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SCIENCE AND TECHNOLOGY IN LESS DEVELOPED COUNTRIES{PRIVATE }

Wesley Shrum

Department of Sociology

Louisiana State University

Baton Rouge, Louisiana 70803

U.S.A.

Yehouda Shenhav

Department of Sociology

Tel Aviv University

Ramat-Aviv

69978 Tel Aviv

ISRAEL

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It is not unusual for scientists to eat their subjects.

Thomas Bass. Camping with the Prince, and Other Tales of Science in Africa.

{PRIVATE }Introduction{tc \l 1 "Introduction"}

The literature on science and technology in less-developed countries (LDCs) is immense and interdisciplinary, but not predominantly academic in character. It would be easy to damn much of it for lack of systematicity, methodological sophistication, and theoretical grounding. A good deal more of it could be condemned for its polemics, idealistic models, and naive assumptions. What must be kept in view, however, is that many of its contributors do not have as their exclusive (or even primary) aim the enhancement of understanding. Instead, they focus on the betterment of that portion of humankind living in less-developed countries or the advancement of organizational goals such as profitability. The work discussed below is much broader than the STS studies currently practiced in many institutions though it falls within this purview. The tasks of synthesizing this literature and theory construction lie in the future.[i]

In the first part we review perspectives on the relationship between science and economic development, the institutionalization of westernized science throughout the world, and the research output of LDCs. In the second part, we review research on technological development, including technology transfer, state intervention and regulation, technology generation, social effects of technological change, and appropriate technology arguments.[ii]

The remarkable diversity of disciplinary perspectives, theoretical interests, and empirical studies precludes any simple summary of received or current wisdom. It is striking, however, that many authors have come to the conclusion--whether or not they state it in these terms--that *science and technology should be viewed in terms of context-specific forms of knowledge* *and practice which interact with a set of globally-distributed social interests.* Such a conceptualization is preferable to those based on grand theory (whether "of" science, technology, or development) and suggests that social network approaches will be useful for capturing the interlocking set of individual and organizational interactions which propel world technoscience.

{PRIVATE **}**I. Science in Less Developed Countries**{**tc \l 1 "I. Science in Less Developed Countries"**}**

All theories of development imply some subtheory or account of the role of science and technology (Agnew, 1982). At one extreme, it is argued that the lack of innovation and resistance to change is the main cause of underdevelopment. At the other, imported scientific ideologies and technological artifacts from industrialized countries are said to generate debilitating dependencies.[iii] In all this, competing characterizations of social actors play a role. Are they passive recipients of Western aid? Are they hidebound traditionalists, reluctant to alter inefficient farming and production methods? Are they rational actors who reject or subvert inappropriate technologies imposed by elites? Are they stooges of multinationals in the capitalist core?[iv]

It is possible to report that many studies, though certainly not all, now go beyond accounts of S&T in less developed countries in terms of individual properties or their simple aggregation. In place of this older "atomistic" view, <u>relational</u> concepts have become more important. Here the principal focus is on relations (also called "links" or "ties") between social actors, whether individual persons, organizations, or nations (Shrum and Mullins, 1988), and the effects of these relations in promoting or constraining forms of action. Macro theories of development typically focus on the relations between nations, or among nations, elites, and multinational corporations (MNCs).

Since national wealth and scientific effort are unquestionably associated, researchers have asked why and with what consequences do LDCs engage in various kinds of research? Does investment in scientific research, as well as investment in technology and engineering development, contribute to economic growth? Three theoretical perspectives have been brought to bear on this question: modernization, dependency, and institutional.

{PRIVATE **}**Modernization**{**tc \l 2 "Modernization"**}**

According to neoclassical economic approaches to development (Williams, 1967; Pavitt, 1973) and sociological modernization theories, technology is a prime motor of social change among nation-states at the same level of modernization.[v] In extreme versions of the modernization view (and especially their characterizations by critics) the main causes of development are internal to a country while the configuration of external relationships is of little significance.

But scientific knowledge and the transfer of technology were thought to be a special case. Modernization theorists believed science was strongly linked to technology, and, like education, improved the ability of a country to promote growth through more efficient utilization of its resources. Technology transfer, aid which promoted the educational institutions, and other forms of scientific and technical assistence were encouraged as part of an appropriate developmental process.

This relationship between science and development was thought to be especially crucial for LDCs which sought to reach a developmental take-off point (Dedijer, 1963; Sussex group, 1971). First, an economic infrastructure, including both labor and capital, is required to absorb scientific knowledge and enable its utilization. Second, scientific knowledge must be relevant and applicable to economic endeavor.

But LDCs often lack a sound economic infrastructure and the question of relevance is still hotly debated. One of the most surprising findings that emerged from empirical work in the 1970s was the negligible influence of the expansion of higher education on economic growth (Meyer et al., 1979). In sharp contrast, both primary and secondary educational expansion are known to have strong positive effects on national economic development (Rubinson and Ralph, 1984; Benavot et al. 1991). School graduates at the secondary level reach the economic labor force (the production and service sectors), whereas higher education channels graduates into occupations which produce no tangible goods (e.g., lawyers, civil servants).[vi]

Implicit in accounts of the relationship between science and economic growth is an underlying premise about the unidirectional influence of science on technology. The conventional belief that technology is deeply rooted in scientific knowledge has undergone substantial revision. While such influence relationships from science to technology do occur, this model does not generally reflect a modal process of research and innovation (Shrum, 1986; Drori 1993). Science penetrates the technological realm through a complex process consisting of several components but they do not occur in any determinate order. Often technological developments influence science.

{PRIVATE }Dependency{tc \l 2 "Dependency"}

Dependency theory was the first major contribution to social science which originated in the LDCs themselves (Hettne, 1983). If modernization theory minimizes the influence of external relations on internal processes, dependency theory (and its close relation, "world system" theory) argues that external relations create obstacles for development because the direction of economic growth is conditioned by forces outside the country.[vii] Position within an international network of relations is a central determinant of economic development. Dependency theorists claim that less developed economies are malintegrated into the international system because of their dependence on a small number of exchange relationships and because these relationships operate, through various mechanisms, to benefit interests in developed capitalist economies.

For example, investments by foreign businesses affect the division of labor and the economic structure in LDCs. Such economic interventions distort internal processes, increasing income inequality, suppressing political democracy, promoting the rise of core-linked economic sectors, and stunting economic development (Evans and Timberlake, 1980; Delacroix and Ragin, 1981; Semyonov and Lewin-Epstein, 1986).

Western science is viewed as another mechanism of domination, not just by producing the technological means for the subjugation of the masses (in some accounts), but also as an ideological force and an inappropriate developmental model. The creation and maintenance of scientific institutions not only absorb personnel and capital but constitute an irrelevant ideological diversion for countries without the resources or connections to pursue Western, specialty-oriented science.

Researchers in LDCs are linked to the "scientific core" in industrialized countries. Knowledge is produced in collaboration with foreign colleagues and research centers without taking LDC needs into account.

