country were patented in all eight countries. This could only happen if all inventions were equally valuable across the range of diverse circumstances present in all eight countries, which would mean that technological distances were nil. No index has a value higher than 4.5, while most are well below 3.0. This is consistent with the notion that most inventions are adaptive modifications to local circumstances of other inventions having more extensive application. But it also appears that industries differ considerably in the potential for direct technology transfer owing to intrinsic differences in technological distance.

The table shows index values both by industry of manufacture and by sector of use. The highest ratios for industry of manufacture are found in drugs, chemicals, and office machinery, which also have high ratios of foreign to domestic inventions in both Korea and India. These industries are characterized by relatively low technological distances. The ratios for sector of use afford a comparison of technological distances in the agricultural sector with those in other sectors. While technological distance in agriculture is indeed comparatively large (i.e., the inter-country patenting index has a relatively low value), agriculture does not exhibit the greatest technological distance on this measure. Several manufacturing sectors appear to be characterized by larger technological distances, as do most service sectors.[44] Reference to Table 2 shows that the non-manufacturing

Table 3
Sectoral Inter-country Patenting Indices
(Eight Countries 1969-1987)

Sector	Inter-country Patenting Indices	
	Industry of Manufacture	Sector of Use
Finance - Business	--	1.687
Wood & Furniture	1.620	1.705
Construction	--	1.735
Transportation Services	--	1.767
Ships	1.664	1.779
Other Manufacturing	1.719	1.814
Other Services	--	1.866
Fabricated Metals	1.806	1.887
Mining	1.842	1.903
Aerospace	1.876	1.929
Other Transport	1.642	1.961
Agriculture	--	1.966
Communication - Utilities	--	2.002
Health Services	--	2.031
Motor Vehicles	2.009	2.044
Other Machinery	2.060	2.084
Food, Drink & Tobacco	2.271	2.106
Electrical Machinery	2.122	2.185
Electronic Equipment	2.199	2.201
Ferrous Metals	2.195	2.217
Instruments	2.015	2.239
Stone, Clay & Glass	2.093	2.260
Petroleum Refineries	2.179	2.264
Rubber and Plastics	1.952	2.381
Paper and Printing	1.900	2.470
Non-Ferrous Metals	2.548	2.483
Textiles and Clothing	2.019	2.488
Chemicals	2.788	2.788
Drugs	2.696	3.039
Office Machinery	2.071	4.345

Note: Sectors are arrayed in ascending order of using sector indices.
Source: Evenson (1993a)

sectors in India and Korea also utilize inventions from other sectors and that, in Korea, the utility model particularly benefits these sectors.

Further evidence that technological distance matters for industrial sectors is found in recent research by Englander and Evenson (1993). Their study examines the relationship between domestic as well as foreign R&D expenditures and TFP growth in 11 industries across 11 OECD countries. Foreign expenditures include only those by technologically more advanced countries, aggregated using labor productivity differentials to weight expenditure values. In a cross-industry analysis incorporating the technology distance indices, they found that foreign R&D expenditure by technological leaders is associated with increasingly higher domestic TFP growth as technological distance diminishes. No less important, they also found that domestic R&D expenditure appears to be increasingly more productive in TFP growth terms as technological distance increases.

In sum, industrial technology is circumstantially sensitive, but this is manifested in a different way than in the case of agricultural technology. In industry, differences in circumstances do not generally preclude the direct transfer of techniques (appropriately engineered) as they typically do in agriculture. But once the techniques are transferred, and given sufficient attention to the acquisition of appropriate capabilities, further adaptive technological changes occur in response to evolving perceptions of local circumstances. In agriculture, inventive capabilities are required to accomplish most transfers; in industry, the transfer of techniques, when effective, triggers a process of simultaneous capability acquisition and technology adaptation, leading ultimately to patenting.

The adaptation of industrial technology to LDC circumstances has,

however, to be seen in historical perspective to be completely understood. Technology developed in advanced countries may cascade through several circumstantially specific stages of adaptation before it reaches the poorest countries, with each successive stage making the technology less suited to advanced countries but more suited to less developed ones. By adopting the appropriate choice of technology, LDCs that are today at a particular stage of development can benefit from adaptations made by countries that have previously passed through the same stage. For example, some of the adaptations in textile machinery made by the Japanese in the early 1900s still remain in use elsewhere. Thus, assuming that knowledge of previous adaptations has not been lost, the need for adaptive effort with respect to economic circumstances is less. More generally, different vintages of technology, if not obsolete, may offer alternatives tailored to a variety of circumstances.

Nonetheless, adaptation is sometimes necessary before transfer. Mikkelsen (1984) showed that the key activity enabling Philippine rice producers to benefit from rice threshing technology developed in Japan was the adaptive invention of a prototype thresher at IRRI. Using this prototype, local inventors made the specific adaptations required to enable the economic use of threshers in the many different circumstances in which they are now used in the Philippines. Mikkelson concluded that utility model protection was an important factor stimulating the post-IRRI inventive activity. What is particularly notable in this example is the implication that the available IPR protection was insufficient to elicit the initial transfer. Had a private producer played IRRI's role, it would have been unable to appropriate sufficient returns owing to the rapid entry of niche-specific competitors. In

different circumstances, absent widely diffused metal working abilities, a private producer might have been able to appropriate sufficient returns.

But it is not always the older vintages that are the most appropriate (either directly or indirectly) for LDCs. Vernon's (1966) product cycle model has exactly the opposite implication; technologies are not transferred (or transferable) to LDCs until they have matured to the point where processes have been invented that enable the use of unskilled labor in mass production. But Vernon's model relates to a different phenomenon, namely the evolution of frontier technology. Moreover, it is not the complete process which is transferred, but only those parts which are amenable to labor intensive production; assembly activity rather than component production, for example.

6. Technological Investment in the Private Sector

Studies of various forms of investment (or the lack thereof) in technology are important for policy purposes because of the need to understand the factors that normally stimulate such investment. There are many issues, including matters of appropriability, that must be addressed. Public sector choices are important as well as private sector decisions. Unfortunately, we have relatively little evidence from LDCs about the determinants of investment activities by private firms.[45]

6.1 Capability Acquisition and Technological Change

Case studies of technological development in industry at the firm level clearly indicate that many important forms of investment in technology are not captured in conventional measures. This is especially true of investments that are made in the course of mastering newly acquired technology. As was previously indicated, most of these investments do not count as formal R&D. Nonetheless, they simultaneously lead to

productivity-enhancing technological changes and to the accumulation of technological capability. In both respects, they are the means whereby the tacitness of technology and of local circumstances is overcome through experience-based learning and complementary additions of technological elements from outside the firm. Moreover, they contribute the foundations from which the capability effectively to undertake formal R&D evolves. In short, without them there can be no meaningful technological development.

One of the few generalizations about technology that has no known exceptions is the observation that no newly acquired technology is initially operated at its potential productivity. No less generally true is the principle that the initial level of productivity as well as the time and resources required to achieve the potential productivity depend on the starting level of mastery. Three factors appear to be most important among those responsible for these phenomena. First, labor can not effectively be trained apart from experience in the activity, while labor training is an art that improves in effectiveness with practice that is consciously monitored. Second, technologies are typically systems of elements that can be integrated in various ways. Achieving the proper integration in the operation of technology requires experimentation, which in turn is an art based on experience. Third, as stressed throughout this survey, technologies are circumstantially sensitive and much of the requisite knowledge about local circumstances and how technology responds to them in its operation can only be acquired through experimentation.

Achievement of mastery in the senses just discussed is by no means automatic; it requires systematic attention to the lessons of experience and often entails the search for elements of technology that were initially

neglected out of ignorance of their importance [Dahlman et al (1987)]. Thus the body of case study research and anecdotal evidence includes numerous cases of failure to achieve the minimum mastery needed to attain the levels of productivity expected when the physical investment was undertaken. It also includes numerous cases of unforeseen success in achieving sufficient mastery to exceed the expected levels of productivity. In the former cases there is no technological development to benefit subsequent investments in implementing the same or similar technology. In the latter cases there is technological development so that subsequent investments are implemented with increasing efficiency due to spillovers from previous experience.

In truth, the degree of mastery that is required to achieve the expected productivity depends on the choices made at the stage of engineering design and the care with which those choices are embodied in the productive facility. It is much easier to master the operation of a well designed and executed project than to overcome the deficiencies of a poorly engineered and executed one. But the ability to make effective choices and to oversee their implementation requires considerable mastery of the technology.[46] Indeed, it requires mastery well beyond that needed for efficient startup under the best possible conditions. This is why it is frequently the case that significant adaptations of the technology are required to realize the expected productivity. These adaptions are not unlike those often found to be necessary in order to respond effectively to changes in market conditions or to enable higher than expected productivity levels, which is typically accomplished by making changes that exploit local circumstances.

