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Working Paper

Science, Technology and Development: A Retrospective View

Center Discussion Paper, No. 268

Provided in Cooperation with:

Yale University, Economic Growth Center (EGC)

Suggested Citation: Ranis, Gustav (1977) : Science, Technology and Development: A Retrospective View, Center Discussion Paper, No. 268, Yale University, Economic Growth Center, New Haven, CT

This Version is available at:

<https://hdl.handle.net/10419/160195>

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CENTER DISCUSSION PAPER NO. 268

SCIENCE, TECHNOLOGY AND DEVELOPMENT: A RETROSPECTIVE VIEW

Gustav Ranis

October 1977

Note: Center Discussion Papers are preliminary materials circulated to stimulate discussion and critical comment. References in publications to Discussion Papers should be cleared with the author to protect the tentative character of these papers.

Science, Technology and Development: A Retrospective View**

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I. Introduction

The difficult task we have set for ourselves in this paper is to attempt to illuminate the relationship among science, technology and development, using the experience of seven countries of widely different characteristics and operating at different stages of development as building blocks.¹ The issues to be addressed are inherently complicated. Relevant theory is, by general consensus, still in its infancy and modest step-by-step empirical approaches consequently cannot help us very much. This is also an area of major discontinuities in behavior, always more difficult for scientists to handle, and one in which the temptation to perceive all dimensions of human progress as relevant is both natural and bound to lead us in too many directions at once.

Nevertheless, the effort should be made--not only to attempt to improve our basic understanding of how we got here, and why, but also because the distillation of such an improved understanding may hold some lessons for the future, especially with respect to the achievement of modern growth on the part of contemporary developing countries.

*The author wishes to acknowledge the assistance of H.T.C. Hu and the comments of Bill Beranek.

¹While in this sense this paper attempts, inter alia, to "synthesize" the work of others, they are not to be held responsible for the interpretations made, conclusions drawn, and errors committed here.

**This is a revised version of a paper presented at the National Academy of Sciences Bicentennial Symposium on "Science: A Resource for Humankind," September, 1976.

The problems and aspirations of that two-thirds of humanity which does not yet enjoy modern growth, but is anxious to achieve it--while deeply puzzled as to the proper role of science and technology--represent our main concern.

The very nature of this effort, necessarily eclectic and tour d'horizon in character, means that we should not expect to find a new, definitive set of answers to these old and perplexing problems. It also means that the temptation to force observations into consistency with some premature unifying theme or preconceived theoretical mold must be resisted. All we can and have tried to do is, by selectively organizing the information and insights gathered by all the participants, to improve somewhat our understanding of these complicated inter-relationships and point the direction which further, more original and basic, analysis might well take. If, in spite of ourselves, we seem at times to have reached out in search of some broader explanatory framework, it is with the understanding that the improvement, or even the reasoned rejection of such a framework, by others, will serve to advance the common cause.

The approach of this paper is frankly historical, focussing mainly on the 18th and 19th century experience of the now advanced and the more recent experience of the currently developing countries. This is because we believe that history indeed represents the most important and as yet most underutilized laboratory for the exploration of these issues.

We recognize, moreover, at this most general level, that while

all societies, historical and contemporary, share the tyranny of their initial endowments, they face substantial alternatives with respect to their objectives and the way in which they decide to organize themselves. To keep the scope of this paper from becoming entirely unmanageable, we shall not concern ourselves very much with a comparative evaluation of organizational systems. We shall assume, especially when dealing with contemporary developing countries, that they are of the mixed, non-socialist variety. Moreover, and not unrelated, we shall not be concerned with possible inter-country differences in social objectives. Instead, we shall assume that all societies may be located on some more or less continuous spectrum of institutional choice and that the "old-fashioned" development objective, sustained increases in per capita income, either is shared by all, or, and more satisfactory, is not in necessary conflict with such other valid non-traditional concerns as distribution and employment.

In order to avoid a veritable parade of definitions, we shall equate "social and economic development" with per capita income growth; by "science" we shall mean the accumulation of basic systematic knowledge about the natural universe around us; and by "technology", the application of such knowledge to the construction of a pool of ideas useful in the production of goods and services. Neither with respect to science or technology will we entertain the plausible notion that such activities may represent some sort of valid type of art form carrying its own cultural, esthetic or consumption values. While we recognize that the relationships among "science," "technology" and "development" as defined

here may be indirect, lagged, multidimensional, uncertain and, above all, complicated, it is these relationships we shall be mainly concerned with.

Our country sample includes Great Britain, the acknowledged historical leader in the transition to modern growth; Germany and the United States, two early followers; Japan and Hungary, two relatively late followers; and, finally, Brazil and Ghana, two contemporary developing economies.