Investments in fundamental research, and consequently in research productivity, are funded not only by domestic sources but also by foreign aid.[viii] This enhances growth in the tertiary sector and increases the size of universities but results in misallocation of national resources at the expense of the productive sectors, interferes with the societal division of labor, and retards economic growth.

Cross-national empirical studies have consistently shown positive associations between economic wealth and research productivity. Such correlations may reflect no more than the general correspondence of a wide range of characteristics of industrialized societies and themselves imply no causal force. It might even be that the association exists because only wealthy countries can support the luxury of prestigious "fundamental" research. A major and still unresolved issue for LDCs is the extent to which investment in science by the state stimulates or retards economic development.

The relationship between scientific and economic status may be different for different levels of development. Shenhav and Kamens (1991) employed a longitudinal analysis (1973-1980), distinguishing between indigenous and Western scientific knowledge. For a sample of 73 LDCs the latter has no relationship with economic performance and even a mild negative association with economic performance in the poorest countries. For the developed nations, on the other hand, scientific knowledge was found to be associated with economic development. Though LDCs invest more effort in applied research, they may also be less capable of converting theoretical knowledge into technological applications.

{PRIVATE **}**Institutional Theory**{**tc \l 2 "Institutional Theory"**}**

Whether or not Western science is useful or detrimental to LDCs there remains the question of why countries are committed to its promotion? Institutional theory is concerned with the determinants of isomorphism, or the adoption of structurally similar forms throughout the world.[ix] In general, the institutionalization of isomorphic science in LDCs is produced by a belief in the universality of science and its necessity for modernization. Scientists, elites, and policy-makers in both developed and less-developed countries share this orientation. Hence, adoption of Western organizational forms serves as a legitimating device to other states and international agencies.

Through mimetic processes by which successful existing systems serve as models (DiMaggio and Powell, 1983), scientific institutions and beliefs are prescribed and diffused as a key component of the modern world-system. Such processes are the main focus of institutional theory, according to which reality is socially constructed to create "truths" which acquire rule-like status.

Practices, processes, and national policies are adopted, transformed, and reproduced not necessarily because their technical superiority has been demonstrated, but rather owing to participants beliefs in the efficacy of certain ways of doing things. Science, like education, is one of the most significant institutions which provide interpretations, cultural meanings, and instrumental leverages throughout the world. Enormous environmental support allows actors and organizations which are accepted as "scientific" to define the meaning of rational activity and encourages their world-wide diffusion.[x]

Scientists and scientific communities are principal carriers of the ideology of universalism, promoting the idea of a world-wide universal and context-free system of science. Relative consensus exists on the nature and aims of science because the most prominent scientists in LDCs who rise to administrative and policy positions are trained in industrialized countries (Gaillard, 1991). LDC scientists are linked initially to international scientific networks (often through educational experiences) and remain connected through cross-national collaborations, the exchange of scholars, bi-national funding, and international meetings.

The maintenance of these linkages tends to work against external interventions and goal-directed science which conflict with the idea that the invisible hand of theoretical need should regulate the advancement of knowledge. Choudhuri's (1985) perceptive comparison of graduate work in India and the US examines the consequences of peripheral location on the research practices and orientation of scientists, concluding that attempts to emulate "great scientists" can even be the cause of actual scientific "failure," rather than an agent of socialization into productive research activities.

By adopting Westernized science and Western organizational forms, LDCs help to promote comparability and compatibility but not solutions to local problems (Turnbull, 1989). Emprically, adoption of Western models does not imply that institutions developed in LDCs are simply mirrors of their Western counterparts, as Eisemon (1980, 1982) and Schwartzman (1991) show.

Institutional theory de-emphasizes the power and interests of social actors in the institutional field, yet the processes it describes are often fueled by mechanisms of power and domination which are best explained by the dependency approach. The "taken-for-granted" can be used as a vehicle in the service of interests. Dependency theory is not at odds with institutional theory but rather complementary, pointing to alternative network mechanisms as driving forces. The former emphasizes that establishing relations with powerful actors induces dependency in the absence of alternative sources. Institutional theory hypothesizes that actors in structurally equivalent positions (i.e., with similar sets of relations to other actors in the system) should behave similarly with respect to models provided by prestigious ("successful") positions.

In sum, whether one believes that most international ties induce development or dependency, it is a mistake to place such a large theoretical burden on any one type of linkage, external or internal. Though the causal importance of connections with MNCs and industrialized countries is now widely appreciated, it is preferable to recognize that developmental paths are historically contingent, without seeking a universal model of development.[xi]

{PRIVATE **}**The Distribution of World Science**{**tc \l 2 "The Distribution of World Science"**}**

The late Mike Moravcsik (1928-1989) was a tireless promoter of "science development" for the benefits, both material and spiritual, that would accompany the advancement of science in developing countries.[xii] But he remained harsh in the mid-1980s in his judgment of Third World science. An essay with John Ziman described a reality behind the "facade of science" in the fictitious land of "Paradisia":

> no more than the fragments of a scientific community, disorganized, disunited, of limited professional competence, poverty stricken, intellectually isolated, and directed toward largely romantic goals--or no goals at all. (1985, p.701)

To what extent has the practice of modern research spread throughout the world? What level of scientific and technological capacity characterizes nations? The principal way of assessing capabilities has been via indicators such as publications, citations, and the number and distribution of technical personnel.[xiii]

High levels of concentration characterize the production of world science. Although the absolute quantity of world science and technology produced by LDCs has gradually increased--regardless of the measure used--many observers would agree with some portion of Moravcsik and Ziman's judgment. None of the LDCs (including India, China, and Brazil, the top producers) has the kind of active and integrated scientific community characteristic of OECD countries (Gaillard 1991; Arunachalam, 1992).[xiv] Measures of inequality in the production of scientific publications are even larger than those in other social spheres (Frame et al., 1977).[xv]

This high level of inequality is illustrated by the fact that well over three quarters of world scientific output is produced by ten countries. All are highly industrialized, apart from India, the leading LDC producer of science. The dominance of OECD and Eastern European countries in producing scientific research is overwhelming. Together, the two regions contribute 94 percent of the indexed scientific literature.[xvi] Between 1981 and 1985, LDCs produced 5.8% of the world's scientific output (Braun et al., 1988).[xvii]

There are, however, important limitations to these studies, particularly the focus on periodical output. Since the peer-reviewed journal is the preferred Western form of disseminating research findings, researchers have often used the Science Citation Index to analyze differences in scientific productivity between countries and disciplines.[xviii] Work published in internationally-oriented journals is distinct in terms of both peer-review procedures and impact from that in national and local journals. Such data bases cover only a small proportion of the total world technical literature, neglecting non-English sources and most of the periodicals in LDCs.