Included among the enormous variety of adaptive changes that have been observed are various means of capacity stretching, bottleneck breaking,

improved by-product utilization, alterations in raw material sources, modifications in product design, and expansions of product mix. It is from these kinds of changes that the complex of production and investment capabilities that is needed to achieve sustained productivity increases is derived. Without sustained productivity increases, international competitiveness can neither be achieved nor maintained in the face of the continual productivity improvements by firms at the leading edge of global competitiveness. Very few of the kinds of changes just enumerated take place in the context of formal R&D or yield inventions that can be patented abroad. Some of them are amenable to utility model protection, but most are simply improvements in various aspects of operation or engineering practice. It is generally only after the achievement of higher levels of mastery acquired through making these kinds of changes that firms go on to establish formal R&D and then begin to engage in inventive activities which may ultimately lead to patenting. But very important is the fact that mastery achieved in relation to these kinds of changes is what enables the efficient acquisition of technology through means other than formal purchase.

It is a striking fact that formal purchase of technology in complete packages through such means as turnkey plant contracts and licensing, plus their functional equivalent -- direct foreign investment, accounts for only a modest share of the technology that has been mastered in Korea, to cite a particularly revealing case about which relatively much is known [Westphal et al (1984)]. In many instances formal purchase contributed the seed from which were developed the capabilities to acquire vastly more additional technology through means other than formal purchase. Sometimes the process of acquiring additional elements of technology was akin to apprenticeship -- participation

with foreigners in project execution and startup provided the initial

learning. Other times the process was one of imitation through sequential

reverse engineering leading to the emergence of new processes and products.

But regardless of how one might characterize the underlying processes, the

basic principle was successively to master individual elements in a

progression running from the simpler to the more complex. It would therefore

be incorrect to characterize the process as one of reinvention; it is rather

one of step-by-step mastery, though the successive steps can often be so

rapidly achieved as to seem to have been undertaken simultaneously.

Thus it is that an effective process of technological development

through the focused acquisition of production and investment capabilities can

provide the means to assimilate and then adapt a great deal of foreign

technology on the basis of selectively importing some of the elements while

developing the others locally. The process is externally constrained only

insofar as key elements of the technology are proprietary and not available

through arms-length purchase. In the past, judging by the experience of the

successful export-led economies, relatively little of the technology required

for rapid industrialization has been proprietary. In turn, again judging by

their experience, purchases of imported capital goods play a vitally important

role in the overall process. First has come learning how to use imported

equipment; learning how to produce equipment has taken place more slowly.

Additionally, a good deal of the information needed to augment basic

capabilities has come from the buyers of exports who freely provided product

designs and offered technical assistance to improve process technology in the

context of their sourcing activities. Some part of the efficacy of export-led

development must therefore be attributed to externalities derived from

exporting.

In sum, much -- perhaps most -- of the investment required by firms to achieve the NICs' level of private sector technological development can not be inferred from conventional statistical sources relating either to technology purchase or invention. The more readily observable investments are but the tip of an iceberg. But this analogy, while descriptively evocative, is analytically misleading because one can not infer the extent of hidden investment simply on the basis of knowing the magnitude of the visible investment. The fact remains that most LDCs have so far failed to achieve a sufficient volume of investment in acquiring technological capabilities. The analogy is additionally misleading insofar as the warranted mix of technological investments shifts with the progress of technological development toward the more readily observable forms. But this consideration is as yet of little real consequence for most LDCs.

6.2. Direct Foreign Investment

The effects of direct foreign investment on the accumulation of domestic technological assets are complex and not easily disentangled. As a means of technology transfer, direct foreign investment is, in the first instance, a substitute for the development of indigenous capabilities. But foreign firms are no less affected by the circumstantial sensitivity of technology and the tacitness of local circumstances than are domestic firms. Thus they may generally be expected to invest in the accumulation of specific technological assets and to undertake adaptive technological changes. But this does not mean that they necessarily make the same choices that would be made by domestic firms acting in their place. In some respects they may be expected, at least initially, to make better choices, because they can rely on

capabilities developed through previous experience elsewhere and because they face lower costs of searching for and evaluating technology. But in other respects they may make worse choices, because they lack experience in the local circumstances and because their objectives are to varying degrees externally determined.

Possible differences in behavior between domestic and foreign firms have in fact been a central issue in the literature on direct foreign investment. Helleiner's survey (Chapter 28 in Volume 2 of this Handbook) of this literature largely focuses on behavior with respect to technology choice and concludes that, if anything, it appears that foreign firms may typically make superior choices. As Helleiner implies, there is much less evidence about behavior with respect to the accumulation of technological assets over time; what evidence there is does not appear to support any particular generalization apart from the statement that ill-advised policies can lead both domestic and foreign firms to the wrong kinds of behavior. Indeed, there may be no valid generalization beyond this one. Consider Korea and Singapore, two countries that have achieved spectacular development success. One, Korea, is an outlier in having relied relatively little on foreign firms for technology transfer. The other, Singapore, is an outlier in the opposite direction, having continually and extensively relied on foreign firms for its technological development.

Considerable attention has recently been given to the possibility that foreign firms may contribute importantly to technological development through spillovers to indigenous firms. The most obvious form of possible externality occurs through the mobility of labor trained by foreign firms. Other externalities may result from the transfer of technology to their local

suppliers. Foreign firms often appear to have important indirect, demonstration effects as well; for example, opening avenues of profitable activities which are soon travelled by local imitators. Several attempts have been made to test for spillover effects using firm-level data that distinguish among sectors as well as between domestic and foreign ownership.[47] Spillovers are inferred if the productivity performance of domestic firms is related to some measure of the extent of participation by foreign firms. Results from these studies have been mixed. Moreover, such studies can at best show that the evidence is consistent with the notion of spillovers. But case study research, like that reported in Rhee and Belot (1990), does demonstrate that real spillovers do sometimes occur. In turn, other forms of technology transfer, for example construction of turnkey plants, may have externalities of equal or greater significance for productivity growth in domestic firms.

6.3. Foreign and Domestic Technology: Complements or Substitutes

Several studies have investigated the relationship between domestic R&D and the purchase of disembodied foreign technology. The typical methodology has been to use data at the level of firms or industries to regress formal R&D expenditures or some other measure of domestic inventive effort on technology purchase and other explanatory variables such as sales [Lall (1983), Katrak (1985, 1990), Kumar (1987), Braga and Wilmore (1991)]. Blumenthal (1979) followed the converse approach, regressing technology purchases per employee on R&D expenditures per employed. In a similar vein, Katrak (1991) performed a probit estimation of the probability that technology is imported as a function of the R&D expenditures of firms. Mohnen and Lepine (1991) used Canadian data to estimate a factor demand system in which technology purchase is one of the variable factors and R&D is treated as a

fixed input.

Studies of the foregoing kind are not conclusive owing to specification errors of several types. First, either R&D or technology purchase is taken to be exogenous, making the estimates subject to simultaneity bias [Arora (1991)]. Second, there is a selection bias in most of these studies because firms are sampled on the basis that they perform R&D, purchase technology, or do both [on the general subject of selection bias, see Maddala (1983)].

Deolalikar and Evenson (1989) used Indian industry level data to estimate a factor demand system in which both inventive effort (proxied by patents granted during the period) and foreign technology purchase are treated endogenously. They found that both variables are significantly and positively related to stocks of U.S. patents in the same industries, but they were unable to identify the relationship between domestic patenting and foreign technology purchase in the absence of prices for each. Fikkert (1993) tackled both problems using Indian firm level data. His sample includes firms that do no R&D and/or no technology purchasing and a maximum likelihood estimation technique is used to take account of corner solutions in these respects. Domestic R&D and foreign technology purchases were found to be substitutes. In other words, a lower effective price for technology purchases induces an increase in technology licensing and a reduction in local R&D and vice versa. Basant (1993), using a different approach based on multinomial logit analysis, came to a similar conclusion.

Case studies of technological effort show that technology purchase and local R&D are in some cases complements and in others substitutes. They are complements when R&D is used in the process of assimilating and adapting

purchased technology. They are substitutes when R&D is used to develop some element of technology that could otherwise have been purchased. Basant and Fikkert interpret their estimates as demonstrating the preponderance of the latter case in India, which they take to be evidence that the Indian government succeeded in its objective of stimulating domestic technological development through regulating the import of technology. However, neither study was able to determine how the relationship between technology purchase and local R&D would have been changed if alternative policies had been followed. If only for this reason, their finding that domestic R&D and technology purchase are substitutes can not be generalized to other LDCs following different policies.

But their findings in other respects may be of greater immediate relevance. They found strong evidence of spillover effects from domestic and foreign invention, with increases in the stock of either being a stimulus to increased local R&D. Moreover, both found that increases in the stock of foreign inventions were associated with greater expenditures on technology purchase. In subsequent joint work [Basant and Fikkert, (1993)], they determined that the private rate of return to domestic R&D in India was at least as high as that found in developed countries, while the private rate of return to technology purchases was much higher still.[48] Taken together, these results imply that increases in domestic R&D and technology purchase expenditures would have been highly profitable in private terms, and -- at least in the case of R&D -- even more so in social terms. The Indian policy regime over the period examined by these authors was characterized by relatively weak patent protection and regulations that discouraged technology purchases. On both counts it appears that India's policies did not stimulate

as much technological effort as could have been productively undertaken.