We will first (Section II) try to define more precisely the issues on which this set of papers is attempting to shed some light. We will then review the relevant evidence from the historical experience of the now mature early developers (Section III), of the late followers (Section IV) and of the currently developing economies (Section V). Our findings and conclusions are summarized in (Section VI).

II. Some of the Issues

Most scientists, whether natural or social, and most officials, whether from developed (DC) or less developed (LDC) countries, share the general conviction that there indeed exist strong relationships among the three variables, science, technology and development, with which we are concerned. There is, however, considerably less understanding, hence agreement, on the precise nature of these relationships or even on the direction of the causal order. Consequently, with underlying behavior not well understood, it is natural that there should exist a good deal of uncertainty with respect to what constitutes appropriate government policy in support of a society's basic developmental objective.

The relatively "easier" part of the puzzle is undoubtedly that which focusses on the relationship between technology and development. A substantial amount of work, both theoretical and empirical, has been done in this area, mainly by economists. This work has permitted us to conclude fairly unambiguously that the association between technology and growth is indeed strong, i.e., that it is changes in the quality of a society's processes and goods which are highly associated with economic growth. The precise character of the technological change associated with growth remains a "measure of our ignorance"; we do not know whether it is manna from heaven (what the economists call "disembodied" and "exogenous") or whether it results from R & D embodied in people or machines. The increased physical availability and application of homogeneous factors, i.e., "more of the same", in the absence of technology change, probably accounts for only a small portion, perhaps as little as 20%, of total growth in most of the advanced non-socialist countries. As Kuznets puts it, even when we acknowledge that new technology may have negative as well as positive impacts on society--including additional social costs and discomforts--"the nettest definition...would still show a rapid increase [of income] per head, against fewer working hours."²

Most aggregative studies--à la Solow, Kendrick and Denison--assign the label "technology change" to everything which cannot be explained via an augmentation of enumerated physical inputs. However, the strength of particular micro-associations and the all-important "richer" issue

²S. Kuznets, "Technological Innovations and Economic Growth," p. 30, to be published, M. Kranzberg, editor.

of what causes technology change endogenously brings us, even here, onto shakier ground. Cross-country studies trying to relate expenditures on R & D (as a percent of GNP) to growth in productivity, for example by the OECD, have come up empty.³ It is just as likely that the major causal chain is reversed: More growth, hence affluence, may simply permit more R & D to be carried out. In other words, while we are fairly sure about the causal importance of technology change for growth, we do not as yet understand the anatomy of technology change well enough to know how to affect its strength or character with any degree of precision.

A large part of this problem is that our understanding of the relationship between science and the other two members of our basic triplet is even more precarious--especially as far as the LDC's are concerned. What we do have is an act of faith on the part of some that science must precede technology, which causes growth. Others see relatively little evidence of a necessary causal relationship between science and technology, at least for any given country, and, rather, view science as something only rich countries should be able to afford, while poor ones borrow. Such extreme points of view naturally lead to equally extreme positions as to policy. On one side are those who would advise LDC's, for example, to acquire and maintain frontier capacity in every major field of science in order to be able to participate fully in the benefits of technology change. On the other are those who would counsel LDC's to let the DC's spend their relatively ample resources on basic science, and then pick and choose only "appropriate" areas of science, if necessary, along with

³See The Conditions for Success in Technological Innovation, OECD, Paris, 1974.

only "appropriate" types of technology, if possible, from the "free" international shelf of human knowledge. Undoubtedly, the truth lies somewhere in between.

Thirdly, the notion of "appropriateness" itself, whether with respect to science or technology, if it has validity, must be relatable to national endowments or capacities, even if these are interpreted from a dynamic and long-term perspective. Just as the product cycle, for example, seems to hold certain useful notions as to the path of product and technology mixes across countries at different levels of development, is there a valid analogy in science? Do different resource endowments really induce different types or directions, as opposed to simply different quantities, of technology change? Again, is anything analogously valid in the field of science?

Fourthly, and closely related to what has gone before, of course, is the issue of the potential role of government in strengthening both the links between technology and growth and between science and technology. This, of course, depends in large part on the illumination of the basic behavioral relationships which will hopefully result from our effort at rummaging through the various available historical laboratories, particularly with respect to such issues as the relative appropriability or inappropriability of new scientific and/or technological know-how and its relation to the perfection or imperfection of goods and information markets.