LDCs may only account for a fraction of journal coverage in the major indices,[xix] but the world share of LDCs in certain fields (such as soil sciences and agriculture) is larger (Arvanitis and Chatelin, 1988). Many researchers publish a great deal in domestic journals, even if they publish internationally (Velho, 1986; Lomnitz et al., 1987; Davis and Eisemon, 1989). While the LDC contribution to the mainstream scientific literature is small, there is no single data base from which reliable estimates of the total contribution to the published literature can be made.

Though the developed countries occupy a position of centrality, linguistic, educational and political factors affect the specific degree of influence one country has over another. Schott (1988) uncovered six structurally equivalent regions in the worldwide influence network. De Bruin, Braam, and Moed, in an analysis of Gulf State co-authorships, show how closely scientific collaboration reflects political and past colonial alliances (1991).

Even more important than where work is published is what kind of work is done. Twenty years ago the Sussex Group estimated that 98 percent of world R&D expenditures were by Western countries while only one percent was associated with problems directly related to the developing world.

Wherever resources originate, problem selection in LDCs is a core issue, both sociologically and politically. It is quite difficult to assess the degree to which published research is oriented towards local problems and needs.[xx] The ideology of a universal science, with all its Western ethnocentrism, has consequences for the integration of the world scientific community and for science policy recommendations. Advocates of a world scientific system argue that smallness and provincialism impede the evolution of a scientific critical mass in a country and hinder communication with competent colleagues. If scientists must belong to the international system, scientific performance in LDCs should be associated with the adoption of foreign institutional forms.

This view, while it is readily explicable in terms of institutional theory, may have undesirable consequences for local economic performance by creating a gap between research effort and national economic needs. Local economies may exert less pressure on researchers when they are integrated into an international scientific community which promotes specialty-oriented science. State-of-the-art research directed towards a discourse of theoretical knowledge may be preferred to research which deals with local health problems, energy needs, and food production.

The rationalized belief in a context-free, specialty-oriented science, reflected in adherence to the values of universalism, is increasingly seen as quaint in contemporary science and technology studies.[xxi] But in the context of the Third World, it may actually be harmful.

{PRIVATE **}**II. The Process of Technological Development**{**tc \l 1 "II. The Process of Technological Development"**}**

The majority of research done in the context of LDCs relates more directly to technology than to science. Technology has more explicit relevance for dependency arguments because it includes the development and improvement of industrial processes, transfer or invention of artifacts, the improvement of crops and food production, and the shaping of social institutions. Just as the literature above points to problematic relationships between scientific and economic sectors, the presence or absence of ties is a key theme in research on technology.

Technological development in LDCs can refer to a wide spectrum of changes, their determinants and consequences. In this section, we review current work on (1) the transfer of technology across international boundaries, (2) the process of state regulation, (3) the generation and adaptation of technology within LDCs, (4) the effects of technical change, and (5) arguments concerning Appropriate Technology.

{PRIVATE **}**Technology Transfer**{**tc \l 2 "Technology Transfer"**}**

Relations between countries are almost always **relations between organizations**, either public or private. "Technology transfer" examines several aspects of of these relations.[xxii] It denotes movement of artifacts and/or knowledge. Products and processes developed in other countries are shifted across the boundaries of LDCs. It has often been observed that most technology transfer by MNCs does not take place for the benefit of the recipient country.

Technology transfer is clearly not a process that characterizes a "stage" in the development of the Third World. It occurs constantly in the First World as well. Nor does it only involve relations between industrialized and less industrialized counties. Headrick's historical overview of technology transfer between Britain and its colonies reveals no simple "advantage" gained from technological imports or exports (1988). The same technology serving as a basis for the influence for colonizers sets in motion processes of social change undermining their power.

In theory, technology transfer is closely related to the **diffusion of innovations** yet linkages between the two bodies of literature have not been close. A bibliometric study of the subject showed that the two fields developed independently in the late 1960s and early 1970s (Cottrill et al., 1989). This had not changed by the end of the 1980s and the decreasing willingness to see technological diffusion as a process of adoption without adaptation suggests it may remain so.[xxiii]

Neoclassical treatments of technology transfer, largely **economic** in character, stress such factors as the (1) complexity of the product or production techniques being transferred, (2) transfer environment in sender and recipient countries, (3) absorptive capacities of the recipient firm, and (4) transfer capability/profit-maximizing strategy of the donor firm (Baranson, 1970). Mansfield discusses forms of transfer, modelling transfer costs as a function of the experience of both source and recipient firm, the number of years the technology has been in existence, and the number of firms which have already applied the technology (1975). In a study of 37 chemical, semiconductor, and pharmaceutical innovations, it was shown that the rate of technology transfer across international boundaries is increasing more rapidly than in the past as a result of the growing influence of multinationals (Mansfield et al., 1983).

Short-term strategies of private enterprises do not necessarily or even ordinarily promote "development" in its variety of meanings except in the trivial sense that some industrial or business activity takes place within an LDC. The notion that LDCs are free to choose autonomously from different technological alternatives or that entrepreneurial activity will always enhance growth and development in recipient countries is anachronistic. The relationship between supplier and receiver often involves a conflict of interests, a claim emphasized by dependency arguments. For instance, Kaplinsky's study of a large, export-oriented pineapple processing factory in Kenya shows in detail how the distribution of gains favors the MNC rather than the local area (1988).

However, there are numerous criteria for successful technology transfer, reflecting the interests of a variety of constituencies. They include operational ones such as return-on-investment or growth in sales, second-order consequences like international competitiveness (export growth), or the development of indigenous capabilities (personnel training, ability to innovate), as well as infrequently measured but still critical social effects such as unemployment and inequality. Much of the literature on technology transfer consists of case studies which pay little systematic attention to these variable dimensions of transfer.

The <u>type of dyadic relationship</u> between the supplier and recipient may be the most significant single factor in predicting the consequences of technology transfer. As Derakshani argues, the location of control (ownership, managerial), personal interaction, initial supplier involvement, and the stability of the relationship are crucial to the motivation of the supplier (1984). Greater control, inteaction, involvment, and stability are associated with supplier willingness to invest in transfer. Since the prices paid for foreign technology are not fixed, but rather depend on bargaining, this process may be a fruitful area for micro-sociological research on the pricing of technology. Helleiner discusses bargaining strategies in a preliminary way (1988).

Technology embodied in artifacts can simply be shipped between countries (in exchange for currency or influence in the politics of the recipient) but the transfer of manufacturing technology takes place on a scale from direct investment (a wholly-owned subsidiary), to independent licensees, through the intermediate arrangement of a joint venture.

Licensing agreements imply relatively distant relationships (fewer interactions) between source and recipient. Some argue that licensing (as well as trademarks and patents) is a form of technological domination owing to the high degree of technological concentration (Vayrynen, 1978) but it is also thought to assist in import-substitution industrialization. Although licensing may be enough for technology transfer to developed countries, LDCs often need more sustained relationships than are implied by the rights to use proprietary information (Marton 1986).[xxiv]

For the same reason, studies of **"turnkey" operations** (Akpakpam, 1986; Al-Ali, 1991; Beaumont et al., 1981) are generally critical of these agreements. The sale of manufacturing hardware, while relatively simple, fails to promote technological mastery in the recipient country owing to constraints on the nature of content of interactions involved.