Case study evidence clearly implies that accessing foreign elements of technology and investing in technology creation are complements in the fundamental sense that firms which are found to have the most effective approaches to managing their technological development do both [see, for example, Bell et al (1984) or Dahlman et al (1987)]. But not all access to elements of foreign technology is through formal purchase; nor are all investments in technology creation done in the context of formal R&D activity. Thus the relationship between formal purchase and formal R&D is a quite separate matter. Nonetheless, there is an obvious reason for thinking that these expenditures must effectively be substitutes over at least some range of technological development. As was discussed in section 4, much of technological development involves substituting for imports of technology and related technological services. One result, as was seen in Table 1, is an increase in the share of domestic relative to imported inventions, which suggests that "make" does effectively substitute for "buy."

But, in truth, the simple make versus buy characterization is fundamentally misguided. This is not merely because the choice to buy is limited by the existing stock of purchasable technology. More importantly, absent this limitation, it is because effective decisions to make typically come after basic elements of technology have been bought by one means or another.[49] Efforts to make technology are rarely successful in economic terms if not founded on domestic experience using elements of the technology, experience which leads naturally to minor adaptive changes and, ultimately, to patentable inventions. Thus decision making is more aptly characterized in terms of "buy, then decide about make", with the fundamental make choices

being related to particular elements of the technology.

More generally, efficient technological effort builds on both the cumulation of domestic capabilities and the evolution of global technology. Thus indigenous adaptations to local circumstances and the incorporation of continuing foreign technological advances are importantly complementary activities. In the past, countries that have sought technological self-sufficiency have sacrificed efficiency gains that can be had by directing technological efforts to derive the greatest advantage from the utilizing global technology. Once created, their R&D establishments typically became locked into programs that focused on improving outmoded technologies introduced at their inception. The Indian automotive, fertilizer, and textile industries, for example, have suffered greatly from the resulting technological isolation, as did the industries of most socialist regimes. In other countries, many in Latin America for example, technological isolation was not so much associated with the early creation of R&D establishments as with later efforts to generate R&D by restricting access to foreign technology.

6.4. IPR Protection and Investment Behavior

Studies that attempt to determine the incentive effects of IPR protection on decisions to invent and imitate fall into two categories: studies of behavior, either of firms holding patents or of firms that conduct systematic R&D and may choose patenting as one option for appropriating returns; and studies -- such as that by Pakes and Schankerman (1986) -- that try to establish for different sectors the intrinsic value of a patent in comparison to the value of other incentives driving private R&D activity. The following discussion focuses on the former studies.

A number of surveys rank patents as being relatively unimportant among
the determinants of R&D investments [Scherer (1986) and Nogues (1990) provide
reviews]. However, a 1981 survey of American firms in the chemical, drug,
electronics, and machinery industries found that these firms would not have
introduced about one-half of the patented inventions that composed the sample
without the benefit of patent protection [Mansfield et al (1981)]. A survey
in Canada, a major technology importer, also concluded that patents were not
the dominant factor in decisions by American firms to invest in establishing
Canadian subsidiaries [Firestone (1971, ch.s 7 and 10)]. Watanabe (1985, pp.
217,250) reports on a survey of over two thousand Japanese firms conducted in
1979-80. In this survey, nearly 30 percent of the firms cited the patent
system as being the most important incentive to industrial innovation;
considered next most important were tax and other financial incentives, with
roughly 13 percent of the firms citing each respectively. But patent
protection ranked third in importance in the motivation of individual
researchers, of whom only some 12 percent considered it the most important
incentive to them as individuals. More important in their eyes were
competition with other firms (23 percent) and academic or technical interest
(17 percent). Greif (1987), however, shows that R&D investments and patent
applications are closely correlated in the Federal Republic of Germany,
suggesting that patents have a stimulative impact.

The survey evidence on the stimulus effect of patents suggests that
the benefits of a patent system vary across industries. Industry studies show
that patents are important for some industries, particularly for
pharmaceuticals. For example, in their effort to simulate the effects of
weaker patent protection in the United Kingdom, Taylor and Silberton (1973,

ch. 14) found that the most affected industries would be pharmaceuticals and specialty chemicals, the two industries that use patents most intensively. Similar findings were obtained by Levin et al (1987) when they interviewed over 600 R&D managers in major U.S. firms. In most of the lines of business covered by that survey, patents were rated as being less effective than trade secrets or sales and service activities as means for securing returns from R&D; the notable exceptions were pharmaceuticals and scientific instruments.

The foregoing evidence seemingly gives only weak support to the proposition that patent protection stimulates R&D. But it must be recognized that much of it is attitudinal evidence comparing patents with other incentives in settings where patent protection has typically been available for long periods. It is not uncommon for respondents in such surveys to understate the importance of institutions that have long been commonplace. Furthermore, the evidence does not generally address the question of what would happen if the patent system were eliminated. Clearer, stronger evidence of its importance is found in the fact that all developed countries have been strengthening their own patent systems over time.

In turn, there is strong evidence that patents do not effectively deter imitation by rivals for very long.[50] This is in part because patents carry the means for their own destruction in the sense that they disclose to rivals the information needed to reproduce the invention. Mansfield (1985) conducted a random survey of 100 U.S. firms in 13 major manufacturing groups that yielded an estimate of the average time period between a firm's decision to commit to a new process or product and the point at which the detailed nature of the new process or product was known to its rivals. The period was roughly one year for product inventions and less than 10 months for process

inventions. Patents were indicated to be a chief conduit through which the knowledge spread.

Moreover, it does not appear from this research that patent protection prevented competitors from entering the market. Firms participating in Mansfield's survey believed that patent protection postponed rival entry for only a matter of months in the case of about one-half of the sample innovations. For only 15 percent of the sampled inventions was it thought that patent protection delayed imitation by more than four years. Though patents were considered to increase the costs of rival imitation, the additional cost was not considered sufficient to markedly affect the speed of entry by rivals. The survey by Levin et al (1987) also found that imitation, even in the presence of a patent, occurs rapidly, in part because of the information that patents convey to competitors. But the fact that imitation takes place rapidly does not necessarily mean that patents have little effect on inventors' revenues, either during the period before imitation or after.

The studies discussed to this point do not allow one to draw any direct conclusions about the behavior of firms in LDCs. But there are very few studies of firms in LDCs that are directly pertinent. One study is that conducted jointly in Brazil by the Action Center for Small and Medium Sized Companies, the Ministry of Industrial Development and Commerce, and the American Chamber of Commerce, cited by Sherwood (1990, pp. 115-6). Approximately eighty percent of the 377 firms responding declared that they would invest more in internal R&D and in labor training if better legal protection were available. In turn, we know of no studies that have rigorously demonstrated losses or damages in any country from strong IPRs. Even for those few level 2b and 2c countries (in Table 1) with pirating

capacity, there is little evidence that stronger IPRs would have resulted in higher net payments for technology from abroad. But there is evidence that suppliers of technology respond to weak IPRs and piracy by withholding technology, often going to considerable trouble in the process [Mansfield (1993)]. Thus countries with weak IPR systems may suffer a double loss, offering insufficient incentives for domestic inventive effort while also experiencing a diminished flow of foreign inventions that would further stimulate local efforts.

7. Returns to Technological Activities

The direct approach to the study of technological development is to evaluate technological efforts as "projects" and to apply standard economic evaluation methods. In principle, one should be able to estimate productivity consequences (benefits) as well as costs, thereby to assess the economic growth consequences of technology investments. In addition, one should be in a position to evaluate distributional consequences. The evaluation methods for such studies, while complex and technical, do not necessarily depend on a detailed technical understanding of the research activities themselves. These types of evaluations, along with case study evidence, constitute the bulk of the empirical foundations on which our understanding of technological development in both developed and developing countries is based.

This section reviews studies of the returns to investments in both the agricultural and industrial sectors; it also considers the conclusions from studies of distributional impacts. For agriculture, we have a large number of studies evaluating research and extension programs in both developed and developing countries. For industry, we are less well situated. We have very few studies for LDCs. We are well aware of the limited relevance of the

empirical studies undertaken in developed countries for developing countries, but we believe a discussion of the developed country evidence is useful nonetheless.

7.1 Benefit-cost Studies for Agriculture

Two methodological approaches to project and program evaluation have been followed in the literature. Both of them are based on TFP growth accounting principles (discussed in section 2.5). The first is based on direct imputation and is an application of project evaluation methods. The second approach is statistical and entails construction of variables derived from investments in research, extension, schooling, infrastructure, and other TFP enhancing activities. These variables are typically expressed in "stock service-flow" terms, with appropriate temporal and spatial weights to reflect time lags, depreciation, and spillovers. These variables are sometimes termed "meta" variables to distinguish them from conventional input variables. Statistical frameworks used have included:

> o TFP decompositions using hedonic regression specifications, where TFP measures are regressed on meta variables of the kind just discussed;
> o production function specifications where meta variables are included together with conventional inputs in a production function framework that is usually Cobb-Douglas in form; and,
> o profit functions or output supply - input demand systems which include meta variables and rely on duality theory plus the assumption of competitive markets to obtain estimates of production function parameters.