Finally--and "finally" only because we must necessarily exercise some self-restraint with respect to the number of difficult issues we can even touch upon within the confines of this paper--is the question

of whether, whatever relationships existed between science, technology and development in the 18th and 19th centuries, these relationships have become fundamentally altered in character in the 20th. Here there are at least two major viewpoints in evidence in the literature: one, that technology used to be empirically based but is now science-based; the other, that technology has always been, and continues to be, science-based, except that science is now "bigger" and the gap between it and technology smaller.

III. The Early Developers: Great Britain, Germany and the United States

It is generally accepted that Great Britain was the world's leader in both technology and growth in the 18th and early 19th centuries, followed, in the first instance, by France and Germany on the Continent, and then by the United States in the "overseas territories." There appears to be substantial agreement as to the factors to which Great Britain owed her original position of preeminence, but less on why it failed to persist, and least on the relationship all of this had, if any, to the role of science.

The so-called Industrial Revolution, associated with the substitution of machines and inanimate power for labor power came first to Great Britain. This is frequently attributed,⁴ among other factors, to her relatively higher level and better distribution of income, hence broader base of purchasing power; her favorable geographic position associated with both greater immunity from war and greater

⁴E.g., see David S. Landes, The Unbound Prometheus, Cambridge University Press, 1972.

access to less troublesome trading partners; her relatively better endowment in natural resources, especially coal; but, most of all, her relatively greater progress in throwing off internal feudalistic and mercantilist interferences. Thus, while all of Western Europe was undergoing significant long-term change associated with urbanization, nationalism and the generally enhanced application of reason to assist man to better manipulate his environment, Great Britain emerged with a clear lead in textiles, as well as in the machinery industry to which improvements in textiles gave rise, until the middle of the 19th century.

Yet, in spite of all efforts to keep advances in technology "bottled up" on the British islands--by prohibiting the export of workers before 1825 and of machinery before 1842--by the time of the Crystal Palace Exhibition in 1851 there were clear indications that the Continent, especially Germany, was taking the lead in the important chemical, pharmaceutical and electrical engineering industries, with the United States forging ahead in mechanical engineering. By the time of World War I, as Cardwell points out, Britain had become an importer of skilled labor and technology. Explaining the more controversial "why" of this change in leadership position in technology and growth is interesting not only for its own sake but also because it may help us to understand better their mutual relationship to science.

Cardwell attributes the decline of British leadership largely to the fact that British technology was substantially "empirically-based"

rather than "science-based." Such a distinction between technology which arises from trial and error manipulations of the environment rather than from changes in our basic comprehension of the laws governing that environment is also made by Rosenberg and others. The British early lead, according to this view, was based on such industries as textiles, metals and brewing which developed on the basis of "tinkering" rather than new scientific insights. Even the smelting of iron ore was presumably carried out without knowledge of the chemistry of oxidation or reduction.

According to this view, one of the principal reasons for Britain's later relative decline is the fact that empirically-based technology change--even if sustained for a time by sequential or "neighboring" problem-solving innovations⁵--ultimately is not sustainable, if not replenished by basic scientific advances. Cardwell sees British science in a long post-Newtonian decline, with pronounced neglect of scientific education, at the very time the country is leading in steam power, textiles, and metallurgy. At the same time the Empire is siphoning off energies and capital and British entrepreneurs are becoming "fat" and more interested in the gentlemanly life than the improvement of their mills and factories. When this is placed in the context of an increasingly strong nationalistic response to the "British challenge" on the Continent, in the form of greater emphasis on science and on science-based education, the loss of leadership in "science-based" industries to France and, especially, to Germany, can

⁵As so thoroughly documented by A.P. Usler The History of Mechanical Inventions, (New York: McGraw Hill Book Co., Inc., 1929).

be explained. The French Ecole Polytechnique had no equivalent in Britain, while the somewhat more pragmatically oriented post-Liebig research labs and engineering schools helped Germany to outdistance everyone in the chemical/pharmaceutical, iron and steel and electrical machinery industries by the end of the 19th century.

An explanation of Britain's relative decline based heavily on her failure to perceive the existence of a direct causal link between basic science and technology does not, however, serve us very well when we examine the relative success of the U. S. experience beginning in the last half of the 19th century. The base for U. S. technology change and its associated growth pattern was clearly "empirical" as well, in the sense that the U. S. exploitation of the idea of mass production with interchangeable parts, which gave it a commanding lead in the mechanical engineering industries, can also be said to have emerged from trial and error on top of largely imported technology. Rosenberg sees the Americans borrowing "freely and extensively from Europe," with very little "genuinely inventive activity" in evidence during the colonial period. There was little government support of science. Beginning around 1850, nevertheless, the U.S. began to innovate meaningfully in the area of production engineering and the application of improved mechanical skills; the McCormack reaper, the Colt .45, the cotton gin and the typewriter were among the products which revolutionized in a rather fundamental way factory production methods generally. While putting out and handicraft production persisted in Europe, the U. S., as Cardwell and Rosenberg agree, quickly became the undisputed leader in industries which lent themselves to the introduction of

labor-saving machinery for the mass production of a standardized product. Before World War I, Singer Sewing established a subsidiary outside Glasgow said to be the "most advanced" in Britain, if not in Europe. None of the industries in which the U. S. began to set the innovative pace can be said to be "science-based," certainly not in contrast with the industries in which Germany assumed the lead.