Economic arguments regarding the appropriability of innovations suggest that for high technology, MNCs find it more efficient to **transfer within the firm** and that many of their characteristics evolve to protect innovations from latecomers and copiers (Magee, 1981). Although part of the variation in transfer decisions is explained by the policies of host countries, the **organizational structure** of the MNC plays an important role. William Davidson's study of 57 US-based multinationals and 954 new products shows that structures which centralize learning benefits are more efficient at transfer than those which distribute them (such as global product divisions)(1983).

It was generally assumed, particularly towards the beginning of the period we consider here, that the role of MNCs and establishment of "internal" or "intraorganizational" transfer mechanisms has eclipsed patents and licensing (Michalet, 1979) and has had the effect of centralizing R&D in the home country, with limited and local R&D labs of affiliates. We return to this point after considering state policies and regulatory mechanisms.

Received wisdom regarding the **R&D activities of multinationals** suggests a variety of negative effects, centering around the generation of dependence in recipients: (1) much technology transfer consists of internal technical trade between MNCs and their subsidiaries, (2) within MNCs there is a lack of correspondence between book price and the real price of any internal technology transfer, (3) MNCs devote more resources to innovating new products than new production processes, (4) R&D activities of MNCs are centralized in parent companies, while R&D activities of subsidiaries are tightly controlled, (5) the R&D burden unevenly distributed, to the detriment of the subsidiary, as a result of the product cycle.[xxv]

Micro studies have emphasized the **characteristics of people** and the way training influences "malleability" of personnel or levels of understanding which can lead to adaptability (Holland, 1976; Holsinger and Theisen, 1977). MNCs are generally more interested in the talent pool, general education, and perceived personality traits of workers (Chen, 1981; Kollard, 1990) than the ability of managers to attend to "ethnomethodological cues" which are equally important (Washington, 1984).

Although the literature stresses the role of MNCs because of their dominant role in technology transfer, there has been some attention to "non-MNCs" (Alam and Langrish, 1981; Meissner, 1988), the role of regional and international organizations (Amarasuriya, 1987; Haas, 1980; McCullock, 1981; Patel, 1984; Sussman, 1987; Del Campo, 1989; Weiss, 1985; Bailey et al., 1986), and universities (Glyde and Sa-yakanit, 1985; Seitz, 1982; Shayo, 1986).

The **transfer of military technology** involves a unique set of issues, and has been studied by a different community of scholars. Military transfers may increase the likelihood of armed conflict (McDonald and Tamrowski, 1987). They can, at minimum, consist simply of hardware and spare parts for counterregime coalitions, or can involve a great deal of research as well (Varas and Bustamente 1983). The recent discovery of the massive and covert Iraqi attempt to develop a nuclear weapons capability with long term assistance from a variety of state and private sponsors heralds an emerging area of specialization: the reconstruction of technical systems. With the decline of competition between the U.S. and the Soviets for military sponsorship of LDCs, many issues of technology transfer will concern ballistic missile capabilities and their technological features (Mahnken and Hoyt, 1990).

{PRIVATE **}**State Intervention and Regulation**{**tc \l 2 "State Intervention and Regulation"**}**

No theoretical argument is needed to underscore the fact that local LDC firms are at a disadvantage in their relationships with MNCs. State action (including industrial, trade, and R&D policy) constitutes third party intervention in these relationships and is deemed crucial to the promotion of science and technology for development. In the 1970s, these policies focused on indigenous S&T institutionalization. Throughout the 1980s, "self-reliant" policies, though never completely rejected, were rethought and redefined. Arguments which suggested the closure of economies by overt state action fell to more moderate positions which did not entirely reject the experiences of industrialized countries as relevant to development (Macioti, 1978).

Increasingly it is recognized that state organizations compete with other institutions in LDCs and that, apart from the few socialist countries remaining, they are often too weak to implement unilateral change (Migdal, 1988). The state may, with sufficient funds, set up national research institutions, promoting technology directly. Authoritarian regimes may actively seek to suppress research--a relatively easy task where resources are scarce (Puryear, 1982). Most of the literature deals with indirect mechanisms of state intervention such as changing the mode of association between foreign suppliers and local operations (full ownership to contractual relations), altering the costs of the transfer (balance of payments, restraints on local firms), and the content of the "technology package" (the information, services, rights, and restraints) (Contractor, 1983). A massive early study of technology showed that links between research and production in LDCs are weak or nonexistent (Sagasti, 1978). The most important conclusion was that policies on foreign investments, credit and interest rates, patent and trade regulations, imports and exports, project analysis criteria, market protection, and social inequity are more influential in determining the direction of technological change than R&D policies per se.[xxvi]

Although openness to trade is often simply argued as a corollary of nonrestrictive trade policies in general or formal economic models (Teece, 1981; Wang, 1990), some challenge the basis of LDC importation policies and argue they are misguided (e.g., Contractor, 1983). It is difficult if not impossible for governments to effectively regulate the mode, cost, and content of technology imports in the context of incompatible national objectives and competing constituencies.

Science and technology **policy planning in socialist countries** has been a major topic of discussion, especially historical accounts of policy shifts, organizational arrangements, and case studies of specific areas (Vien, 1979; Volti, 1982; Simon, 1986; Saich, 1989; Jamison and Baark, 1990). China's experience during and following the Cultural Revolution is an instructive but still little understood episode (Dean, 1972; Chai, 1981; Mendelssohn, 1976; Baum, 1982; Fangyi, 1987). On the one hand, a general policy of promoting science and technology (exemplified in Deng Xiao Peng's slogan "Science and Technology are the First Productive Force") through the system of government ministries was designed to decentralize funding decisions by allowing regional and local bodies to make decisions and disburse funds (Blanpied, 1984). On the other, the networks of interpersonal relations (guanxi) so critical for support and resources in centralized economies tended to recentralize and undermine local control, as program directors who had been passed over used their direct ties with the ministries to gain resources (Fischer, 1984).

India's technology policies, which became increasingly restrictive from the mid 1960s after relatively open policies in the 1950s, have been subjected to intensive study, not only because it is the largest LDC for which information is readily available, but because of its active social scientific community (Ahmad, 1981).[xxvii] By the mid 1960s, India had a collection of state-sponsored agencies whose activities were not directly related to the production system and an industrial system heavily dependent on foreign technology. During Indira Gandhi's regime, it witnessed the creation of new agencies for research and administration, changes in relative allocations among agencies, restrictive and selective policies towards foreign investments and collaborations, as well as efforts to link the S&T system with other production sectors of the economy through an S&T plan (Natarajan, 1987). In spite of political infighting and bureaucratic conflicts, the development of research and technological capabilities in India has been considerable.