The key issue in the direct imputation studies is typically the identification of an appropriately matched sample of before-and-after or with-and-without observations relating to technology or program use. Once this has been accomplished and any remaining issues of selectivity bias have been properly dealt with, productivity differences can be attributed to program use and the benefits measured in relation to costs. The classic study

by Griliches (1957) demonstrated the basic methodology.[51] Griliches utilized

data on the first generation of hybrid corn varieties developed by both

private firms and public experiment station systems. The costs of developing

these varieties began to accrue around 1905. Experiment station and farm

level data enabled Griliches to estimate the yield advantage of hybrid corn

varieties over the older varieties in each state. These data were used along

with adoption data to compute year-by-year benefit values, given by the change

in producer plus consumer surplus. The resulting cost and benefit time series

were used to compute benefit-cost and rate of return measures.

The statistical studies employing meta variables have in some cases

estimated both the temporal and spatial spillover weights utilized in

constructing these variables. Temporal weights estimated for agricultural

research programs indicate that TFP responses generally begin one or two years

following expenditures, rising to reach a peak after 7 to 10 years and then

declining as pests and diseases begin increasingly to erode the value of the

technology. Agricultural extension programs have faster and shorter-lived

impacts. Studies for industry usually do not attempt to estimate temporal

weights; rather, weights (typically non-increasing with time) are simply

assumed.

Spillover weights are designed to capture the value contributed by

research programs outside of the region. Often they are combined with

technological distance measures of the kind discussed in section 5. Earlier

studies used climatic indicators as simple proxies for technological distance.

Industrial studies typically specify that a firm benefits from R&D undertaken

by other firms in the same industry. Griliches (1991) provides a review of

studies that have examined spillover effects.

The estimated coefficients on the meta variables in these studies are used to compute the economic impacts from an increment in investment. The marginal benefits from the increments have temporal and spatial dimensions which are taken into account in deriving benefit-cost and rate of return measures. In turn, some studies provide parameter estimates which can be used in computable general equilibrium models to examine the distributional

7.1.1 Returns to R&D

Table 4 summarizes results of 156 studies estimating returns to agricultural research programs and 40 studies of industrial R&D. Most of the agricultural studies surveyed utilized secondary data (district-level data by year in India, for instance) and were to some degree based on cross-section variation in the meta variables. Cross-section variability in research and extension inputs has been quite important in permitting the identification of their impacts; very few studies based on simple time series have been able to identify their impact. The TFP determining variables include measures of research, extension, schooling, roads, markets, prices, and related variables. In principle, the included variables should encompass the full range of TFP enhancing activities, but not all studies have succeeded in this respect.

Several of the studies estimated the separate contributions of pre-technology scientific research and of downstream applied research. Several also estimated the contributions to agricultural TFP growth of private sector R&D by firms supplying inputs to the agricultural sector. This contribution constitutes a pecuniary spillover from industry to agriculture, one which occurs because supplying firms capture only part of the return to their R&D through higher prices for improved inputs. Of the 292 reported rates of return to public agricultural research summarized in Table 4, 139

Table 4
Estimated Rates of Return to R&D

	Number of Studies	Estimate Not Significant	Range of Estimates				Mean
			1-24	25-49	50-75	75+	
Public Sector **Agricultural Research**							
Africa	10	1	2	3	3	1	41
Latin America	36	2	14	22	13	13	46
Asia	35	2	7	20	23	25	56
All Developing Countries	85	5	23	45	40	44	80
All Developing Countries*	71	5	21	54	26	29	48
Private Sector **Industrial Research**	5	0	0	3	3	2	58
Developing Countries	35	0	10	20	10	5	44
Developed Countries							
Public Sector **Agricultural Extension**	17	1	4	2	4	6	50
Developing Countries	6	0	1	0	3	2	63
Developed Countries							

*   Includes International Agricultural Research Centers.

Note: Rates of return are in percent.

Source: Evenson (1993b).

were above 50 percent; only 11 fell below 10 percent. The distribution of estimated returns shows higher estimated rates for programs in developing countries compared to those in developed countries. The few studies reporting rates of return to private sector R&D used in agriculture also showed high returns.

Fifty three of the 156 studies gave estimates pertaining to entire agricultural research systems rather than to individual commodity research programs. The distribution of estimated rates of return in these studies did not differ from that for studies focused on specific commodities. The similarity between the distributions of system-wide and commodity-specific programs suggests that the latter studies do not suffer from a serious selectivity bias; that is, that they have not focused only on the best programs. Nonetheless, as in other types of studies, it remains possible that there has been some failure to report estimates that are not deemed "high enough" to report.

One way to test the likely validity of the estimates is to examine the growth of output or productivity that is implied by the rates of return when considered in relation to the amounts invested. Unfortunately, few studies have made the relevant calculation. One that did is the study by Rosegrant et al (1993), which provides a full accounting for Indian TFP growth in agriculture over the 1956-88 period. Public sector research and extension were found to account for approximately 60 percent of TFP growth. R&D in the private sector, domestic plus foreign spillovers, accounts for 30 percent, with infrastructural improvement accounting for the remainder.

A number of observers have been puzzled by the result that agricultural research programs in LDCs appear to be generally as productive as

similar programs in developed countries. They argue that LDC programs suffer from lower skill levels and poor organization cum management, implying that the comparative deficiencies should lead to lower returns. Two counter arguments are pertinent. If a country is underinvesting in these activities, marginal and average rates of return may be relatively high. Thus, an appeal to diminishing returns can explain why a low quality system subject to under-investment could have a marginal impact as large or even larger than a higher quality system with less under-investment.

Alternatively, large returns to LDC research may reflect their receipt of greater spillovers from developed country research than can be realized among developed countries. Indeed, LDC systems, in concentrating on adaptive invention, do rely on the international agricultural research centers (IARCs) and developed country systems for pioneering invention and pre-technology science. At least in principle, this ought to enable them to generate equal returns with lower skill levels. Moreover, it does in fact appear that most IARCs are enabling significant spillovers to LDCs. Several of the studies reviewed by Evenson (1993b) found high rates of return to the IARCs' research programs. For example, one of these studies [da Cruz and Evenson (1989)] examined the role of a program for the Southern Cone countries in Latin America that has made particularly concerted efforts in facilitating international exchanges of technology and found high returns to this activity. Another, recent study of genetic resources in rice [Gollin and Evenson (1991)] reported high returns to the International Rice Research Institute's (IRRI) international system to maintain genetic material. In turn, the Rosegrant et al (1993) study, discussed above, found substantial spillovers from foreign private as well as public sector R&D.

7.1.2. Returns to Extension

Investment in agricultural extension has been seen as an attractive policy option in LDCs for several reasons. Among the valid reasons is the fact that the real costs of extension services in LDCs are comparatively low relative to the costs of research activities. LDCs spend only one fifteenth as much per extension worker as is spent in the advanced countries; in agricultural R&D, they spend half as much per researcher. Less valid is the often encountered twofold presumption that technology invented in the advanced countries is immediately transferable to developing countries and that extension services play the major role in transfer.

Experience in Asia and Latin America in the 1950s and 1960s ran counter to both notions. Large investments in extension and rural development programs had relatively small impacts in many countries. T.W. Schultz (1965), in his classic monograph on traditional agriculture, argued from this and other, micro evidence that traditional peasants were "poor but efficient," having exhausted the potential of the best suited technology. He, of course, noted the importance of education and skills, but he argued that in a setting where little new technology was being made available to farmers, even the least skilled farmers would learn to do the best that could be done given the available technology. Thus it was generally accepted in the 1970s that the gap between the average and the best productivity levels was much smaller than earlier thought, so that extension could be productive only after local research programs generated new, circumstantially tailored technology. This perception was greatly reinforced by the development of the high yielding rice and wheat varieties that came to be associated with the green revolution. It was easy to identify the associated productivity gains with the widespread

adaptation of these varieties to different local circumstances, which only strengthened the view that extension programs were of secondary importance and could not generate significant results.

Perceptions have changed somewhat in recent years. A new approach to extension, the Training and Visit (T&V) system, was developed in World Bank projects in the late 1970s [see Benor and Baxter (1984)]. This system imposes a formal structure linking extension workers to technical specialists and entails a fixed schedule of extension worker visits to farmers and farm groups. In its initial applications, the T&V approach proved successful in overcoming the frequently criticized absence of sufficient extension worker skills and disciplined management in previous approaches. Thus it has been introduced into a large number of Bank funded programs and has, in fact, become the principal program in the Bank's lending for agriculture in Africa, which has generally not yet benefited from invention of new technology. In some cases the introduction of the T&V system in Sub-Saharan Africa has led to a reduction in extension and related personnel, but in the majority of cases expenditures on extension are higher than under previous systems.