A somewhat different explanation of why Britain's leadership role was gradually eclipsed may simultaneously provide us with an approach to a better understanding of the relationship between science, technology and growth. This explanation would essentially start by rejecting the notion that any sustained technology change can really be "empirically-based" as opposed to "science-based." There clearly exist marked, and important, differences in the directness of the link, from either the physical or temporal points of view. But we find it difficult to accept the notion that British technological advances in textiles and metallurgy were not firmly based on steam power or that the steam engine in turn was not based on prior basic advances in man's understanding of physics.⁶ Even if Watt's steam engine can be relegated (as Cardwell does) to the realm of an "isolated exception"--which we doubt--it is a most important one. And there were others. For technology change to occur, something has to be "in the air" in the form of recent, or past, improvements in our basic understanding of the universe--even if the innovator himself is not a scientist working in a laboratory. Arkwright's

⁶First pointed out to me by Simon Kuznets in private correspondence.

water frame (1769) is viewed as "wholly barren of science" by Cardwell, yet the fact that he was previously an apprentice to a barber and a wigmaker does not mean the invention was not based on previously acquired science. As Cardwell puts it, "if [such innovations] have scientific content...it is so well known that it can be taken as common knowledge." But that is just the point. Just because the idea utilized has not recently sprung from the garret or the research lab of some scientist does not make it any less science-based.

This is, of course, not to say that we cannot, or indeed should not, distinguish between relatively major or epochal types of technology change and relatively minor, successor (or adaptive) types.⁷ The former may be more obviously and directly science-related, e.g., a new hybrid seed and Mendelian laws, or plastics and molecular chemistry; but the new combinations of fertilizer and water required to render the new seeds most effective, and the new industrial applications of plastic materials, are surely just as much related to science as the initial major technical advance.

Closely related to this question, and thus perhaps shedding additional light on it, is the possibility of a "reverse" causal ordering, running from technology change to scientific progress. As both Bernal and Kuznets have pointed out,⁸ science is likely to be stimulated by new data, new tools and new "puzzles" which emerge in the course of the application and modification of technology. Thus,

⁷ Cardwell himself contrasts "revolutionary inventions and evolutionary improvements."

⁸ S. Kuznets, op. cit.

the original smelting of iron may have (as already mentioned) proceeded without full understanding of the chemistry of oxidation or reduction. Yet the fact that the Bessemer process initially worked in England but not on the Continent (where the iron ore had a higher phosphorus content) led to new scientific inquiries into basic metallurgy and, in turn, to the improved Thomas-Gilchrist steel-making process. Similarly, the difficulties encountered in the transplanting of improved seeds from one country to another have led to substantial new breakthroughs in agricultural chemistry.

It may therefore be useful to think of science and technology as more of a closed mutually reinforcing and mutually dependent circle-- and for both scientific and technological advances to be viewed as moving points on a spectrum, some indicating major cataclysmic or epochal "jumps," others less spectacular advances in understanding and accomplishment. Does such a notion almost serve to obliterate the difference between the concepts of "science" and "technology"? We do not think so; the definitions previously adopted stand up rather well. What it does do is cast doubt on the usefulness of the distinction between "science-based" and "empirically-based" technology change. It might perhaps be more useful to speak rather in terms of "science-intensive" versus "engineering-intensive" technology change along that spectrum. This might help us to distinguish between what was happening during the last half of the nineteenth century in the chemical/pharmaceutical industries of Germany and in a number of the interchangeable parts/machine technology dominated industries in the United States.

But where does this leave us with respect to our search for an "explanation" of why Britain lost her lead in the "science-intensive" industries to Germany and her lead in the "engineering-intensive" industries to the U. S.? It is perhaps more useful to seek such an explanation in the realm of the changing impact of differences in the endowment and in public policy over time.

Britain's early leadership position was, as we have already noted, closely tied to her relatively abundant natural resources, in particular coal and iron ore, as well as to the relatively more pronounced laissez faire position of her government--guaranteeing not only non-intervention at home but market access abroad. It is plausible to argue that some of these advantages turned to disadvantages later on.