A study of the Indian scientific instruments industry from 1947 to 1963 found restrictions on imports aided the growth of a domestic industry, but it required a decade before production could take the place of imports (Clark and Parthasarathi, 1982). Alam examined foreign collaborations approved between 1977 and 1983 (1988). Interviews with 211 technology-importing firms and government officials revealed a huge demand for technology and restrictive policies had a limited effect in promoting indigenous development. A study of 42 British exporting firms found that owing to the diversification of suppliers, restrictive Indian import policies were having a negative effect on the modernity of technologies (Bell and Scott-Kemmis, 1988). These authors argue that restrictions enlarged the gaps between potential, planned, and actual content of technologies transferred. The effects of the new Indian policies of the late 1980s--simplified licensing procedures, increased competition, and greater technology importation--are yet to be evaluated (Bhagavan, 1988).

Detailed studies of <u>how</u> science and technology policy is made in LDCs are still rare. Hill notes the general acceptance of S&T indicators for planning but a lack of influence of science and technology planners owing to an absence of ties to central decision-makers (1986). However, there are many case studies of the policies and performance of specific governments, e.g. Sri Lanka (Ramanathan, 1988), a series of UNESCO studies, microelectronics in Brazil (Hobday, 1985; Erber, 1985; Westman, 1985; Evans, 1986; Langer, 1989), and petrochemicals in Nigeria (Turner 1977). Such studies of policy do not thoroughly consider the role of elites and constituencies in its formation but others tackle this problem (Adler, 1988; Anderson, 1983; Botelho, 1990; Morehouse, 1976; Ranis, 1990; Sharma, 1983).

In the midst of much legitimate concern over the "carriers" of self-reliance and its likelihood in the light of current international economic and political relations (Ernst, 1981; Forje, 1986), a number of instances arose of countries which seem to be success stories, defeating the predictions of those who thought underdevelopment a permanent state. Government involvement in science and technology policy is evident in studies of the **Newly Industrializing Countries** (South Korea, Hong Kong, Taiwan, Singapore, Mexico, Brazil). Following the lead of Japan, the idea that industrial development would precede technical development led to government investment in industry and in the education of workers. The importation of technology from North America and Europe was not seen as a threat, but rather an opportunity for assimilation, improvement, and reverse engineering (Shishido, 1983; Chiang, 1989; see Vogel, 1991 for a readable introduction the "four dragons").

Some of the best studies use the Korean example to illustrate state involvement in a selective manner, particularly in negotiating the terms imposed on foreign technology suppliers (Enos and Park 1984).[xxviii] Arnold's comparison of Korea and Taiwan (1988) shows the dual motivation of this involvement in both upgrading industrial capacity and strengthening military capability. Moreover, different levels of centralization in science policy seem to be effective,[xxix] though the precise mechanisms are debated (Jacobsson 1985). It should be noted that in the past two decades, as Korea has industrialized, private expenditures on research have increased from 12.6% to over two-thirds, while funds for public research labs have decreased from 84% to less than one-fourth (Lee et al., 1986).

Based on the relative success of these "upper tier" LDCs, James' (1988) conclusions reflect the views of many: states should be selective in supporting specific areas for R&D, shift funds to applied projects, and avoid projects with international prestige but limited local usefulness. That is, restrictive policies should be targeted to specific ends rather than guided by a general philosophy. The initiation of production may require intervention, while production for export may require liberalization. Regulations must be specific to technologies rather than general (Marton, 1986).

{PRIVATE }Technology Generation{tc \l 2 "Technology Generation"}

The most important development since the mid-1970s is the enlargement of research interests beyond the neoclassical question of choice of technique (the intensivity of labor and capital in the production process). Just as there has been a general recognition in science and technology studies that researchers must examine the local conditions of production and the tacit character of much knowledge, a consensus emerged that technological capabilities in LDCs must be examined in more sophisticated and differentiated ways.

Purchasing, plant operations, duplication of existing technologies, and innovation (Desai, 1988) are all forms of knowledge which require detailed studies. In explaining the development of the NICs, the process of innovation is an important component, but innovating new products and processes is not crucial or even necessary for industrialization if a country acquires other capabilities (Pack and Westphal, 1986). As Fransman effectively argues, relevant capabilities can be gained even in the search for new products. Processes and deep forms of technological knowledge are not necessarily preferable (1985).

By the late 1970s technologies were not simply "adopted" but "adapted" to the local environment (Teitel, 1977). It was realized that significant processes of technical change were occurring within some LDCs and certain industrial sectors (Katz, 1987; Lall, 1987). For example, Girvan and Marcelle's (1990) study of a Jamaican company attributes its success to active strategies of developing relationships with suppliers of raw materials and in-plant experimentation. Teubal attempts to measure technological learning in firms and the extent to which it is embodied in exports (1984). The drive for self-sufficiency can result in poor productivity: foreign and local technological elements must be combined. Dahlman, Ross-Larson, and Westphal provide a well-documented statement of this viewpoint (1987). Commitment to local technological improvement is a critical factor (Bowonder and Mijake, 1988).

What is the relationship between research performed in LDCs and imported technology? Some studies show local R&D is insufficient for international competitive purposes (Agarwhal, 1985). Wionczek (1983) examines pharmaceuticals in Mexico and shows the expected relationship between imports and low domestic R&D, while Evans (1979, pp. 172-94) summarizes activities in Brazil, including a number of taken-for-granted justifications used by MNC managers for their lack of interest in local R&D.

Yet a number of studies challenge this "either/or" view. Fairchild and Sosin (1986) show Latin American firms competing sucessfully with MNCs through their own R&D activity. Blumenthal (1979) shows that industries/countries that import greater amounts of technology also spend more on R&D. The complementarity between technology imports and domestic R&D was confirmed for the private sector and "low tech" firms in India by Siddarthan (1988). Katrak's (1989) study of Indian firms shows imports increased the chances a firm would begin R&D and that firms which spend more on imports also spend more on R&D.[xxx] A related study showed that firms which imported technology through licensing tended to complement this with more of their own R&D (Kumar, 1987).

A number of investigations parallel studies of communication, productivity, or value systems in developed countries. Ebadi and Dilts establish an association between frequency of communication and performance for a sample of 49 research groups in Afghanistan (1986). Singh and Krishnaiah (1989) found work climate in R&D units was related to effectiveness for a large sample of units in five countries (including Egypt, Argentina, India, and Korea) and concluded that climate was more affected by the sociocultural setting than by institutional locus. Using the same data Nagpaul and Krishnaiah (1988) found that external linkages to users and to researchers was related to effectiveness. Suttmeier's study of fraud in Chinese science is Mertonian in orientation, with an interesting twist on the notion of normative violation (1985). A particularly fascinating example is Blecher and White's account of the effects of the Cultural Revolution on the organization and operations of a 248 person technical unit in western China, based on the encyclopedic recollections of a single participant (1979).

