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INSTITUTIONAL DEVELOPMENT OF APPROPRIATE INDUSTRIAL TECHNOLOGY IN DEVELOPING COUNTRIES: R+D POLICIES AND PROGRAMMES

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INSTITUTIONAL DEVELOPMENT OF APPROPRIATE INDUSTRIAL TECHNOLOGY IN DEVELOPING COUNTRIES: R+D POLICIES AND PROGRAMMES

by

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The incremental improvement in a nation's technical capabilities which is possible through receiving transferred technology makes such activities extremely attractive. Yet, while there is no disputing the historical contributions to economic progress which have been experienced in a variety of nations as a result of the receipt of technology, such transfers are typically long, difficult, demanding processes which, if successful (and most are not completely successful), all too often result merely in the acquisition of just one thing--a particular hardware capability; not the ability to grow new technology; not the ability to significantly improve the existing technology; not even, often, the expectation of full utilization of the transferred item. In short, technology transfer is most often just that: the transfer of a particular technology and the associated know-how to operate and maintain that particular technology, nothing more.

There appears to be a growing awareness in the developing world that this is not enough. Over the past decade increasing attention has been given to discussions of "appropriate" technology, "codes-of-conduct" for the transfer of technology, and the need for developing indigenous scientific and technical capabilities in the developing world. The focus of attention in technology transfer has been consistently moving towards emphasizing the role of the recipient, rather than simply the attraction of donors.

Obviously, when one talks about improving the position of the recipient in technology transfer, or even more ambitiously, of eventually making the recipient of technology an independent producer and perhaps even donor of technology, one must necessarily consid r the capabilities and potential of the recipient. Here is where we come to speak of an institutional (or socio-technical) infrastructure, namely those public or private institutions which: provide financial resources for the development and for adoptation of technologies, which produce research and development results, which expedite the movement of technology within or across national boundaries and which directly or indirectly use the technology (1). In addition, the socio-technical infrastructure includes the value systems and educational and social institutions which shape national capabilities to invent, adapt, and accept technology.

Given the centrality of research and development to technological innovation, adaptation, and transfer, this particular element of the institutional infrastructure will be emphasized in this paper. Specifically, the focus of this paper is to discuss appropriate roles for industrial research and development in the developing world, within the broader context of an institutional infrastructure, as a means of facilitating the processes of technology acquisition and innovation.

THE CASE FOR INFRASTRUCTURE DEVELOPMENT

The overriding economic and political significance attached to technology transfer lies in the realities of the existing international economic order. The great majority of all technological invention and innovation presently occur in the industralized world. The contribution of this technological effort to improved productivity and product attractiveness is obvious and contributes to the widening gap between the developed and developing world. Technology transfer, in its many manifestations, represents the only means at present by which the developing world can realistically share in the developed world's technological progress. Yet, technology transfer too often is accompanied by perceptions of technological dependence, inappropriate utilization of local factors of production, and a supression of local industrial and inventive activities. It seems clear that if the developing world is to achieve an acceptable level of self-reliance then it must seek to emphasize participation in higher-order technology transfers where the recipient is prepared for some sort of responsibility for the future development of the technology* as well as preparing its resources for technological leadership in its own right.**

The accumulated literature concerning technology transfer is certainly replete with examples of the importance of infrastructure development to the transfer process. Among the limited body of empirical studies of technology transfer (2), considerable emphasis has been placed on determining the characteristics of national absorptive capacity for transferred technology. Solo (3) suggests that this absorptive capacity consists of "... the capacity to recognize the feasibility of attempting directly to transfer or adopt advanced technology, the capacity to adapt technology to the physical, social and economic context, and the capacity to adapt social and economic conditions to the requisites of technology...."

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*Ruttan and Hayami talk of "capacity" transfers where the "technology transfer occurs primarily through the transfer of scientific knowledge and capacity with the effect of creating the capacity for production of locally adapted technology," as opposed to "material" or "design" transfer where merely hardware or plans are transferred. See Ruttan, V. W. and Hayami, Y. "Technology Transfer and Agricultural Development," Technology and Culture, vol. 14, no. 2, Part I, 1973, pp. 119-151.

**Teitel has gone so far as to state that "...the key feature which distinguishes the LDC's from the DC's [is] their incapacity, in general, to create their own products and processes." S. Teitel, "Notes on the Transfer and Adaptation of Technology in Latin America, With Special Reference to Industrial Development in the 50's and the 60's," in Colleques Internationaux Du Centre National De La Recherche Scientifique, No. 538 - L'Acquisition Des Techniques Par Les Pays Non-Initiateurs, Paris: Editions Du Centre National De La Recherche Scientifique, 1973, p. 188.

Attempts at empirically modelling absorptive capacity, although crude, provide support for Solo's concepts. Studies of the pattern of Japan's (4) and the Federal Republic of Germany's (5) purchases of foreign technology, which provide some insights into national absorptive capacity, emphasize the importance of the technical sophistication presently existing in a society's industrial and educational institutions, the financial support available for technological acquisition and innovation, the quantity and quality of exposure to new, foreign technology, and the motivations for technical achievement acting on a society's managers and entrepreneurs (6). Less specific, but still indicative of these findings, is a recent study of nineteen chemical and petroleum technology transfers at the level of the firm, from developed to developing countries, which found that Gross National Product, appearing as a surrogate variable for national infrastructure development, approaches significance when explaining the relative importance of the recipient vis-a-vis the donor in a transfer of technology (7). In other words, the relative role of the recipient in these transfers appears to increase as a function of infrastructure development.