Let us begin with natural resources. There is little doubt that Britain's advantage in coal, iron and geography heavily contributed to the smugness and loss of entrepreneurial energy previously noted. But it also meant that the Continent, especially Germany, felt under great pressure to catch up. Even after the exploitation of the Ruhr's coal deposits began in earnest, fuel costs remained higher on the Continent. The same was true for iron ore. Consequently, "continental ironmasters were making more of their resources than their competitors across the Channel; and since fuel economy was the key to efficiency in almost every stage of manufacture, the tentative advances of the 1830's and 1840's were the starting point of a scientific metallurgy that was to pay off in major improvements a generation later."⁹ There can be little doubt that Germany's spectacular success in the science-

⁹ D. S. Landes, op. cit., p. 181.

intensive chemical industry was very much related to a strong nationalistic drive aimed at finding substitutes for her deficiencies in natural resources at home and colonies abroad.

With respect to the United States, that country could increasingly take advantage of her relatively much more abundant wood supply to manufacture lighter textile and other machinery. Such machinery was first considered an amusing oddity, but later generally recognized as technically superior. The relative abundance of her natural resources base also gave her the continuing advantage of a cheaper supply of fuel, first based on steam, then, built on the scientific advances made elsewhere in the field of induction, on electric power. Moreover, her labor shortage removed most institutional (e.g., Luddite), as well as economic, obstacles to a thorough-going exploitation of labor-saving technological opportunities. From textiles to metallurgy and to the many later applications of machine-making in routinized mass production industries, the response to changes in the environment was usually rapid. Rosenberg points out that as the comparative advantage in cheap wood later dwindled, we find iron replacing wood, and coal and coke replacing charcoal as the primary source of fuel. The rapid overall pace of industrialization was also accompanied by increasing capital intensity and associated scales. Increasing pressure for labor-saving technology in industry, together with the existence of a large, dependable and expanding domestic market, propelled by the expansion of the railroad, provided the cornerstone for the "American System" of mass production.¹⁰

¹⁰ See also H. J. Habbakuk, American and British Technology in the 19th Century (Cambridge University Press, 1962), for a detailed U.S./U.K. comparison.

In U. S. agriculture, the favorable man/land ratio led to a mechanization trend, initially of the horse-drawn variety, later of the tractor type--both labor-saving and land-using in character. The application of what Hayami and Ruttan have called the biological/chemical kind of technology change did not seriously come into its own until after the closing of the frontier (circa 1890) seemed to make such increased reliance on the resource-saving effects of science rather more warranted.

But the patterns which evolved in Britain, the Continent and the United States over time were due as well to government policies which acted either to facilitate or to obstruct the system's above-described accommodations to its changing relative endowments and capacities. With respect to Britain, for example, a policy of substantial laissez faire which had been a liberating advantage in the 18th and early 19th centuries vis-a-vis the more mercantilist and still somewhat feudalistic countries of Europe may have become a handicap later on. When technical education continued to enjoy a relatively low prestige and, as Cardwell puts it, the Indian Civil Service Exam drew more attention than the Cambridge Mathematics Tripos, the government, instead of leaning against this wind, chose to stand aside. With supremacy already having been achieved in textiles and metallurgy and colonial markets safely protected, it did not feel the need to encourage scientific research or education. Delegations of businessmen visiting the U.S. in the 1850's could not convince the establishment at home that anything was amiss. It took World War I to bring a sharp realization of the extent to

which Britain had become dependent on German science and science education and on U.S. machinery engineering accomplishments. It was only then that (belated) government action was taken. Cardwell, in fact, notes that even to this day, in spite of the new universities of the post-War era and the increase in defense-related R & D, Britain still finds herself in something of a "technology trap," with higher technical education something of a step-child and routinized R & D not yet a major management tool.

Nineteenth century Germany, on the other hand, represented, as Fischer puts it, a case of "Smithian liberalism tamed by enlightened governmentalism." Spurred by the threat of British economic hegemony as well as by competition among the various German states, these governments generally did not question their responsibility to help--either via protective tariffs, as in the case of the rise of the important beet sugar industry, or via the support of scientific research labs and scientific education--as in the case of the von Humboldt reforms. Prussia went so far as to set up costly state enterprises and to issue invitations to moneyed private parties to establish factories; but mostly, in contrast to the heavy interventionism of the French, the German effort was a more indirect one, e.g., via expositions, awards, subsidies, technical advice, and the establishment of a whole network of technical and scientific institutions at various levels, to provide formal training, from engineers and mechanics to manual arts and design. German government assistance to

the institutionalization of private credit and the provision of public overheads, via the Credit Mobilier type of mechanism, compared increasingly favorably with the inadequacies of the British private market for venture capital.