Some of the early studies to investigate the return to extension relied on variables measuring extension worker contact with farmers as indicators of extension provision. Since extension contact is at least partly determined by farmers' behavior, such variables are endogenous and positive correlations between them and farm productivity can not be used to claim the existence of a causal link between extension and productivity. Later studies have overcome the problem of endogeneity by using extension supply variables. Technological and price information is diffused to farmers through a broad range of channels, with farmer-to-farmer communication being especially

important.

        Birkhauser et al (1991) reviewed 40 studies of returns to agricultural

extension programs. Few of the early studies showed significant returns.

But, of the more recent studies, 15 of the 26 that provide estimates of rates

of return report values in excess of 50 percent (see Table 4). These include

two recent studies [Bindlish and Evenson (1993) and Bindlish et al (1993)] of

T&V extension in Kenya and Burkino Faso, suggesting that countries in Africa

still have considerable scope for reducing inefficiency even when new

technology is not being made available to farmers.

7.2. Returns to Industrial R&D

        Surveys of returns to private R&D in developed countries show that

investments in R&D, when evaluated ex post, yield private returns that are at

least as high as returns to other investments [Mohnen (1990)]. Mansfield et

al (1977a) report on 17 case studies of innovation for which the median

private rate of return was 25 percent. Griliches (1980) reports rates of

returns for large U.S. industrial firms ranging from 30 to 50 percent.

Mairesse and Sassenou (1991), on reviewing a number of studies giving

statistical estimates of the impact of research expenditure on firm-level

productivity covering several advanced countries (France, Japan, and the

U.S.), found that all implied positive and highly significant elasticities,

with approximate rates of return ranging from 14 to 24 percent. They found

corroborating evidence in another set of firm-level studies that gave direct

estimates of rates of return, leading them to conclude that, for the countries

covered, private rates of return to R&D were no less than those for other

forms of investment. Significantly, in the case of Japan, the estimates, and

thus the conclusion, relate to the 1960s when it was largely engaged in

adaptive R&D using imported technology as germplasm.

Social rates of return should exceed the private rates owing to the individual firm's inability to appropriate, or capture, the full benefits from conducting R&D. Even in the presence of strong IPR protection, a private firm's rents from licensing or product sales generally represents only a fraction of the real value of the invention to the economy; that is, of the invention's social return. Indeed, according to the previously cited study by Mansfield et al (1977a), social rates of return (median, 56 percent) were in most cases more than double the private rates. Griliches (1991) has reviewed a number of empirical studies to estimate spillovers from R&D and concludes that spillovers are of considerable importance, which is consistent with the evidence that social returns are considerably in excess of private returns.

Very few studies have estimated returns to industrial R&D in LDCs. The study by Basant and Fikkert (1993) is seemingly unique in providing soundly based econometric estimates derived from firm-level data covering a wide range of manufacturing activities. As was discussed in section 6.4, their estimates of the private returns to R&D in India are no less than comparable estimates obtained for developed countries. They also find evidence that social returns exceed private returns. Two studies of industrial R&D in industries supplying agriculture have reported high rates of return as measured by the impact on agricultural productivity [see Rosegrant et al (1993)]. Pack (1987, 1990) computed potential returns from productivity enhancing expenditures that would both accomplish adaptive modifications and elevate levels of mastery over disembodied aspects in a sample of Philippine textile firms. He concluded that more than 80 percent of the firms in the industry would realize higher returns from such expenditures than from

alternative investments.

Pack's estimates pertain to investments designed to reduce the dispersion of TFP levels across firms within the industry by moving the inefficient firms closer to the best practice frontier. To understand their full significance, they must be considered in relation to the fact that all studies of firm-level productivity differences within LDC industries find high variance in TFP levels across firms.[52] Most LDC firms are well behind the local production frontier and even further behind the frontier of international best practice. Given this evidence, Pack's estimates suggest that there is tremendous potential for realizing high returns from investments that would enable the achievement best practice.

It is exceedingly difficult to measure directly the overall volume of technological effort related to technological change in the industrial sector.[53] Generally, one can at most infer the results of such activity from estimates of productivity growth. It appears that very few LDCs have experienced discernible TFP growth in industry over the past three decades [Pack (Chapter 9 in Volume 1 this Handbook)]. Korea and Taiwan are notable exceptions, where recent research indicates that TFP in the industrial sector has grown at an average annual rate of roughly five percent, considerably more than can reasonably be attributed to sources external to the technological efforts of individual firms, and sufficient to have contributed a sizeable share of the growth of real value added.[54]

A comparative historical study of the textile industry in India and Japan by Otsuka et al (1988) gives strong evidence about the gains that can be derived from investments in mastery acquisition and adaptive change. During the late 19th and early 20th centuries, Japanese firms invested much while

Indian firms invested little. The consequence was that Japan displaced India in world markets and became a leading exporter of textiles. The authors trace the source of the difference in performance to Japanese policies which both removed price distortions and encouraged technology transfer and adaptive investment.

Indirect evidence also suggests that there are high returns to technological investments. Consider: given what is known about the high volume of technological effort in Korea and Taiwan, one can only conclude from the apparent absence of significant TFP growth in most other countries that they have either failed to invest sufficient amounts in technological change or that their technological investments have been seriously misdirected. Inward looking trade policies and restrictions placed on international flows of technology are undeniably important sources of misdirection, as discussed in elsewhere in this chapter.

Very few LDCs have managed to establish coherent and aggressive technological development strategies for the industrial sector, comparable to those that have been implemented in most countries for the agricultural sector. The evidence about the returns to technological efforts of various kinds, while limited, does not suggest that the reason is a lack of high payoff investment opportunities. It is more likely that there has simply been a failure to recognize that such opportunities do exist and to provide incentives and support for them.

7.3. Distributional Impacts

A number of studies have attempted in different ways to evaluate the consequences of technological change for income distribution. Many authors have followed Kuznets in examining the relationship between income growth and

income distribution. Their work can be regarded as indirectly concerned with the distributional impact of technological change insofar as technological change is what produced the underlying productivity changes. This literature will not be reviewed here, except to note its general conclusion that the distributional consequences of productivity growth are largely determined by a host of non-technological factors.[55] Two kinds of study are especially germane to this survey -- studies employing computable general equilibrium (CGE) models and studies of micro-empirical evidence.

Careful attention to product mix and regional disaggregation is important in the specification of CGE models to evaluate distributional consequences in agriculture. Product disaggregation is required to capture the fact that a research induced change in the production function for a single product has an effect on the supply functions for all products competing for the same resources as well as on the demand functions for variable factors. Indeed, the availability of improved rice and wheat varieties had a major impact reducing the supply of other cereals and pulses, something generally overlooked in the literature appraising the green revolution [Evenson (1992)]. Also too frequently neglected is the impact of the circumstantial sensitivity of the new technology, which makes it suitable for adoption only in regions having the requisite circumstances (for example, the possibility of controlled irrigation). Many micro studies, conducted for regions where the new technology was adopted, have concluded that employment and incomes were increased by its adoption. However, they have failed to recognize that there were negative distributional impacts in regions that were unable to adopt it.

A principal result from nearly all CGE and micro studies is that the

major gainers from new agricultural technology are the consumers of agricultural products. For urban consumers, improved agricultural technology leading to lower prices is an unmitigated blessing no matter where or how the gains are realized. Farmers and rural workers also gain as consumers, but may lose as workers and owners of rural assets. The central parameter of concern in this regard is the demand elasticity for the product.[56] With inelastic demand, total farm revenues and demands for variable inputs fall. This can result in a decline in the incomes of small farmers and rural workers. Subsistence farmers tend to be insulated from such changes because they consume most of what they produce [Barker and Herdt (1985)]. In an open economy facing a highly elastic world demand for the product, total farm revenues increase and farmers as well as workers gain.

Many of the micro studies were motivated by a concern that advances in agricultural technology harmed the poorest rural families, small farmers and landless peasants. There appears to be a consensus that this is generally not true and that losses, where there they have occurred, have accrued to landowners in areas that were circumstantially unsuited to adopt the new varieties. Barker and Herdt (1985) review studies for rice showing that small rice farmers adopt new technology about as rapidly as do larger farmers and thus share in the gains to early adopters. In turn, a recent study for rice at IRRI examined wage differentials within seven countries across regions which are differently endowed with respect to the ability to adopt the new varieties and found that they have been largely eroded by labor mobility. Instead of wage differentials, land rent differentials have emerged [David and Otsuka (1990)].

Thus the empirical evidence, at least for agriculture, is consistent

with the basic analytical implications of general equilibrium theory. Improved technology enables more production from given resources. Various equilibrating mechanisms, labor mobility being one of them, insure that any losses ultimately accrue to fixed factors that are disadvantageously located relative to the technological change.

We are unaware of any studies that have systematically addressed distributional issues in relation to industrial technological change in LDCs. The studies of Becker et al (1992) for urbanization in India do show impacts on regional employment and migration, but generalizations are difficult to make. Virtually all improved technology, when implemented, changes the demand for factors in spatially specific ways. With sufficient mobility, both locationally and occupationally, gains become widely dispersed. Ranis (1990) found that such mobility has been an important factor in maintaining, and indeed improving, Taiwan's relatively equitable income distribution. High degrees of mobility are also found in other countries; what evidence there is suggests that it has generally insured favorable distributional outcomes over time from technological change.