In a field of study as immature as that of technology transfer, the so-called "wisdom" literature and case studies are probably more important than are the fledgling empirical studies (8). Here too, historical and case-analysis attest to the importance of infrastructure to the technology transfer process. As illustrations of this: the ability of Germany to acquire technological innovations in the eighteenth and nineteenth centuries has been largely credited to: 1. a tradition of handicraft expertise, 2. government support for innovative and acquisitive endeavors, and 3. the establishment of technical education (9); technological growth and acquisition in post-Meihi Restoration Japan was greatly facilitated by governmental promotive policies and the placement of technical elites into both governmental and industrial policy-making positions (10), furthermore, the successful development and diffusion of high-yield variety crops during this period was dependent upon the existence of necessary technical-support capabilities such as extension-services and the relatively well-established water control facilities in Japanese paddy fields (11); the attainment by Britain of notable technological superiority over continental Europe, during the period 1750 to 1850, has been attributed to 1. a social environment receptive to technological change, 2. the existence of specific social needs requiring technological solutions, and 3. the availability of social resources for the development and application of appropriate innovations (12), and the speed of diffusion of this new technology to other countries appears to have been highly correlated with indicies of formal national educational attainment for the recipient nations (13).

As is often the case, the failures of technology transfer are often as instructive as the successes. This appears to be true regarding the importance of infrastructure development. The relative lack of prominence of technical subjects in Latin American educational systems and employment and promotion practices which do not reward technical achievement have been offered as examples of infrastructure deficiences which have frustrated an ability to increase data-processing sophistication in the Latin American nations (14). Problems with being unable to translate purchased technical documentation into practical production capability, resulted in an inability on the part of East European enterprises to fully take advantage of design and technical data purchased from Western firms in the past and, hence, also represent deficiencies attributable to the existing infrastructure (15). Similarly, there are several chronicled examples of an inability of the local technical infrastructure to support technology acquisitions in India, which have led to higher-than-anticipated costs in the achievement of the transfer experience. Among the problems were: an inadequate level of technical, managerial, and supplier sophistication (16), overly ambitious government technology policies (17), and lack of basic facilities such as pilot plants (18). One analysis of ten successful and ten unsuccessful technology transfers between nation-states surmised that transfers to developing countries are primarily donor-initiated and that "the cases of missed transfer opportunities could have been avoided had there been a stronger capability for organized transfer in the developing countries" (19). In sum, the identification of indigenous scientific and technical manpower and education, and technically-oriented government policies, in both the empirical and the historical studies, as being crucial to successful technology acquisition and innovation, attests not only to the general importance of local infrastructure, but also to the particularly important role played by scientifically - and technically - oriented personnel in determining a nation's technical absorptive and growth capacity. Since such personnel are typically associated with research and development activities and since the modern R&D group represents the focused assemblage of scientific and technical resources, it appears natural to consider the nature of "appropriate" R&D if one is to understand the future ability of the developing nations to advance technologically.

The Appropriateness of Industrial R&D to Institutional Infrastructure Development

When one looks at the industrial innovation process, R&D, although it amounts to something less than 10% of the total cost of innovation (20), lies at the very heart of the process. It is the well-spring of new ideas and the preparer of future capabilities to deal with new situations. Yet the questions must be posed, in terms of discussing infrastructure development: what should the role of industrial R&D be in developing countries; to what extent should developing countries aspire to establishing their own indigenous industrial R&D capabilities?

Given the official reports of a number of major international conferences (21), it seems clear that the nations of the developing world are intent upon establishing indigenous R&D activities of their own. While the intent seems clear, the manner in which this could and should be achieved are far from clear. And, of course, in many minds the wisdom of such efforts is certainly questioned. If, however, we take this determination to be a fact, then the issue becomes one of "what is the appropriate nature of indigenous R&D for a developing nation?" And this, in turn, requires an answer to the question of "for what reasons do developing nations need indigenous industrial R&D activities of their own?"*

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*In this regard, Nelson notes that "there certainly are apparent causal links that run from availability and activity of scientific and technical personnel to the pace and character of economic development. It is not clear, however, that the return to putting resources into augumenting scientific capabilities is highly relative to other forms of investment." R. R. Nelson, "Less Developed Countries - Technology Transfer and Adaptation: The Role of the Indigenous Science Community," Economic Development and Cultural Change, 1964, Vol. 23, pp. 61-77, p. 72.

It would appear from the volume and the tenor of recent discussions that, in the short-run, the developing world's primary need for indigenous R&D activities is to facilitate the development of so-called "appropriate" technology, either through the acquisition of foreign technology or through local innovative efforts. To the extent that one can't, or won't, depend upon the originator of a technology (most typically a multinational corporation) to adapt it for the peculiarities of a particular environment, then some indigenous capability, namely an R&D group of some sort, must exist to undertake that adaptation. In fact, even the decision process which must be followed in deciding whether-or-not to adapt a technology to a local situation requires technical familiarities and analytical competences normally found only within R&D groups. A telling observation in this regard is that Bar Zakay's data on missed transfers vividly points out that most missed transfers are the result of poor analytical capabilities on the part of the recipient (22). Similarly, Wallender's analysis of 67 case studies of firms in the developing countries, concludes "In-short, the[se] firms do not have a capability of understanding what they need, how to get it, or what to do with it once it is transferred" (23).