{PRIVATE }Social Effects of Technological Change{tc \l 2 "Social Effects of Technological Change"}

At the beginning of the 1980s, Hebe Vessuri called for an understanding of the process of technical change in Latin American agriculture in terms of the establishment of relations among actors (1980). To a limited extent this has occurred. There are many case studies of technical change and warnings about the negative impacts of new technologies (Muga, 1987; Nilsen, 1979). The largest body of work on the effects of technical change concerns the consequences of the Green Revolution--that is, developments in agricultural production technology--on productivity, employment, inequality, and landownership[xxxi] as well as health, the environment, and social unrest (Anthony, 1988; Goody, 1980). More recently, the new biotechnologies have been a focus of interest.[xxxii]

Studies of the transfer of Western agricultural practices (modern varieties of seeds, fertilizers, and pesticides, along with mechanized production) tend to fall into distinct camps, depending on whether the authors support or oppose these developments. Theories of the relationship between technology and employment suggest that new agricultural technologies may increase yields but require capital investments that increase local inequalities and dependency on suppliers.[xxxiii] Pearse (1980) provides the basic review of U.N. studies indicating that where inequalities exist Green Revolution strategies result in the persistence and creation of poverty in rural areas.[xxxiv]

Another group of authors feels the negative consequences of the Green Revolution have been exaggerated.[xxxv]Forsyth and colleagues attempted to show that the adoption of labor-intensive technologies does not reduce unemployment

(1980), while Gang and Gangopadhyay (1987) argue that they may actually create long-run unemployment. Bayri and Furtan examined the Turkish case, finding that high yield crops only displaced labor because wheat is generally less labor intensive than the crops it replaced, and that real wages fell owing to population growth (1989). Blyn seeks to demonstrate the positive effects of tractorization in India (1983).

Other studies find little impact at all. Herdt's study of Phillipine rice farmers generally shows little change in the real incomes of rice farmers or laborers over the period from 1965 to 1982 (1987), while Diwan and Kallianpur (1985) found new fertilizers had a minor impact on grain production. Leaf's study of a village in the Punjab from 1965 to 1978 found real gains, economically and ecologically, including an increase in equality (1983). Interesting, and perhaps tellingly, Zarkovic's study of the effects of technological innovation on agriculture over a twenty year period showed that the agricultural labor force increased in the Punjab but decreased in Haryana (1987), suggesting that one cannot generalize about the Green Revolution as so many have done. Although labor-saving technology is usually not considered desirable, even this does not completely generalize (for Saudi Arabia, see Looney, 1988).

The comprehensive recent volume by Michael Lipton with Richard Longhurst (1989) seeks to solve the "mystery" of how modern seed varieties "work" but fail to alleviate poverty. Modern varieties <u>do</u> reach small farmers, reduce risk, raise employment, and decrease food prices. But since the poor are increasingly landless workers or near landless farm laborers, these benefits are readily diluted or diverted. In general, the negative impacts of the Green

Revolution have been greatest when modern technologies are introduced under conditions of high inequality (Buttel and Raynolds, 1989).

Clearly, much remains to be done in analyzing the social effects of new agricultural technologies in terms of their interactions with political systems and the increasing interest in gender. Sugar cane harvesting in Cuba has been used to suggest that socialist countries can adopt mechanized techniques with fewer social dislocations than capitalist countries (for the comparison with Jamaica, Edquist 1985; for the Dominican Republic, Clemens and de Groot, 1988). The effects of technical change on women show that modernization has done little to free rural women from traditional roles (Ahmed, 1986; Stamp 1989). In western Africa, von Braun found that technological change led to improved nutrition, but that productivity improvements, rather than improving the lot of women, simply led to an inflow of males into crop production (1988).[xxxvi]

One must conclude that (1) different disciplinary perspectives and research traditions lack integration and (2) studies of the social impacts of technology in LDCs have yielded considerable information on particular types of situations, but there are too few comparative studies to allow a systematic assessment of social effects. The debate over Appropriate Technology helps to encapsulate many of the most fundamental practical and theoretical issues in the area.

{PRIVATE **}**Appropriate Technology and Technology Assessment**{**tc \l 2 "Appropriate Technology and Technology Assessment"**}**

Throughout discussions of technology choice and the effects of technological change, the concepts of Appropriate Technology (AT) and the prior term Intermediate Technology (IT) as well as diverse but related offshoots such as "technological blending" (Bhalla and James, 1986) and "optimal technology" (Rao and Dubow, 1984) are pervasive. The idea of "appropriateness" has been applied to everything from bicycle manufacturing (Onn, 1980) to management (Leonard, 1987) to information technology (Davies, 1985). The point of most discussions is that technology should be designed and assessed, adopted and adapted with some concept of basic needs in mind (Yapa, 1982).[xxxvii]

Originating in the 1970s with the work of E.F. Schumacher, the idea that some of the negative consequences of capital-intensive technologies imported from highly industrialized countries could be reduced or prevented by the adoption of smaller scale, labor intensive, less mechanized technologies, was transformed into a kind of social movement (e.g., Dunn, 1978).[xxxviii]

The classic economic work on the subject, Frances Stewart's Technology and Underdevelopment (1977), lays out the basic assumptions. Investment in technology by LDCs is associated with dualistic development, benefits accruing primarily to the modernized sector, and growing unemployment. The technologies themselves are not to blame, but rather poor selections of technology conditioned by the environment in industrialized countries where they are developed and hence ill-suited to the vastly different conditions of LDCs. This selection is influenced by the alliance of interests between the developed countries and the advanced technology sector in receiving countries. Stewart argues that choice of technique should be defined to include all the different ways in which basic needs may be met. Appropriate technology is likely to be older technology from advanced countries, traditional technology from the Third World, or recent technology which has been designed with local conditions in mind.

Perkins' study of ten industries in Tanzania exemplifies the problem (1983). Although most of the output came from small-scale production practices, the state purchased more capital-intensive, less efficient technologies, owing in part to budgeting procedures. Ahiakpor surveyed 297 Ghanian manufacturing firms of five basic types: foreign owned, private, mixed foreign-private, state-owned, and mixed state-foreign. Based on import dependency and the highest capital-labor ratio, he concludes that mixed state-foreign firms select the least "appropriate" technologies, suggesting to some the collusion of local and foreign elites supported by the state (1989). A large number of empirical studies of appropriate technology are annotated in Ghosh and Morrison (1984).

Critics of AT have not been wanting (Ndonko and Anyang, 1981; DeGregori, 1985). It is ironic that the Appropriate Technology movement, which drew much of its appeal from its acknowledgement that technology is not context-free, was quickly criticized for neglecting the social and political context in which ATs were to be introduced (Howes, 1979).[xxxix]

Some kind of assessment of technology would seem to be implied in the idea of appropriate technology, but assessments are often abstract and theoretical rather than systematic and empirical. Often they are simply of no interest to participants.[xl]

Elzinga's discussion of the ideological and methodological presuppositions built into the evaluation process for development aid (1981) applies just as well to technology assessment. There are built-in limitations to the ability of LDCs to undertake technology assessment. Randolph and Koppel studied technology assessment in seven Asian countries, finding that activities had already peaked and that most countries were simply interested in accelerated adoption (1982). The United Nations and the World Bank have been active in this area (programs and projects are reviewed in Chatel, 1979, and Weiss, 1985). Numerous proposals for various assessment and decision-making methods are now in existence (Hetman, 1977; Sharif and Sundararajan, 1984; Thoburn, 1977; Salmen, 1987; Trak and MacKenzie, 1980; Flores-Maya et al., 1978).