8. Policy Issues

Technology policy is made by public bodies at the international, national, and regional levels. Private enterprises and individuals also make policy, largely by responding to incentive systems established by public policy makers. This section discusses policy options for international and multilateral agencies as well as for national (and, to some degree, sub-national) governments.

8.1. International Policies

Until recently, IPRs were administered on an international level

through international "conventions" or agreements -- the Paris Convention for patents, the Berne Convention for copyrights, and so on. As noted previously and discussed in a number of studies, the mechanism for administration and enforcement of IPRs has recently shifted to trade law. The United States has pursued this shift most vigorously by treating weak or absent enforcement of IPRs in LDCs as forms of "unfair" trade practice, subject to sanctions under Section 301 of U.S. trade law. With the conclusion of the Uruguay Round of the GATT, a new and powerful enforcement mechanism is in place to facilitate the harmonization of IPR laws and their administration throughout the world.

This development has two important implications for LDCs. First, it ostensibly provides a mechanism under which they might seek compensation for opening their markets to foreign technology. Such compensation can be in the form of trade concessions, but these will be granted only if the governments seeking them are effectively able to negotiate them. The second and more immediate implication is that most LDCs no longer have the option of seeking to pirate technology under systems of weak IPR protection to foreigners.

These changes will affect different countries in different ways. For level 1a and 1b countries (see Table 1), the stress will be on developing effective IPR systems were they do not now exist. Emphasis in the level 1c countries will be placed on building more effective IPR systems. Level 2 countries are likely to find that defiance and laggard efforts on full harmonization of IPR systems will be very costly in terms of restricted market access and technology withholding. An important issue in IPR policy for all national governments is that they not let policy be determined or dominated by the interests of the developed countries who have pressed for the new GATT agreement. As discussed below, it is crucially important that domestic

inventions be given adequate incentives in national IPR policies.

There is considerable evidence of the effectiveness of international research and information centers as well as training efforts directed toward the agricultural sectors (and possibly also the health sector). The international agricultural research centers have clearly served to facilitate international exchange of technology and parental germplasm. Their effectiveness has been dependent on national agricultural research centers, extension services, and farmer schooling. There is little doubt that these programs in support of agricultural technological development warrant continued support.

Far fewer resources have been directed toward similar programs for the industrial sector. Past initiatives to establish organizations that would roughly parallel those for agriculture have been stifled. This may in part be due to the unwillingness of private firms to share knowledge and technology openly. Trade secrecy is much more a part of industry than of agriculture. But, even adjusting for this, we do not observe the same effectiveness in programs of research and information exchange for industry as for agriculture. But there is sufficient promise in this domain to warrant further experiments seeking more effective international programs in support of technological development in industry. The same conclusion would appear to hold for the service sector as well.

8.2. National Policies

The policies of national governments are constrained by international policies. But the constraints do not hinder the formulation of appropriate national policies that would be sufficient to achieve rapid technological development in tandem with meaningful economic progress. Indeed,

international policies, even in the realm of IPRs, are actually supportive of
and complementary to adequate national policies.

The public sector has two roles to play in technological
development.[57]   One is to provide an appropriate policy environment for
private-sector investments in technology. Policies that directly affect
private sector technological development include regulations on trade in
technology (for example, on technology purchase agreements) and in goods that
significantly embody technology (capital goods, for instance) as well as
tariffs on the latter. They also include subsidies and taxes that affect
technological efforts of various kinds along with domestic IPRs. The public
sector's other role is to be the investor in areas where the private sector
can not effectively operate. Public investments include expenditures on R&D
and technology dissemination as well as support for training and related
activities. There are important policy issues with respect to both roles as
well as in relation to the proper boundary between them. In the following,
boundary issues will be dealt with where most appropriate in the course of a
discussion that focuses first on promotional policies and then on public
investments.

8.2.1. Trade Policy

Protectionist policies to foster import substitution have historically
been the principal tool for attempting to stimulate private-sector
technological development. The fundamental rationale for protection is found
in the tacitness of technology, which implies that internationally competitive
levels of productivity can not be reached without experience-based learning
which entails comparatively high costs that must in some way be financed.
But, as is well recognized, tacitness per se is not a sufficient grounds for

granting protection, since an efficient capital market would provide the financing to cover any losses from warranted learning. In this respect the first best policy is to promote the development of an efficient capital market. In fact, financial institutions in most LDCs appear to lack effective capability in relation to financing technological investments of all kinds. Thus the importance of capital market development for technological development can not be denied, but there are no quick fixes in this realm just as there are none in the technological realm. The gains from improvements in the financial sector will be largest for countries at higher levels of technological development; capital market development alone will achieve little in the level 1a and 1b countries owing to their lack of basic production capabilities.

Externalities that preclude the complete appropriation of returns to technological investments provide the most general and compelling rationale for promoting technological development [Pack and Westphal (1986)]. This has long been recognized with respect to related investments in labor training. But the recognition that externalities pervade the process of technological development has been slow in coming. Externalities related to the nonrivalrous nature of technology have their source not in its tacitness but rather in its circumstantial sensitivity and in the tacitness of local circumstances. Additional sources of externalities are found in the increasing returns that characterize many forms of technological investment and in the savings in transactions costs that result from technological development.[58] Some of the externalities are real or "technological" [Scitovsky (1954)]; many are Marshallian externalities -- pecuniary insofar as they are transmitted through market transactions; others take the form of

spillovers, including demonstration effects.

None of the foregoing forms of externality constitute a sufficient grounds for protectionist policies. Apart from considerations of strategic trade policy -- which, if relevant, would apply only to the most advanced LDCs (level 2c), protection is never the first-best policy on theoretical grounds; subsidies to technological investment are first-best, as is well known. Thus the only case that can be made for protection is one based on pragmatic grounds [see, for example, Pack and Westphal (1986)]. That said, the evidence overwhelmingly indicates that protectionist policies have not fostered successful technological development except, perhaps, in those few countries where they have been coupled with additional policies that effectively insure the rapid achievement of internationally competitive levels of capability, so that protection is indeed a temporary "necessity." The only policies so far known to possibly qualify in the latter respect are those that make the rapid growth of exports profitable. Export activity also has the additional benefit of greatly facilitating spillovers from foreign entities.[59]

The foregoing discussion applies equally to all forms of protectionist policy including those aimed at various kinds of technology import. Temporary protection against technology imports, through such means as restrictive licensing of purchases of capital goods and disembodied technology or domestic content regulations for project engineering, might appear -- on pragmatic grounds -- to offer a strong means for encouraging technological development. However, such policies can more easily have the effect of severely retarding technological development by blocking access to critical elements of foreign technology. Like all protectionist policies, but even more so, their potential effectiveness depends entirely on whether they are administered with

adequate enforcement mechanisms to insure that they are indeed promoting meaningful technological development.[60]

Consider that both India and Korea have used similar, albeit differently administered, protectionist policies to restrict technology imports. There can be no doubt that, coupled with an inward-looking policy regime, they had disastrous consequences in India.[61] But in Korea they may well have been generally effective. The most apparent and undoubtedly consequential difference between the Indian and the Korean implementation of the policies was one of timing. They were seriously applied in Korea only at a relatively late stage of technological development, after the achievement of high levels in a wide range of production capabilities and in some investment capabilities. The Indian strategy was more nearly one of attempting to acquire the full range of capabilities through efforts, that were initially centered in the capital goods industries, to reinvent technology. Among other effects, these efforts had the unintended consequence of locking producers in many sectors into the use of outmoded technologies. Another important difference in the implementation of protectionist policies in these countries may be found in the distinct structures of their bureaucracies. The Indian bureaucracy was seemingly incapable of accomplishing the high volume of administrative processing that would have been required to enable rapid growth.

8.2.2. Domestic Policies

Given the factors that constrain public policy in all LDCs, the pragmatic argument for protection is an ex post rationalization of its possibly successful use, not an ex ante justification in its favor. Other kinds of incentive policies offer a more straightforward means of stimulating

technological investments. Direct subsidies and tax preferences have theoretical justification but are of limited relevance insofar as some important kinds of technological investment, particularly some of those related to the achievement of mastery, are not readily separable activities. Formal R&D activity, purchases of technology, and related labor training are the only readily identifiable investments. Many countries, particularly those at level 2 where formal R&D becomes increasingly more relevant, provide subsidies for R&D activity. As with subsidies for other activities, they do not always achieve the desired results, sometimes leading only to the relabeling of activities anyway undertaken. Nonetheless, they are a means to achieve more R&D by producers.

The inherent difficulty of directly subsidizing many relevant forms of technological investment would seem to imply that IPRs and indirect measures must be the principal means, apart from institution building, of promoting private-sector technological development. IPRs are discussed at some length below. Among the indirect measures, most important are the assurance of a stable macro environment, the enforcement of competitive market behavior, an open-economy strategy with respect to trade of all forms.[62] No country has achieved sustained technological development without continual attention to these policy imperatives. Of the other indirect measures that have been discussed in the literature, four merit brief mention here.