From a slightly longer time-frame, the potential of indigenous R&D capabilities to reduce the costs of technology acquisition, and perhaps even influence technology design while in the research stage, provides a reason for the establishment of indigenous R&D capabilities. If one accepts the definition that the cost of a technology transfer is the cost incurred by the originator and recipient of a technology to establish whatever organizational structures and procedures are necessary to communicate the technology (24), as well as the costs incurred by the recipient to screen and direct potential technology inflows*, then the reduction of transfer costs as well as the influence of design can best be accomplished if effective communication can be established between the user and the producer of the technology**. Such effective communication relies upon the establishment of similar enough sub-cultures within particular units of the donor and recipient so as to facilitate effective interaction***. In terms of industrial technology transfer, the relevant units requiring sub-culture similarity are the R&D and operating units, and this can be achieved only by the recipient's gaining a degree of

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*One has only to consider the efforts established by Mexico Argentina, Brazil, and the Andean Group countries to appreciate the costs involved in such technology assessment activities. See Robert E. Driscoll and Harvey W. Wallender, III (eds.), Technology Transfer and Development: An Historical and Geographic Perspective, (New York: Fund for Multinational Management Education and the Council of the Americas, 1974) especially pp. 139-258.

**This assumes, of course, that there is a strong enough economic motivation to interest the originator of the technology in becoming responsive to the needs of the recipient. In other words, good communication is a necessary, but not sufficient, requirement for transfer cost reduction and/or the transmission of influence in a product's or processes' research phase.

***Powelson makes the point that "strictly speaking, there is no such thing as "cross-cultural" communication. Any communication at all depends on the sharing of some subcultures." John P. Powelson, Institutions of Economic Growth, (Princeton, N.J.: Princeton University Press, (1972), p. 122-123. Lowell Steele puts this into the specific relationships of R&D when he notes that "... the transfer of technology from one country to another country must, if at all possible, occur at the same level of science and engineering. Science developed in one country must be diffused to scientists in another country, and then the process of diffusion down through the technical chain into applied research, development, and engineering can occur in the second country. If an attempt is made to transfer scientific results in one country to applied technologists in another country, the barriers of language and culture added to the differences in technical point of view and terminology make the process virtually impossible," Lowell W. Steele, Innovation in Big Business, (New York: American Elsevier, 1975), pp. 215-216.

technical sophistication sufficient to make two-way communication practical and desirable.

In the long-run, the ability of a nation to become a fully-functioning member of an interdependent international economic system requires indigenous scientific and technical capabilities. No nation can hope to grow by merely "following-up" (25) someone else's inventions. If for no other reason than to preserve the alternative of doing without someone else's technology, without experiencing severe disturbances, a nation must encourage some indigenous R&D.

Just as there are different rationales for the establishment of indigenous R&D capabilities in the developing nations, depending upon the time period discussed, so there are also different factors to be considered in suggesting "appropriate" roles for R&D as a function of planning horizons. In the long run, the development of indigenous industrial R&D capabilities is much more a function of investment in, and philosophy of, formal education systems, than would be true in the short run. Because of the immediacy of the technological needs of the developing world, however, the ensuing discussion will emphasize the short-run situation, with a planning horizon of at least several generations of higher-education, or somewhere from 5 to 20 years.

The short-run situation in the developing nations, relevant to indigenous industrial R&D, is quite clearly going to be heavily influenced by the behavior of multinational corporations. At present, the developing world has an extremely low level of qualified scientists and engineers available for employment in industrial R&D activities (26). To the extent that the developing countries have established industrial R&D activities, the measured results have not been encouraging. Teece (27), in an empirical study of nineteen chemical and petroleum technology transfers, found little support for cost reduction in these transfers attributable to the existence of indigenous R&D capabilities, and Thomas (28) failed to find "learning" benefits in Nigerian industries which might reflect government funding of industrial R&D. In both cases the argument might be made that the amount of R&D funding was too small to achieve a measurable impact. However, such an argument simply underscores the matter of just how large does an investment in industrial R&D have to be if it is to contribute to national goals and can the developing nations afford such committments?

In contrast to the developing nations, the multinational corporation posesses relatively abundant amounts of scientific and technical expertise. Typically, however, these resources are the products of highly-industralized societies and are physically located at corporate headquarters. The presence of a multinational corporation in a developing country does not necessarily mean that the corporation's scientific and technical talent will be addressing projects pertinent to the developing country. Obviously then, the extent to which such talents are or are not serving the needs of a developing society is of utmost importance to the nature of the "appropriateness" of any indigenous industrial R&D undertaken by that society. It is clear that one cannot discuss local R&D in the developing world without at least considering the probable behavior of multinational corporations in providing R&D services to those same nations.

The Role of Multinational Corporations in R&D Efforts for the Developing World

The dominance of the multinational corporation as a provider of goods and services and as a creator and transmittor of technology is a reality of modern life. Accordingly, the behavior of multinational corporations in applying their R&D resources to the needs of the developing world becomes an important consideration in discussing what the appropriate role of indigenous industrial R&D capabilities should be in the developing world. The issues of whether or not multinational corporations are actively pursuing "appropriate" technologies for developing markets, or whether or not multinational corporations are locating R&D units in developing nations, have important implications for the form which indigenous R&D efforts should take. Similarly, if the multinationals exhibit certain types of behaviors towards certain host government technology-related policies or if there are common historical patterns involved in the evolution of multinational overseas R&D location development, then such information becomes important to policy-makers in developing countries. The purpose of this section of the paper is to address such questions by presenting some preliminary findings from a study of 34 multinational corporations, with headquarters of major R&D decision-making bodies located in the U.S., conducted during the summer of 1978*.