Even with respect to the acquisition of general cognitive skills by the population as a whole, Britain remained elitist and indifferent by contrast. In 1860, for example, only 50% of British school-aged children attended elementary schools; in Germany, as a consequence of compulsory education laws, the equivalent figure was more than 97%. This is in addition to a longer period of schooling and a quality differential in favor of Germany. As Landes put it, "once science began to anticipate technique--and it was already doing so to some extent in the 1850's--formal education became a major industrial resource."¹¹ While the British turned to enjoy their successes of the past in a gentlemanly fashion, exhibiting an increasing disdain for the (underpaid) scientist and the technically educated, German princes vied with each other in founding technical schools and research institutes as well as becoming the patrons of individual scientists.

The role of government in the United States, while clearly more limited than in Continental Europe, also served to facilitate the system's path in the directions indicated. Rosenberg, in commenting on the growth of the multi-faceted U. S. machinery industry, speaks of a surprising volume of public/private collaboration in "visiting one another's plants, sharing new technological knowledge and even

¹¹D. S. Landes, op. cit., p. 150.

occasionally borrowing one another's workmen." Other observers place heavy emphasis on the role of widespread general education which provided for a measure of technical literacy at lower skill levels-- and for substantial empirical problem-solving capacity at higher levels. Even if most technology was borrowed and even if there was no first-rate scientific establishment in evidence, Rosenberg observes that the U. S. was "highly discriminating in borrowing patterns and highly selective in the uses to which imported technologies were put." Clearly, the mechanical skills and ingenuity required for this task were considerable. And while the U. S. produced little in the way of contributions to frontier science until much later, the diffusion of labor-saving technology change and adaptations, from firearms to clocks, to watches, to harvesters and to typewriters, all part of the "American system," required engineers who had at least a grounding in science and its use, even if they were not active contributors to it.

Little wonder that the 19th century United States attitude towards science and technology has often been called extremely pragmatic. While higher risk basic science was neglected, technology was borrowed and improved upon. The continuing shortage of labor resulted in continuing labor-saving technology bias. Only agriculture was, to some extent, an exception; with private risks larger, so was the role of government. The unique institutional framework focussed on the land grant college system was able to generate substantial technology change tied to progress in the chemistry-related agricultural

sciences and diffused widely after the turn of the century.

Nineteenth century United States may thus be characterized as a frontier society disposing over what seemed like unlimited natural resources, including fuel, and therefore, unlike Germany, not much inclined to invest heavily in basic science. Nevertheless, innovative activity, based largely on imported technology and assisted by public sector action, especially in education and agricultural research and extension, proceeded at a very rapid pace, associated with rapid increases in per capita income. If we accept the notion, previously put forward, that all technology is likely to be, directly or indirectly, science-based, it is nevertheless true that this divergence of the historical paths taken by the two early followers, Germany and the United States, is most instructive. It tells us that a combination of differential endowments and policies may lead one country to participate in growth via basic science and science-intensive industries, another by borrowing technology and using a broadly-based scientific literacy to improve upon and diffuse such technology.

III. The Late Followers: Hungary and Japan

Turning our attention to the two successful late-followers in our sample of historical country cases, Hungary and Japan, we may note, that, in terms of initial endowment and international "opportunities," the gap between them and the early arrivals was

substantial, probably as substantial as that between the late followers and today's LDC's.

Hungary, for example, had a considerable disadvantage in terms of human and natural resource endowment relative to Britain, Germany or the United States. While she shared with them a common European cultural heritage, she was not, in fact, a full member of the elite inner circle of scientific / industrial exchanges via trade, migration, professional meetings, industrial exhibitions, etc., all of which had such an active life in Western Europe, especially after the middle of the nineteenth century. When to this is added the effects of 150 years of Turkish occupation, frequent wars and the strong grip of feudalism, we should not be surprised that the transition to modern growth was delayed by at least half a century.

As Szántó, Vas-Zoltán and Csöndes put it, Hungary experienced a "second edition" of serfdom between the 16th and 18th centuries, while Western Europe was undergoing a major transition into mature growth, combining a free labor force and nationalistic governments to build, first commercial and overhead, later the basic fixed industrial capital structure required. But perhaps Hungary's biggest handicap was that there was little possibility for an agricultural revolution preceding (and fuelling) the industrial revolution to follow; and when the possibilities for "catching up" finally existed, Hungary was assigned a position within the Habsburg Empire which did not permit them to be adequately pursued. The quasi-colonial division of labor under the Austro-Hungarian regime called for Austria, Bohemia and

Moravia to provide the industrial base, with Hungary assigned to a largely agricultural role. While this might have been an appropriate static role initially, this colonial assignation of resource allocation deprived Hungary of a chance to move gradually into industrial activities of comparative advantage until much later.