From the perspective of LDCs, factors which should be important in decision-making include the question of whether the technology is at the right level of sophistication for the country in question and whether it offers the best value in the long run, rather than its initial cost. Ahmad's pragmatic and thoughtful discussion of the issue identifies the main issues of evaluation for developing countries in terms of cost, quality, scale, degree of sophistication, risk of failure, and environmental risks. Along with many authors, Ahmad feels that the AT movement has romanticized the problem and frequent conflicts of interest prevent realistic assessment (1989).[xli]

{PRIVATE **}**Conclusion**{**tc \l 1 "Conclusion"**}**

This review has focused on published material in English on science and technology in less developed countries from 1976 through 1992. In this sense it is just as limited as the productivity studies discussed in part one. Science and technology studies in the LDCs themselves have grown voluminous over this period.

In China, to take only one example, a field known as the Dialectics of Nature began with the translation of Engel's work in the 1930's. Populated mainly by scientists, the field was dominated by philosophical issues, Soviet influences, and a focus on pre-twentieth century materials until its disappearance during the Cultural Revolution. During the past decade, new professional associations and doctoral programs have been established. The Dialectics of Nature is now an umbrella for more than 3000 professionals who study the history, philosophy, and sociology of science and technology as well as science policy. Marxism remains the dominant perspective, but the extent to which it provides a genuine organizing framework has decreased. Works by Merton, Kuhn, Popper, and Price are now widely read as a new generation of students searches the Western literature for alternative critical perspectives.[xlii]

Given our cultural focus, as well as the splendid interdisciplinarity of the field, it seems facile to speak of common understandings. Descriptively we identified (1) a new focus on the incremental technical change which characterizes most LDC activities; (2) a recognition that it is unproductive to distinguish sharply between the generation of new technology and the modifications necessary to new conditions; (3) a new emphasis on the transfer of technology which is tacit rather than explicit and codified; and (4) an awareness that the ability to produce basic science is not strongly associated with the adaptation and use of technology. The reorientation has not occurred, as the story goes in some areas of S&T studies, as a result of theoretical or epistemological considerations. It is more readily told that people wondering <u>how technology was done</u> in LDCs--rather than speculating about why it was not up to world standards--began to examine local conditions for the production of knowledge (cf. Fransman 1985, pp. 580-610; Rosenberg and Frischtak, 1985, pp. vi-xvii).

It has been argued, for instance, that the nature and dispersion of agricultural R&D in Africa are largely responsible for its irrevelance

(Lipton, 1988). But researchers in LDCs have been, if anything, more sensitive to the process of technological adaptation, or "ethnoscience" in informal field and community-based research settings (Herrera, 1981; Hainsworth, 1982).[xliii] An important focus of research will remain the beliefs and practices of small groups of specialized S&T actors, but the generation of knowledge need not be studied in research laboratories, and should certainly not be confined to the activities of scientists and engineers.

Nor will micro-level processes be sufficient to account for variation in the development of science and technology. As organizational theorists argue, the configuration of relationships within and among firms, national laboratories, and universities provide an important context for decision-making and resource allocation. An understanding of technology transfer requires a sophisticated knowledge of the causes, varieties, and consequences of interorganizational relationships (Shrum and Wuthnow, 1988; Plucknett et al., 1990). At the macro level, the question resolves itself into a debate over whether the nation or the organization is more important to competitive rivalry (Dore, 1989; Shrum and Bankston, 1993).

Social network models offer an opportunity for integrating micro and macro approaches through their focus on social actors--both individual and organizational--and a conceptualization which involves both the presence and absence of relations within a social system.[xliv] A low density of ties between researchers and users, especially when combined with ties to Western research centers, can translate into inappropriate technologies or irrelevant research (Baark, 1987; Crane, 1977, Vessuri, 1986). Scientific "centers" in developing countries may even be less relevant, in the sense of responding to national policy, than regional institutions (Jimenez et al., 1991). Owing to the fact that organizations are differentiated entities and develop internally competing interests, the mechanism of accumulative advantage is different at the micro and macro levels.

The world technical community is now a reality, but one characterized by high levels of differentiation and inequality. The task of the next fifteen years is to examine it without national bias.

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Notes

i. One of our reviewers suggested that the constructivist emphasis in STS programs during the 1980s was responsible for a decline in internationally-oriented STS studies. Too, the 1970s flow of funds into social scientific studies of development declined substantially during the 1980s. But we are aware of no decline in research or interest in S&T by writers across the broader range of disciplines.

For an introduction to both social constructivism and theories of development, see Yearley's Science, Technology, and Social Change (1988). For a masterful review of developmental economics in the late 1970s and early 1980s see Fransman (1985; republished as Technology and Economic Development by Westview, 1986). Shrum, Bankston, and Voss (1993) provide references and annotations for the entire period covered in this essay, from 1976 through 1992.

ii. Notable omissions from the variety of topics considered under these broad headings are personnel issues such as the "brain drain," and the specialized information and library technology literature. We also exclude the large body of research on educational systems and university-industry relations. David Hess's work (1991) provides a case study of Brazilian Spiritism and an introduction to another neglected area, the shifting boundary between science and the occult.

iii. For a Muslim view, see the works of Sardar (1977) or Zahlan (1980).

iv. Surprisingly, in the light of all that is said about the orientations of people in LDCs, studies of **attitudes** toward science and technological change are relatively scarce (but see Malik, 1982; Ghazanfar, 1980; Gomezgil et al., 1975, as well as Pattnaik, 1989, for science and religious belief).

v. See Portes, 1976, and Badham, 1984, for general reviews of these approaches.

vi. Recently, however, Ramirez and Lee (1990) decomposed total tertiary enrollments into tertiary science and tertiary non-science enrollments, finding that between 1960 and 1980 economic development was positively influenced by the relative number of tertiary science enrollments.

vii. Although we do not properly review the distinctions here, both are "relational" approaches to development. While world system theory is a "holistic" network approach, treating the relations among positions within the world system of relations, dependency is an "actor-centered" approach which focuses on the array of (dyadic) relations influencing particular nations. The several versions of the dependency argument incorporate science and technology in different ways and some are critical of the "classical" dependency view that connections with highly industrialized countries prevent development. For example, Evans' account of dependent development in Brazil emphasizes the technological dependency which occurs in the context of a "triple alliance" between elite local capital, international capital, and the state (1979).