Total overseas R&D expenditures by U.S. multinational corporations amounted to more than $1 billion annually in 1971 and 1972, which represented

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*The interviews reported on were conducted as part of a study of "Overseas R&D Activities of Transnational Companies," funded by the U.S. National Science Foundation. Dr. Jack N. Behrman was Principal Investigator. The author wishes to acknowledge his appreciation to Dr. Behrman and the Fund for Multinational Management Education for their support. All views expressed are solely those of the author.

approximately 10% of domestic R&D expenditures of all corporate-funded R&D in the U.S. The large majority of this R&D effort is in applied research and development and nearly two-thirds of U.S. overseas R&D is located in three countries - Canada, the United Kingdom, and the Federal Republic of Germany. Only about 3.3% of U.S. overseas R&D spending in 1973 was committed to developing countries (29). A review of our sample of 34 firms, in general, corrobarates the statistics cited above but provides some insights into the nature of the U.S. multinationals' overseas R&D activities, as well.

The firms interviewed in our study were selected on the basis of having a relatively prominent international sales committment among the membership of the U.S. Industrial Research Institute. This selection procedure, although not pretending to be random, served to ensure a reasonable coverage of large U.S. R&D performers as well as U.S. firms with overseas R&D efforts. Using the OECD "Science-Base of Industries Continuum" (30)* the sample appears as follows:

Table I

Science-base Profile of Sample of Thirty-Four Multinational Corporations Interviewed

Science-based	Mixed-industries	Average	Non-Science Based
16	7	7	4

Of the thirty-four firms in our sample, at least fifteen had some scientific and technical activity located in a developing country.

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*The OFCD Science-Base of Industries Continuum is based upon the relative-degree of an industry's research intensiveness, in the U.S., in 1962. To qualify as science-based, an industry must have had R&D expenditures amounting to 2% or more of sales, or scientists and engineers amounting to 1% or more of total employment. For a discussion of this scheme see: J.E.S. Parker, The Economics of Innovation, (London,: Longman, 1974), pp. 146-149.

For the most part, those R&D activities of these firms, which are located in developing countries, are typically small, of a technical support nature, and located in one of the more advanced developing countries such as Brazil, Mexico, or India. The primary motivation for locating these activities in a developing country is market-related: technical support for marketing sophisticated products and/or the need for "on-site" resources in order to adapt products for particular markets. The role of joint-ventures and corporate acquisitons as determinants of overseas multinational corporate R&D presence, while seemingly quite important in the industralized countries, appears to be considerably less important for developing countries. This reflects the lower level of scientific sophistication among firms from the developing nations. Multinational corporations find few attractive opportunities for bi-lateral technical partnership in a joint-venture with a firm from a developing country. Similarly, there is little probability of a multinational corporation acquiring and expanding existing indigenous R&D resources as part of the acquisition of a firm from a developing country. The import of all of this is that, in general, there appear to be two probable major growth paths for the establishment of multinational corporate R&D activities in developing countries: through a relatively long evolutionary process from technical support to marketing and manufacturing, to modification of inputs for the production process, to rather limited local product development activities, or alternatively, a discrete major increase in R&D activities as the result of a specific decision to establish a local R&D group.

The probability of one or the other of these growth paths leading to the establishment of R&D activities in a developing country, by a multinational corporation, is a function of a variety of factors, the most important of which appear to be: whether or not a competitive advantage is to be gained by a particular strategy, the nature of the industry involved, the attractiveness of the market in terms of volume and stability, and the nature of the local scientific and technical infrastructure.

While the evolutionary increase in technical activities eventually leading to some form of R&D appears to be a familiar growth path for overseas multinational corporate R&D groups, in general, it does involve a considerable period of time and lacks much of the promise which is attached to the establishment of specially designated R&D units. However, multinational corporations will only initiate overseas R&D activities when they perceive it to be to their competitive advantage to do so. Corporations do R&D in order to gain competitive advantages, not for the sake of doing R&D. The performance of R&D is an integral part of the innovation process, the ultimate objective of which is new products and/or processes. To separate out R&D and speak of it as a disconnected element is not realistic. Corporations do not simply sit-back and decide if they should place an R&D unit here or there, rather they make decisions as to whether or not an R&D investment is necessary to support a particular product or market. In markets where science-based industries are selling to customers with low technical sophistication, as is the case with most of the firms in our sample who have R&D activities in developing countries (and especially the science-based firms), there is little need for very much on-the-spot sophisticated R&D; they are not dealing in state-of-the-art requirements. Similarly, to the extent that product or process adaptation, and intermediate or appropriate technologies, need more engineering than R&D, there is little reason for a committment of R&D resources to the local operation. Furthermore, such activities would tend to be so situation-specific so as to be unattractive as the basis for establishing a specially-designated R&D unit in any one developing country.

In terms of undertaking R&D in developing countries there appears to be an important distinction between those industries whose products are marketed on the basis of the subjective tastes of the consumer (typically non-science based industries) and those industries whose products are marketed on the basis of internationally recognized technical performance, quality, or standards (typically science-based industries). Since the subjective tastes to which the non-science based industries tend to market their products are often extremely localized, these industries have more inducement to perform whatever R&D they do near the ultimate market. In addition, the firms in these industries tend to be structured on a polycentric basis (1), with a high degree of autonomy enjoyed by their foreign subsidiaries. In most such cases, it is the local management of the foreign subsidiary who is responsible for making the decision to inititate an R&D program of some sort. Although such decisions are subject to review and reversal at higher managerial levels within the multinational corporation, the indications from our interviews are that local management does, infact, play an extremely important role.