The Hungarian paper reports that in the middle of the seventeenth century, only one university was in existence, in an area not under Turkish rule. By the end of the 19th century, a number of universities and institutes had been established, making their contribution to both science and technology. However, in spite of increasing state support to redress the balance within the Empire after 1867, via subsidies, improved conditions for attracting foreign capital, and enhanced support for scientific agriculture (in the inter-war period), continued political instability handicapped Hungary's development until virtually World War II.

Since then, under the socialist mode of organization, a substantial effort has been made to "catch up," mainly by the extensive use of R & D allocations. The latter have increased at a more rapid rate than GNP and are now reported at 3% of GNP, one of the highest on record. But as Szántó, Vas-Zoltán and Csöndes acknowledge, in spite of the 1968 reforms which, inter alia, served to encourage R & D by making it chargeable as a current cost, as yet "the incentives of production...do not seem to give adequate encouragement to the assimilation of newly developed technologies."

Japan represents the case of a small late-comer country which can today even more definitively be labelled mature. Like

Hungary, Japan before the Restoration in 1868 may be considered feudal and poor, although it had the definite advantage of not having been subjected to colonialism and of having experienced substantial development of her internal markets and of her agricultural and human infrastructure during the Tokugawa period. While her "initial conditions" may thus be considered favorable relative to most contemporary LDC's, her successful transition to modern growth from initial endowments substantially closer to those of LDC's than those of Western Europe or the U.S. has aroused unusually strong interest among development analysts and policy makers.

Most observers, including Nakayama, have detected the existence of important sub-phases in Japan's transition, during which the relationships among science, technology and growth underwent considerable change. Partly because of the extra-territoriality treaties imposed by the West and partly because of the long seclusion period pre-dating the Restoration, Japan's initial efforts to support her industrialization drive via government intervention--what we would call import substitution today--represented a relatively mild version. Nevertheless, as Nakayama also reports, we do encounter, between 1868 and roughly 1890, determined government efforts to "catch up with the West". With protective tariffs largely unavailable, government intervention took the form of public sector participation in directly productive activities, subsidies and other ways of influencing relative factor and product prices.

The Meiji government initially encouraged the large-scale borrowing of technology from abroad for both the agricultural and non-

agricultural sectors. As Nakayama points out, substantial errors were committed by attempting to apply Western-style, land-abundant agricultural methods--mainly developed for wheat--to a small-scale, land-scarce rice economy. Similar errors were committed in industry by importing inappropriate "turn-key" technology for use in public sector plants, some of which subsequently failed. Both the advice of the large numbers of foreign experts which were invited and the findings of the even larger numbers of Japanese sent abroad to reconnoiter as to the "right" country from which to borrow were frequently wide of the mark during this period.

While these facts have often been lost sight of by overly enthusiastic observers of the Japanese experience, it is perhaps more instructive to note that it took the Japanese relatively little time to recognize not only that imported technology had to be selected carefully, in the first instance, but also that, for maximum effectiveness, it had to be substantially adapted to local conditions. In agriculture, for example, (except for the northern island of Hokkaido which had an atypical, almost U.S.-like, factor endowment) attention had shifted completely by the early 1880's from labor-saving (mechanization-oriented) Western methods to the diffusion of land-saving (fertilizer and cultivation practice oriented) technology using the experienced or "Veteran Farmers", supported by government demonstration farm and extension efforts.¹² In industry, trial and

¹² Hayami and Yamada ("Technological Progress in Agriculture," in Klein and Ohkawa, eds., Economic Growth: The Japanese Experience Since the Meiji Era, Irwin, 1968) have demonstrated that the diffusion to all parts of Japan, of the best-known agricultural practices of the day accounted for most of the (substantial) growth of agricultural productivity during this period.

error led to greater reliance on private sector decisions as to appropriate technology choice. In 1885, Nakayama reports, the Ministry of Technology was dissolved--and the gradual withdrawal (by sale to the private sector) of the government from all but some heavy industries was more or less completed by 1890.

The Japanese case has often been cited in support of the notion that a country can stay out of high-risk science and concentrate instead on lower-risk technology imports. The Meiji government spent relatively little effort or resources on the advancement of pure science. Yet the quick empirically-based response of Japanese engineers and industrialists would not have been possible without a strong and well dispersed educational base, both general and technical, which had been part of the Japanese scene from the beginning. To borrow wisely and to adapt, with an eye to differences in both the endowment and demand patterns, requires, as Nakayama points out, intermediate-level scientific manpower, not "big science" or heavy R & D expenditures which the Japanese generally made efforts to avoid.¹³ In this sense, we may detect a strong parallel with the 19th century U.S. case: pragmatic borrowing of technology from abroad, plus extensive indigenous technology change supported by high, well-distributed levels of scientific and technical literacy.