viii. Although it is difficult to calculate, dependency of LDCs on research funds from core countries is significant. Up to 2/3 of LDC research budgets come from foreign sources, while foreign aid pays for about 40% of agricultural research (Gaillard, 1991: 142-4).

ix. By "institutional" or "neo-institutional" theory we refer to the Stanford school associated with John Meyer, as distinct from Ben-David's work on the institutionalization of science in Europe which is Mertonian in emphasis. See Zucker (1987) or Scott (1987) for reviews.

x. Deborah Fitzgerald (1986) demonstrates that foreign aid of the Rockefeller Foundation in Mexico was guided by the ethnocentric strategy of increasing crop productivity through those crops, farmers, and agricultural students that most closely resembled their American counterparts. International organizations often enforce these mimetic processes.

xi. See Evans and Stephens' account of the "new comparative historical political economy" (1988).

xii. The reader may consult Moravcsik (1975) for a review of materials before the period covered by this essay.

xiii. Morita-Lou (1985) and Arvanitis and Gaillard (1992) both provide excellent collections of work on S&T indicators for LDCs.

xiv. Moreover, as Schott emphasizes, since population growth is more rapid in LDCs, their per capita share of world publications is decreasing (1991, p. 456).

xv. For example, the Gini coefficient for inequality in scientific productivity in 1973 was 0.91, compared with 0.85 for economic inequality (measured by GNP), 0.75 for the distribution of national population, and 0.74 for the distribution of national land area (see also Hustopecky and Vlachy, 1978).

xvi. When the research contributions of Israel and South Africa are removed, non-Western countries contributed only 4.6 percent of the volume of world science (Frame et al., 1977: 506).

xvii. Garfield (1983) found that North America, Europe, and the USSR contributed 94 percent of world scientific production.

xviii. The data base, compiled by the Institute for Scientific Information (ISI), includes bibliometric data for 150 countries and 106 scientific fields.

xix. See Sen and Lakshmi (1992) for the Indian case.

xx. Even this may not be relevant to the question of research emphasis, if, as Dhirendra Sharma estimates, countries such as India devote up to 60-70% of their research funding to military, nuclear, and space science, fields in which results are largely unpublished.

xxi. See, e.g., Goonatilake (1988) and compare Rabkin (1986).

xxii. Often the term International Technology Transfer (ITT) is used in the context of cross-national transfer to distinguish it from intra-national processes.

xxiii. Our assessment is shared by Reddy and Zhao (1990) in their excellent review of International Technology Transfer.

xxiv. The relationship between licensing and dependency was examined by Mytelka (1978). A survey of general and production managers in Costa Rice whose firms were producing under license indicated problems with licensing (Grynspan, 1982). For investment licensing see Bhatt (1979).

xxv. This shortened version is from an OECD paper by Michalet (quoted in Wionczek, 1976).

xxvi. But see Pack and Westphal (1986), who argue that technology policies are more important than trade policies.

xxvii. India is the best-documented case for most problems in LDC science and technology (Krishna, 1992; Rahman, 1981; Visvanathan, 1985).

xxviii. See also Lee (1988) and Choi (1988).

xxix. Taiwan's National Science Council is somewhat weaker than Korea's Ministry of Science and Technology but both have been relatively successful in promoting science and technology.

xxx. Imports of technology help promote in-house R&D, but the effect is limited. Larger firms have proportionately lower R&D spending.

xxxi. This remains an area of much controversy. Alauddin and Tisdell (1989) review the effects of the Green Revolution in Bangladesh, showing a concentration of landownership along with a reduction in variability of foodgrain production and yields. Chadney (1984) documents disparities in India, while Jaireth examines class differences in tubewell utilization (1988).

xxxii. Lawrence Busch, William Lacy, and colleagues provide an introduction and analysis, with some attention to LDC issues (Busch et al., 1991, pp. 169-90; also Buttel et al., 1985; Rigg, 1989; Kenney, 1983). See the debate between Buttel (1989, 1991) and Otero (1991) on the issue of whether biotechnology is "revolutionary" or "substitutionist."

xxxiii. Burke's study shows larger Mexican farms benefit disproportionately from new technology (1979). Quiroga's study of irrigation systems in El Salvador concludes that these require not only management but mechanisms to insure that benefits actually accrue to peasant cultivators (1984). Walker and Kshirsagar's study of the introduction of threshing machines shows primary benefits are to the owners of capital who buy and rent the machines (1985). See also Shaw (1984).

xxxiv. See also Griffin (1974), Dahlberg (1979) and Byres (1981) for important Green Revolution critiques.

xxxv. Y. Hayami and V. Ruttan (1971) should be consulted for their theory of induced innovation, suggesting economic forces induce technical change which explains variations in agricultural productivity (for a history of the theory and a critique, see Koppel and Oasa (1987)). Induced innovation theory stresses the distinctively public nature of much agricultural R&D. A decentralized network of research centers is funded by developed countries specifically to promote innovation in crop science and its adaptation to local conditions (Ruttan, 1989). The Lipton and Longhurst study (1989) discussed below originated as an impact assessment of the work of these centers.

xxxvi. Technologies of control and communication have been examined by Buchner (1988), who examines the diffusion of the television and telephone crossnationally with reference to their different possibilities for centralized control. Ogan (1988) examines the culturally specific uses of the videocassette recorder in Turkey. Straubhaar's study looks at of the development of television in Brazil in the context of the transition from military to civilian rule (1989).

xxxvii. Peter Heller treats most of the basic concepts of transfer while supplying 21 case studies focusing on its myriad effects (1985). The volume is excellent for teaching purposes. For a polemical and amusing introduction (anti-AT in orientation), Rybczynski's Paper Heroes has been reprinted (1991). See also Inkster (1989) for terminology and Long (1978) for a related concept of basic needs.

xxxviii. Ghosh (1984) is a good reference source on this subject. McRobie (1979), Ovitt (1989), Smil (1976), and Riskin (1978) offer a number of interesting examples of successful AT.

xxxix. The informative 1987 debate between Frances Stewart and Richard Eckaus.

xl. As one AT proponent said to the first author, when asked how he knew that a particular technology worked: "Well, someone may have that kind of information but we don't know. Our group just tries to disseminate it."

xli. Few go as far as Hamelink in arguing that lack of responsibility in technological choice should be criminalized (1988).

xlii. Gong Yuzhi, "Chinese History of Dialectics of Nature (Parts I-IV)." Studies in Dialectics of Nature (1991, Nos. 1-4) and Huang Shunji "Dialectics of Nature in New China." Studies in Dialectics of Nature (1991, No. 1). Xu Chao, trans.

xliii. Biggs and Clay, for example, examine the efficiency of formal and informal R&D in agriculture, focusing on biological and environmental characteristics that shape the process of innovation by means of case studies of farmers engaged in continuous process of innovation (1981). Paul Richards' work on Indigenous Agricultural Revolution (1985) provides an excellent introduction to this important line of work.

xliv. See the debate over the conceptualization of international science and technology between Schott (1993) and Shrum and Bankston (1993).