One is the use of public enterprises to transfer and develop technology. More often than not, the pursuit of non-market objectives by these enterprises retards rather than promotes technological development. However, there are some notable exceptions, such as the USIMINAS steel firm in Brazil [Dahlman (1979)]. A closely related measure is the selective promotion

of certain industries on the grounds that they are the drivers of technological development; the contemporary favorites include the familiar "hightech" industries such as "informatics." At some levels of technological development there clearly are certain activities that merit priority; metal working and simple machinery repair at levels 1a and 1b, for example [see, for example, Pack and Todaro (1969)]. But there are few such obvious cases, and even with respect to them there is too often little attention paid to performance monitoring and enforcement.

Also closely related in its apparent rationale to the promotion of public enterprises is the promotion of large scale, conglomerate firms, such as the chaebol in Korea. Here the comparison between Korea and Taiwan is telling. Taiwan's industrial structure is as much dominated by small and medium enterprises as is Korea's by super-large ones. Yet the two countries have comparable records of technological development. This suggests, as does other comparative evidence, that large firms have no inherent advantages in relation to technological development [see, for example, Levy (1991) and Levy and Kuo (1991)]. The final indirect measure is the promotion of direct foreign investment. It is indirect because of the need for complementary measures to realize the full gains from the operations of foreign firms. In Singapore, for example, foreign investment promotion has been coupled with extensive public support to technical education and training in order to insure continued technological development through the attraction of a rapidly changing mix of foreign firms. Except in some industries, direct foreign investment is neither a necessary nor an obviously superior means of technology transfer. But it may be the only effective means to initiate a process of sustained technological development in the level 1a and some level

1b countries. Here its potency will depend on the use of complementary policies to insure spillovers through labor mobility into local small and medium enterprises.

8.3. IPR Policy

Developing countries have an obvious incentive to pirate foreign inventions unless there are effective penalties against doing so. Penalties are both overt in the form of sanctions imposed by foreign governments and covert in the form of supplier reluctance to sell technology of any kind. As discussed previously, the imposition of sufficient penalties in the case of the level 2 countries can now seemingly be considered a fact of life. If these countries do not recognize the IPRs of foreigners, they will suffer from retaliation in their export markets and will be unable to obtain elements of technology needed to fuel their technological development. But the recognition of foreign IPRs is only half of what is needed. Strong domestic IPRs are also needed to stimulate adaptive cum imitative invention, in part as a legitimate counter to the recognition of foreign IPRs. Existing and prospective international arrangements do not place any barriers to the implementation of strong domestic IPRs.

Strong IPRs can be a powerful instrument for encouraging many forms of investment at all levels of technological development if they are sufficiently focused on promoting those forms of investment which are respectively important at each level. More imagination than has previously been given to their design is clearly in order. Breeders rights and utility models exemplify the gains to creativity in this area. Utility model protection, for example, is actively sought in the few countries, like Korea, that grant it. Moreover, the evidence suggests that it stimulates the kinds of minor,

adaptive inventions that are important in the early to middle phases of technological development.

The development of improved IPR systems in the level 1a and 1b countries is, however, probably not feasible; other activities, particularly the establishment of a legal infrastructure for property rights enforcement, take precedence. The level 1c countries need to evaluate their existing IPR systems, which are in most cases colonial legacies, in order to develop systems better suited to their own needs. Given their level of technological development, the use of IPRs to facilitate imports of technology through formal means is an important consideration. Level 2a and 2b countries typically have weak IPR systems reflecting the previous dominance of international concerns to the detriment of domestic interests. They need to recognize the importance of IPRs in stimulating domestic inventive effort and refashion their IPR systems accordingly.

8.4. Public Sector Investment

The issues relating to public sector investments in technological development are neither easily summarized nor readily resolved. Where there is sufficient justification, such investments can yield high returns. This is evident from public sector investments in R&D and extension relating to biological (agricultural and medical) technology. Unfortunately, the rationale for public sector investment is nowhere else so clear-cut.[63] But rationale alone is not enough; adequate management is also required. The principal difficulty in managing public sector investment is insuring that it meets the real needs of its clients. A workable model for doing so exists in agriculture. The absence of comparable models for investments in other areas imposes additional costs and uncertainties of undeniable significance. From

the scanty, largely anecdotal, evidence that is available, one has to conclude that various forms of public sector investment in other areas have in some places and at some times yielded high returns. One can only guess at the average returns on a global basis for any of the modes; the best guess is that the returns have been quite low. But more often than not it would appear that the reasons for low returns have as much, if not more, to do with poor management than with inadequate potential returns to the activity if properly directed.

Of the more specific lessons that may be drawn from past experience, those in two areas stand out. The first relate to industrial R&D undertaken by public sector research institutes. R&D to reinvent technology simply does not pay unless it is conducted to overcome absolute restrictions on supply, a consideration that is relevant only to the level 2c countries attempting to enter certain industries. Otherwise, seemingly successful cases of reinvention turn out on closer inspection to be instead well managed cases of adaptive transfer; notable examples of this kind of research have been undertaken by Taiwan's Industrial Technology Research Institute. In turn, the obstacles to achieving high returns from adaptive public sector research on technologies already well established in production are nearly insurmountable. To be productive, industrial research must be conducted in close proximity to experience gained in production. Simply stated, the good ideas for implementable adaptive invention come largely from production experience and are not easily communicated beyond the plant perimeter. Ways around the obstacles to adaptive research can be found, but few institutes appear to have discovered them.

The second area where important lessons have been learned relates more

generally to the fact that the public sector's role as a direct investor is too much taken for granted by those concerned about the promotion of technological development. Consider public sector extension services to serve industry. The most obvious point to be made here is that the returns to promoting the development of private sector suppliers of technology may well exceed those to investing in public sector extension. But seldom are such private sector alternatives even recognized. In turn, diffusion of best practice technology has in some countries been effectively performed by industry associations acting on behalf of their private members. As a rule, too little attention is paid to stimulating such private institutional means of providing what are essentially club goods. These observations are not intended to suggest that private sector solutions are necessarily best; in truth they are often infeasible. Rather, possible private sector solutions merit attention because such solutions can be expected to accelerate technological development.

8.5. Complementary Investments

Some final comments about investments in science and in human capital formation are in order lest it be thought that inattention implies unimportance. Evidence of high returns indicates that investments in pre-technology sciences are important for adaptive invention in areas where technological distances are large. In turn, comparative human capital data strongly imply that the NICs could not have succeeded without investing heavily in technical and scientific education through the college years and in vocational training. But in nearly all LDCs the problem has been on the demand side, not on the supply side. It makes no sense to invest more in high-level technical human capital formation until sufficient progress is

achieved in realizing technological development.[64]

9. Research Directions

There are many studies, both analytical and empirical, that are being undertaken with some success at present. On the analytic front, endogenous growth and dynamic trade models are offering more to the field than much earlier theory. Further contributions and insights will undoubtedly be forthcoming. The specifications of imitation and spillover in models to date are clearly not yet capturing the full richness of real world phenomena; distinct levels of technological development need to be incorporated into this work more clearly. The same can be said with respect to important distinctions among modes of technology transfer ranging from direct foreign investment through informal apprenticeship. Without capturing significant differentiations in these respects there is likely to be little progress in adequately distinguishing between cases of success and failure in catchup growth.

It goes almost without saying that theory, at least as regards technology, unsupported by empirical work deservedly has a rather short life. Also that more than simply stylized facts are needed. Theorists must develop testable propositions, and empiricists must devise ways to do the kind of testing required to discriminate between alternative hypotheses. This is not to say that carefully conducted case studies are unimportant. But in the future case studies will need to be conducted with more attention to analytical rigor and careful quantification of costs and benefits than has been true in past; that is, they will have to do so if they are to contribute useful results that go beyond suggestive interpretations. Case studies of seemingly successful public sector investment programs outside of agriculture

are especially needed.

This survey makes clear that there are many significant gaps in the body of pragmatic empirical studies as between developing and developed countries. There can be no question about the need for many more studies estimating rates of return and examining relationships between domestic investment and foreign technology in the industrial sector. Here future studies should be guided by the methods and specifications now being used in state-of-the-art research on developed countries. A methodology for addressing issues concerning externalities and spillover is at hand and should be widely applied. Another important branch of pragmatic studies employs direct questioning of managers to obtain insights regarding decisions and decision making processes. Such studies of foreign suppliers and domestic purchasers of technology can add importantly to the understanding of motivation and behavior.

Suggestions for a complete research agenda are not made here. In particular, studies of factor bias and distributional impact are not considered. This is not because such studies are without value, it is rather because the first order of business in a large part of the developing world must be the improvement of productivity through policy reform and investment in technology. Distributional problems can usually be dealt with (when they occur) using policy instruments that do not affect the overall pace of technological development.

FOOTNOTES

[1.] The Schumpeterian (1934) definitions of "invention" and "innovation" are used throughout this survey; the terms refer to the creation and commercialization, respectively, of new technology. Many authors in the field use "innovation" to mean both things.