A second important characteristic resulting from differences between the science-based and non-science-based industries is the general tendency of the former to pursue worldwide product standardization. Our interviews strongly indicated that firms pursuing worldwide product standardization could not be counted-on to also be actively involved in the development of "appropriate" technology, nor are they likely to undertake more than a limited amount of R&D at locations other than established central laboratories.

These perceived differences between science-and non-science - based industries suggest that the best prospects for the establishment of designated R&D units in the developing countries, by multinational corporations, lie with those industries where products are marketed to subjective consumer tastes by relatively autonomous local subsidiaries. In the case of science-based industries, it is far more likely that R&D activities in developing countries will grow, and be limited, by an evolutionary process. Such a conclusion immediately raises some issues for future discussion. One issue which must be faced is how important are the consumer-oriented industries to the plans of the developing countries for the establishment of a scientific and technical infrastructure? While consumer-oriented R&D would provide local exposure to the methods and practice of a modern R&D unit, it would also compete with other activities for scarce trained manpower and capital.

A second issue, which is raised as a result of the relative autonomy of the local subsidiaries of multinational corporations in consumer-oriented industries, concerns their tendency to establish R&D activities as a function of market size. Larger markets, while more likely to percipitate the establishment of indigenous R&D activities, are also more likely to increase the attractiveness of employing capital-intensive production processes to serve the larger-volume market. Thus, policies which might be considered by developing country governments to attract R&D establishment by multinational corporations could conceivably be counter-productive to the encouragement of the use of "appropriate" process and distribution technology by these same firms. The extent to which a possible tradeoff exists between the performance of local R&D and the adoption of "appropriate" technology is worth considering in the policy-determination process.

The relative attractiveness of a particular market as a factor in the R&D location decision is closely associated with the nature of local scientific and technical infrastructure development. In a conundrum-like dilemma, developing nations hope to attract R&D operations in order to facilitate infrastructure development, yet without a developed infrastructure they are unattractive candidates for corporate R&D units. One of the major reasons given by the respondents in our sample for not locating R&D operations in developing countries was the absence of a developed scientific and technical infrastructure. This observation included: lack of available qualified scientists and engineers, inadequate supporting industries, and lack of a market-place wealthy enough and sophisticated enough to demand products with high R&D content. The need for economic and political stability was also frequently mentioned. However, such matters are only of secondary importance to the major issues of whether or not R&D is necessary and, in the event that it is, are there any overriding advantages to doing it outside of the established corporate labs.

The type of R&D likely to be performed by multinational corporations in developing countries, and even the feasibility of performing that R&D, is dependent upon the availability of scientific and technical resources such R&D activities require. The observation was made, in our interviews, that product R&D, in general, requires a substantially larger and more diversified group of personnel than does process R&D, and so, if that were the only consideration, process R&D would be more suitable to the relatively limited R&D personnel resources of the developing world.

Standardization of production processes, however, appears to be a fairly common objective among most of the firms interviewed, irrespective of science-orientation. To the extent that significant adaptations to process machinery or design are made, they are typically a function of production volume (i.e., market size) rather than host-country factor endowments. Furthermore, the R&D activities which these corporations presently have in the developing countries are more related to market considerations and particularly to unique market conditions, such as: tropical diseases and environmental conditions, particular raw materials, and unique product offerings, than to process improvement, which is much more "engineering" intensive and which is often undertaken by equipment vendors, rather than the manufacturing company, anyway. Thus, given that most multinational corporate R&D activities in developing countries appear to be product- rather than process-oreinted, the availability of adequately trained scientific and technical personnel becomes that much more important.

Within the R&D community, the concept of a critical-mass for an R&D group is one that enjoys a substantial following. Briefly put, the critical-mass concept suggests that there is some threshold size for an R&D group which facilitates the achievement of a level of output sufficient to justify the group's continued existence. The critical-mass for an R&D group is a function of the scope of the group's mission and the nature of the science and technology involved, and, by and large, is that size necessary: to ensure rich communications both within the group and between the group and its environment, to allow the degree of scientific and technical differentiation among the group's personnel necessary for fulfillment of its mission, and to acquire whatever instrumentation and organizational slack necessary for acceptable performance.

The concept of a critical mass being necessary for R&D productivity, and a recognition of the economies of scale which affect the performance of R&D, appear to be principal reasons why multinational corporations are not more active in locating R&D units overseas. Since R&D is essentially an information-creating and sharing activity (32), it is essential that it be done in groups. Furthermore, heterogeneity in terms of projects and people is particularly important for product-oriented R&D productivity (33). Thus, to be successful, an R&D unit needs groups of groups. In addition, the modern instrumentation and facilities necessary for product-oriented R&D are expensive to the point where with a small group of researchers the fixed costs of establishing a facility will overwhelm any reduced variable costs of professional salaries in the developing world. Thus, the feasibility and nature of R&D activities by multinational corporations in developing countries is certainly affected by an industry's critical-mass for R&D and the ability of a local scientific and technical infrastructure to meet those needs.

Table II presents some estimates of critical-mass for particular R&D groups. In all cases it should be remembered that these estimates were made on the basis of experience with organizations possessing significant support capabilities; something which cannot be taken for granted in the developing world. It is apparent, however, from Table II, that there is considerable variation in the estimates of R&D managers concerning critical mass. It is also apparent from Table II that the critical mass of technical people believed necessary for a productive R&D group in industries serving consumer markets is considerably less than that needed for industries with a higher degree of scientific orientation. What the numbers within the table do not show, but what was made clear in our

TABLE II

Estimates of Critical Mass for R&D

Industry	Critical Mass Estimate	Remarks
Pharmaceuticals	100-200	To obtain specially differentiation.
Pharmaceuticals	60 - 80 technical people	8-9 Ph.D's in any one area
Pharmaceuticals	50 technical people	Better off with 100-400
Chemicals	25-30 technical people	Number needed to afford instrumentation and to ensure interaction
Paints and Chemicals	25-30 technical people	Necessary for interaction
Paints and Chemicals	2-5 technical people	Short-range technical projects only
Transportation Components	200-300 technical people	This type of applied R&D needs familiarity with a lot of different technical areas
Automotive Components	20 technical people 150 technical people	Applications R&D Fundamental R&D
Machinery	6 technical people	
Tobacco	5-6 technical people	Sufficient, not broad, research capability
Food	1 technical person	Plus some sub-contracting

interviews, was not only do the consumer-oriented R&D groups require less personnel, they also require less sophisticated personnel and less variety in personnel specialization.

In sum, our discussions with R&D decision-makers in a number of multinational corporations indicates that the greater the scientific orientation of a firm, the less likely it is to be a source of appropriate technology. Furthermore, multinational corporations, in general, are not likely, in the foreseeable future, to be a major source of R&D performance in the developing world. On the other hand, the interviews did indicate that the multinational corporations already have some limited R&D involvement in the developing countries and that at least in industires where products are marketed on the basis of subjective consumer tastes there is a reasonable likelihood of eventual establishment of R&D facilities in support of local markets,providing the markets represent attractive business opportunities. In science-based industries, although direct placement of R&D is less probable, direct foreign investment by multinational corporations is likely to be accompanied by the establishment of technical support groups for manufacturing which can be expected to eventually evolve into R&D units of a limited scope.

Some Observations on The Appropriate Role of Industrial R&D in Infrastructure Development

On the basis of the foregoing discussion it seems reasonable to conclude that the developing countries will, and should, continue to work for the establishment of indigenous R&D capabilities. These capabilities should not be envisioned as an attempt to challenge the multinational corporations on every front, that is simply unrealistic. Rather, indigenous industrial R&D capabilities should be closely tied to existing resource and market strengths. It would appear from the interviews with R&D executives in multinational corporations that, by and large, if "appropriate" technologies are to be developed for developing countries, local R&D resources will have to do it. Accordingly, this section of the paper offers some observations on the "appropriate" nature of industrial R&D in the developing countries. This will include brief discussions on the nature and location of indigenous R&D resources, linkages between R&D and other institutions within the socio-technical infrastructure, government policies to influence R&D location decisions by multinational corporations, and matters of human resource development.

Agglomerating Resources: Regional R&D Centers

The interviews with R&D managers of multinational corporations clearly indicated the importance of market-size as an inducement for the establishment of R&D activities. Market size is also an important factor when considering the desirability of developing indigenous R&D capabilities, for the same reasons as expressed by the multinational corporations: a market has to be sufficiently large, wealthy, and sophisticated, if the performance of R&D is to be worthwhile. While most developing nations lack sufficient market volume to attract R&D, markets can be increased in size by agglomeration via a regional association of some form, supporting centralized R&D activities serving the regional membership.

The idea of regional technical cooperation has, in fact, generated some support. According to Germidis (34) "... owing to the small size of the developing countries' own enterprises and the relative, and sometimes even absolute, poverty of these countries, the only way to develop R&D is through regional cooperation. By pooling a region's financial, technical and human resources its member countries could attain objectives which they could not hope to attain by going it alone. Moreover, the resulting coordination of effort would make their R&D work less fragmentary and avoid overlapping, so helping to rationalize the use of resources available." The Advisory Committee on the Application of Science and Technology to Development (ACAST) to the Economic and Social Council of the United Nations has similarly stated that "An important goal for developing countries is the achievement of a substantial degree of scientific and technical independence, based on adequate and vigorous national institutions. Until that stage can be reached in some countries, regional institutes must be relied upon ...." (35).

While there is good reason to believe that the developing countries will be attracted to the idea of an agglomeration of scientific and technical resources in a regional R&D center*, there are several drawbacks to such schemes. Perhaps the most important of these drawbacks is

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*From a behavioral conceptualization of international responses to technology, Nau concludes that actors with a relative lack of scientific and technical expertise will opt for collective action in the face of technological challenge. "An institutional response allows some intermediate action." Henry C. Nau, "Collective Responses to R&D Problems in Western Europe: 1955-1958 and 1968-1973," International Organization (1975), vol. 29, pp. 617-653. Hirschman has similarly noted a preference for institutional responses in developing countries when the desire to affect change is high and capabilities are low. Albert O. Hirschman, Journeys Toward Progress: Studies of Economic Policy-Making in Latin America (New York: The Twentieth Century Fund, 1963) Chapter 7.

the distance typically experienced between centralized R&D facilities and the consumers of the R&D product. In R&D, proximity, both in terms of geography and mission, is essential to success. National R&D institutes are often too distant, in both respects, from the consumers of their products to be useful (36).* The likelihood that a regional center would be located in a different country, possibly of a different culture, exacerbates this problem.