[2.] Their effectiveness in doing so is, however, constrained by the tacitness of local circumstances.

[3.] A prime example is the Indian Ambassador automobile. The original model remained unchanged for 30 years, this in spite of global advances in engine efficiency, braking systems, and the like.

[4.] The arguments are built on micro foundations provided by previous research on the generation of new technology and the formation of human capital which demonstrated that R&D and schooling are not conventional factors of production, both being characterized by important positive externalities. On R&D, see Arrow (1962a), Mansfield, et al (1977b), Scherer (1986), Griliches (1991); on schooling, Denison (1962), Becker (1964).

[5.] See Lau (forthcoming chapter of handbook) for further discussion of endogenous growth models. Rodrik discusses endogenous growth theory in relation to issues of policy reform.

[6.] We review the limited empirical work regarding IPR impacts on R&D investment in section 6.4.

[7.] Patents apply to the first two kinds of invention; utility models, to the third. More is said about these forms of IPRs in section 3.1.

[8.] Nelson and Winter (1982) built an evolutionary theory of what would now be termed endogenous growth on the basis of a somewhat different search model.

[9.] As will be seen in section 5.2, research results obtained elsewhere and transferred in the form of germplasm are the dominant mode of biological technology transfer in agriculture.

[10.] Kortum (1992) demonstrates diminishing returns under more general specifications of the density function. Only "fat-tailed" Cauchy-type distributions do not yield diminishing returns in this type of model. See Nordhaus (1969) for applications.

[11.] Empirical evidence of exhaustion in some fields is reported in Evenson and Kislev (1975) and Evenson (1992).

[12.] The dependence of one firm's adoption decision on prior decisions by other firms has been variously interpreted in terms of information costs, risk reduction, and competitive pressure.

[13.] Plotted against time, the estimated value of p(t) appears as a forward falling S; the proportion of adopters first grows slowly, then rapidly, and then again slowly.

[14.] See, for example, Mansfield et al [(1977b), chs. 6 and 7].

[15.] On the roles of education and extension in agriculture, see Griliches (1957), Birkhauser et al (1991), and Jamison et al (1991).

[16.] Lau (forthcoming chapter of handbook) focuses on research falling within this tradition.

[17.] Nelson (1993) provides extensive descriptions of the technological infrastructure that has been established in Argentina, Brazil, Israel, Korea, and Taiwan.

[18.] See Siebeck et al (1990) for a review.

[19.] The movement toward stronger IPRs in all developed countries is likely to bring these changes to more countries.

[20.] The evidence regarding IPRs as stimulants to invention is discussed in section 6.4.

[21.] Nordhaus (1969) gives the standard treatment.

[22.] See also Evenson (1990).

[23.] See Timmer, Chapter 8 in Volume 1 of this Handbook, for additional discussion.

[24.] Huffman and Evenson (1993) provide extensive descriptions of archetypal hierarchical structures.

[25.] Unlike seeds for open pollinated crops, hybrid seeds can not be obtained from the previous year's harvest. Instead, they must be produced continually through a sequence of inbreeding and crossing. This creates a market for improved seed varieties, since new seeds must be purchased from seed producers annually.

[26.] Huffman and Evenson (1993) also discuss the historical evolution of the pre-technology sciences, observing that they were not developed until invention oriented researchers at level III expressed a demand for more science of a distinct kind to enhance their inventive activities.

[27.] "Manufacture" here refers to the sector in which the patented input is produced, which need not be -- but often is -- the same as the sector from which the patent originated.

[28.] Tables 2 and 3, discussed in sections 4.3 and 5.4, respectively, show applications to Indian and Korean data as well as to international data used to determine a measure of technological distance.

[29.]One can also apply the concordance to data on R&D expenditures or scientists and engineers engaged in R&D to get some idea, for example, of how much R&D within the manufacturing sector is for the benefit of the agricultural sector, or of how much R&D attention is given elsewhere to sectors that perform little or no R&D.

[30.]This is clearly demonstrated in Table 2, as is discussed in section 4.3.

[31.]The term "spillovers" generally refers to benefits of any kind conveyed in the form of externalities derived from invention. In this survey, "spillovers" refer to benefits derived from the transmission of knowledge used either directly or indirectly (as inventive germplasm) by other units.

[32.]Westphal et al (1985), Fransman (1986), Lall (1990), and Enos (1991) discuss the capability concept at some length. Westphal et al (1990) discuss a systematic, quantitative application.

[33.]Cortes and Bocock (1984) provide an illuminating description of alternative modes, and of factors on both sides of the market that affect choices among them, in the case of petrochemical technology.

[34.]In a turnkey project, a local owner contracts with a foreign agent to provide all the elements needed to design and establish a facility as well as to initiate production. Among the elements is enough training to impart the rudimentary mastery needed to operate a well maintained facility under assumed conditions relating to such things as material input availability and specifications.

[35.]As discussed in section 5.3, transfers of new biological material from international agricultural research programs substitute for absent fundamental R&D capabilities and thereby complement local experimental and extension capabilities.

[36.]Lall (1990) provides data for a more comprehensive set of indicators relating to technological development in the manufacturing sector for level 2 countries. The range of possible indicators is quite extensive, as may be seen from those given in National Science Board (1991) and OECD (1993). Similar compilations are available for several of the more advanced developing countries.

[37.]India, which has long had an atypically extensive system of public industrial R&D institutes, is a level 2b country.

[38.]An empirical measure of technological distance is discussed in section 5.3.

[39.]Implicit throughout this survey is the belief that there is no general justification for LDCs to go beyond inventive adaptation in undertaking R&D. Some authors, Stewart (1977) for example, have argued -- using the induced innovation hypothesis -- that there is ample justification, on the grounds that invention in the advanced countries is increasingly irrelevant to the developing countries owing to growing divergence between them in key circumstantial factors.

[40.]Note that D_{ji} need not equal D_{ij} owing to the impact of differences in circumstances between locations i and j.

[41.]These values relate to average yields in location i for the three crop varieties that have the highest yields in location j relative to the three varieties that have the highest yields in location i. To obtain the distance measure, the not unreasonable assumption was made that unit costs vary in direct but inverse proportion to yields.

[42.]For analysis and evidence indicating that this is not so even in the developed countries, see Cohen and Levinthal (1989).

[43.]However, owing to changes in macroeconomic policy, they suffered a serious loss of market share in the 1980s.

[44.]Measurement at lower levels of aggregation would show considerable variation among technologies within sectors. Evenson (1993c), for example, has found that the use of imported patents among advanced countries is proportionately much greater in the manufacture of agricultural chemicals than in the production of harvesting machinery, which reflects the relative variability of soil characteristics.

[45.]Cohen and Levin (1989), in their survey of the evidence from developed countries, make many general observations that are of relevance in the LDC context as well.

[46.]A high level of mastery is not sufficient by itself to insure an efficient outcome. See, for example, Desai (1972) for a case study illustrating some of the many things that can go wrong in a complex industrial undertaking over which local control is lacking due to financial exigencies.

[47.]See, for example, Blomstrom and Persson (1983) or Haddad and Harrison (1991).

[48.]Specific rates of return are not given here because estimates for India, as for developed countries, are highly sensitive to the specification employed.

[49.]For example, through machinery imports.

[50.]Except in certain chemicals-related areas, it is generally rather easy to devise a functional substitute for a successful new product that does not actually infringe the original inventor's patent.

[51.]Some of the results from this study are discussed in section 5.2.

[52.]Pack (Chapter 9 in Volume 1 of this Handbook) surveys these studies.

[53.]Mikkelson (1984) demonstrates one approach to the problem.

[54] The recent studies are summarized in World Bank (1993, ch. 6). Notable studies for Taiwan and Korea include Pack (1992) and Pilat (1993), respectively. Lau (forthcoming chapter of handbook) gives an alternative view regarding TFP gains.

[55] General literature surveys are given by Taylor and Arida as well as by Adelman and Robinson in Chapters 6 (Volume 1) and 19 (Volume 2), respectively, of this Handbook.

[56] Among the relevant CGE models are those constructed for the Philippines by Quisumbing et al (1993) and for India by Quizon et al (1991).

[57] See Ergas (1987) for a general discussion of technology policy.

[58] Stewart and Ghani (1991) provide a detailed discussion of the forms of many relevant externalities.

[59] Pack (1992, 1993) explores externalities that may be associated with export activity. The linkage between export-led industrialization and rapid TFP growth is examined in a CGE modeling framework in de Melo and Robinson (1992).

[60] Stewart's (1979) survey of technology licensing policies makes this point forcefully.

[61] Lall (1987) provides a detailed discussion of Indian performance in technological development.

[62] On the importance of indirect policies more generally, see Sagasti (1978) and Stewart (1987).

[63] Justman and Teubal (1986, 1991) demonstrate the elements of a rigorous justification for public investment in technological infrastructure to benefit the industrial sector.

[64] Enos (1991) provides a comprehensive discussion of the relationship between technological development and human capital formation.

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