A further drawback to the regional R&D center concept concerns the equity of the distribution of benefits resulting from such activities, to the partner states. Unless the member states participating in a regional R&D scheme have similar scientific and technical factor endowments, levels of national technical and industrial achievement, and reasonably similar yet mutually compatible economic objectives, any pooling of R&D resources is bound to be unsatisfactory to some of the parties. At the very least, the very placement of the center is bound to provide one member with an incremental benefit over the others. Regional R&D centers, after all, are susceptible to the same problems as is any integration scheme, particularly since "... in every region some

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*Particularly apropos of this is the observation that: "There is little incentive for most research institutes in developing countries to actively seek contract research support, as the institute income usually reverts to the government treasury and is not under the control and management of the institute director. The institutes thus tend to engage in programs with little relevance to industrial needs or to the national plan. The research institute staff has limited or infrequent interaction with industry or government enterprises." James P. Blackledge, "The Role of the Research Institute in Industrial Growth," Appropriate Technologies for International Development, September 1972, NTIS Accession No. N71-20921, as quoted in Nancy Beach, Survey of Selected Studies and Research on Technology Transfer to Developing Countries, Program of Research on the Management of Research and Development, Northwestern University, 74/61 (Rev. 7-74), June 1973, p. 26.

countries are more advanced than others and benefit more from integration, at the expense of the others. So [any such] agreement is [inherently] unstable." (37).

Nor are regional R&D centers cheap. Although less costly, in a global sense, than having redundant R&D efforts in a number of member states, regional R&D centers do require a committment of scarce trained manpower. To the extent that such skills are invested in efforts not fully in support of national objectives, the opportunity costs associated with membership in such a regional R&D scheme can be quite high.

Institutionalizing Linkages Between R&D and the Users of R&D.

The discussion of regional R&D centers emphasized the need for strong linkages between the doers and users of R&D. This has not typically been the case in the developing countries where the tendancy at both R&D institutes and universities has been to pursue fundamental R&D, not immediately compatable with national needs (38). The Sabato triangle (39) illustrates the need to link governmental decision-makers, the industrial sector, and scientific and technical activities together so that technology contributes directly to development: "Factories must have access to, and influence on, laboratory or univeristy researchers. Conversely, governmental planners must be able to influence which technologies manufacturers will use. Unless circulatory flows link all elements of the triangle, there can be no sound incorporation of technology and science to national development" (40).

In numerous studies of scientific and technical communications the idea of a gatekeeper who can access communication networks external to his/her organization and transmit the information so obtained to their own organization in a usable form has gained considerable acceptance (41). Allen has suggested that gatekeeping institutions can exist to fulfill this role in a national context (42). Apparently, the key to such an organization's effectiveness lies in its possession of adequate resources and the credibility necessary to interact in a meaningful fashion between donors and recipients of the technological information (43). The establishment of such organizations, while possibly sharing some of the disadvantages attributed to regional R&D centers of being too far from its clients, might yet serve to satisfy calls for organizations "... whose function would be to identify sources of appropriate technical know-how and match supply and demand for immediate absorption and adaption...." (44)* In short, to act as institutional linkages between the relevant parties in the national scientific and technical infrastructure.

Government Policies Influencing R&D Location by Multinational Corporations

There are obviously a multitude of ways by which national governments can attempt to influence the activities of R&D groups in their country. As both the historical and empirical studies of technology transfer have shown, and as the concept of the Sabato triangle vividly illustrates, a well-developed, active, government role in scientific and technical matters is extremely important to technology acquisition and innovation. The Indian experience with import substitution, for example, did result in the formation of R&D activities as firms coped with adapting inputs to their production processes. This activity was not, however, related

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*Nayudamma calls for "liason-networks" in this regard which should be familiar with both industry and research and be able to "sell" research performed in national research institutes to industry. Y. Nayudamma, "Promoting the Industrial Application of Research in an Underdeveloped Country" Minerva (1967), vol. 5, pp. 323-339.

to the export performance of these firms (45). Direct government funding of industrial R&D has proven to be stimulating in some industries and nations and not in others (46). In the short-term future, perhaps what is most important to the policy-makers of the developing world are those policies which serve to define the relationship between the nation-state and multinational corporate performers of R&D.

The results of the interviews conducted among the multinational corporations indicate quite clearly that the only policies which will attract overseas R&D investments are those policies which make for a stable, hospitable, investment climate and which provide assurances of a community of interests among all parties involved. Tax subsidies were by far the most attractive of policies mentioned and nearly every company interviewed had seriously considered a Canadian R&D location because of the R&D tax subsidy program in effect there. However, the relative unimportance of such benefits, compared to the overwhelmingly important considerations of competitive advantage, market size, and the economies of continuing to perform R&D in existing corporate laboratories, is evident in the fact that very few corporations had actually taken advantage of the very generous Canadian inducement.

Among the policies which seek to place constraints on multinational corporations in an effort to induce R&D investment, the general consensus among the R&D managers interviewed is that they absolutely discourage the attraction of new firms and most often simply represent additional burdens to be avoided by firms already in the market. As an example of the latter, the most frequently mentioned corporate response to import-substitution and local-content requirement policies is the temporary visitation of several headquarters-based technical people who come in to make the necessary adjustments and then depart, leaving very little tangible scientific or technical residue from their visit. The local infrastructure is generally regarded as not sophisticated enough to undertake the adaptation and no thought is given to permanently increasing the local R&D staff because once the adaptation is accomplished there is no further need for these services. Hence, import-substitution and local-content requirements too often result in a one-shot technical fix administered by outside resources with the only durable result being a product less desirable from the corporation's perspective than that originally produced, and the attainment by the host-country of an image of being a difficult place to work, thus, possibly deterring establishment of local commercial activities by other potential foreign investors.

A further undesirable result of import-substitution is in the creation of local monopolies for producers protected by the trade barriers. In the course of our interviews, at least two examples were found of firms with foreign subsidiaries who under normal conditions would have been performing R&D in the local market but who, enjoying local monopoly positions as a result of import substitution, were doing no R&D instead.*

The disproportionately large role played by the industrialized nations in the world patent system has led to some suggestions that the developing nations might consider dropping out of this system as a means of aiding in the development of their own scientific and technical infrastructures (47). While such suggestions do present the illusion of an apparently easy way to gain scientific and technical advantages as well as a means of putting an end to non-working of patents, our interviews did find that the

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*Teitel also cites the high profit monopolistic markets in Latin America as restricting innovation. See Teitel, op.cit.

protection of intellectual property is still reasonably important for R&D location*. It was clear from the interviews, for example, that Italy's pharmaceutical patent policy did discourage R&D location in that country. Furthermore, the impression was given that patent policy was a signal of government-corporate relations which was considered in assessing the attractiveness of a particular location. From a longer-run perspective, it would appear that if a developing nation aspires to create its own indigenous R&D efforts, then protection of the intellectual - property generated by those R&D activities constitutes a reason for maintaining a patent system.

Human Resource Development

The interviews with managers of R&D in multinational corporations noted that the unavailability of adequately qualified scientists and engineers was an important deterrant to establishing R&D activities in the developing countries. Similarly, a survey of industrial research organizations in developing countries (48) reported that "industrial training of technical personnel" was the number one priority need of these organizations, and visitations to approximately fifty research centers in thirteen developing countries identified a "shortage of modern research institute management skills" to be a major problem (49).

In the short-run, multinational corporations represent one source of technically up-grading the local work force. While Peno (50) has reported disappointing experiences with multinational corporations in

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*According to at least one study, however, patent availability is not a critical determinant of direct foreign investment, in general. See P. O'Brien, "Developing Countries and the Patent System: An Economic Appraisal," World Development, Vol. 2 September, (1974), 27-36.

high-level manpower employment of host-country nationals, our interviews found almost 100% employment of host-country nationals in overseas R&D groups and host-country nationals in most of the overseas R&D directors ships. A lack of formal training ("know-how") programs, which was observed among the firms in our sample performing R&D in developing countries is probably explained by the relatively high educational levels among R&D personnel, the limited missions of R&D groups in developing countries, and the burden of responsibility placed on autonomous foreign subsidiaries in consumer-oriented industries. There was, however, considerable evidence of on-site "do-how" training, to upgrade a variety of technical skills, conducted by brief visitations of headquarters personnel.

Once scientific and technical skills are obtained by virtue of employment-related opportunities, employee turnover amongst the workforce of a multinational corporation can be a potentially significant method of diffusing these sophisticated technical skills in a developing country. Behrman and Wallender (51), for example, found evidence of substantial workforce turnover in their case studies. Our interviews, however, found turnover to be a relatively insignificant factor among professional R&D employees working for multinational corporations in developing countries. In addition, to the extent that such turnover does occur, it appears that R&D workers tend to move between highly sophisticated firms (meaning mostly other multinationals) within the same industry, rather than diffusing their skills to the broader economy.

The importance of the formal education process in long-run infrastructure development is obvious from the historical cases cited at the beginning of the paper. Education will certainly not yield results quickly, but it is essential for the longer term. In the short term, however, educational programs must be focused on contributing necessary technical skills to national needs. In reviewing Korea's experience with providing foreign education for its nationals, the Minister of Science and Technology has observed "... we were able to locate many Korean scientists working abroad, who had extensive academic training, but not many in fields which the country could find immediately useful (52)." In an effort to remedy the slowness of education and to focus educational efforts on immediate needs Korea has moved to mold educational institutions as "centers of relevance" rather than "centers of excellence."

Care must also be given to the growth and maintenance of a skilled corps of technicians who may very well serve as the backbone for technical development. Rawski's (53) review of technological growth in the People's Republic of China has vividly shown that the productive success of the Shanghai and Tientsin regions was a result of their experienced workforce in small engineering firms with prewar heritages who "...act(ed) as technological intermediaries between the mass of Chinese producers, whose mission is to attain "advanced national levels" of quality, cost, and technique, and the outside world, whose standards become the target of Shanghai's technological aspirations." As the technological level of a nation grows, it is easy for such sub-professionals to lose prestige. In order to prevent this, approaches such as Korea's military-service exemption for skilled technicians and status-enhancing qualification examinations (54) are worthy of consideration. Many of our interviews revealed that the lack of technicians and maintenance people, in developing countries, was as inhibiting of further growth in R&D activities as was the availability of scientists and engineers.

Infrastructure Development in General

The various facets of infrastructure development discussed here present many alternative paths to accomplish this goal. Perhaps most important, any of the paths to infrastructure development chosen should be part of, and in consonance with, a coherent national science and technology policy (55). The path chosen should be a "local" path. As Powelson (56) has put it "transplanted institutions tend to be ineffective because their functions, caught between two cultures, are not clear." The alternatives discussed in this paper should be taken as general suggestions of infrastructure development, not precise prescriptions.

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