Nakayama notes that the early public sector's import-intensive industrialization efforts were dominated by ex-samurai who had been displaced by the abolition of feudal rights. It is equally interesting to observe that many of the medium- and small-scale private entrepreneurs

¹³ Except, apparently, when the customer was the military.

who later helped shift the center of gravity to indigenous technological experimentation and adaptation came from the ronin or lower (and less well-connected) strata of samurai.

Production increases based on the diffusion of the "best" known agricultural technology naturally ran out of steam after some time, and, as Nakayama reports, chemical science-intensive agricultural innovations became increasingly important after 1885. The trend quickly spread to the agricultural input industries, e.g., tools, seeds, fertilizer, with substantial science-intensive (mostly Germany-oriented) technology change in evidence. This was also the time when government support of industry in general, as we have seen, became more indirect than direct and, incidentally, more export-oriented (and thus of necessity more competitive) than during the import substitution period.

With respect to industrial technology, the need to compete in international markets for silk, cotton yarn, textiles and, later, rubber and electrical goods, provided an added impetus to the search for additional innovations and adaptations intensive in the relatively abundant unskilled labor force.¹⁴ Nakayama cites the rather remarkable increase in patent applications during this period, the large majority of which were process- rather than product-related. A piece of interesting historical evidence which has come to this author's attention is the switch from mule to ring spindles in the Japanese cotton spinning industry in 1887. Rings, it turned out, could accommodate much

¹⁴See the author's "Factor Proportions in Japanese Economic Development," American Economic Review, September 1957.

more unskilled labor per unit of capital, could produce a wider variety of yarn quality and could accommodate greater variations in the quality of the raw cotton input. What is most interesting for our purposes is the almost instantaneous switch of all cotton textile mills in Japan while Indian textile mills, supplied at the time mainly by the same capital exporter (Platt's of London), and facing an even more extreme surplus of unskilled labor, substantially stayed with the less efficient mule technology.

Some observers would place the approximate date of Japan's successful transition into modern growth shortly after World War I, others, after World War II.¹⁵ What is more important for our purposes, however, is that in Japan, as in the U.S., technology and industry became more directly science-based or science-intensive in the inter-war period, with basic sciences receiving major attention for the first time, as reflected in the growth of public and private research labs, the rise of sponsored research and university science departments, and the growing demands of the military. Nakayama considers the creation of Riken (the Institute for Physical and Chemical Research) in 1917 to be a landmark, with 85% of the funds coming from industry rather than government. Another was the creation in 1931 of the Japan Foundation for the Promotion of Science. At the same time, Japan, which had never really opened its

¹⁵ See, for example, Fei and Ranis, Development of the Labor Surplus Economy: Theory and Policy, Irwin, 1964, and R. Minami, The Turning Point in Japanese Economic Development, Tokyo Univ. Press, 1970.

doors to direct foreign private investment,¹⁶ now experienced a new wave of foreign technology inflow embodied in joint venture or licensing arrangements (e.g., the G.E./Shibaura alliance, responded to by the agreement between Westinghouse and Mitsubishi). Also an increasing number of indigenous innovations, beginning with the Toyoda loom, but moving into chemistry and later to electronics and related fields, began to make their appearance. Clearly, as in Germany at an earlier date, science had become increasingly viewed as an essential national instrument, especially in countries such as Japan, short of natural resources, and thus increasingly dependent, once labor surplus had become exhausted, on the ingenuity and resourcefulness of their people.

V. The Developing Countries: Brazil and Ghana

Brazil and Ghana are the two developing countries represented in our study. As is so frequently the case when anyone attempts to generalize about "the" developing world, these two systems clearly have as many differences between them as they do with respect to a "typical" developed economy. While it might be useful to deal with our two cases within the context of a systematic typological framework which differentiates among LDC families, for example, by size, land/labor ratios and/or human resource endowment, this would take us beyond the limits of

¹⁶ The minor flows in the 19th century and the rather more substantial flows thereafter mainly took the form of loan capital. The absence of any marked colonial pressure surely had its effects in precluding the appearance of some of the more customary manifestations of multinational business interests.

time and space of the present paper. We will therefore attempt to draw what reasonable generalizations seem to emerge concerning the relationships among science, technology and development in the LDC case, and content ourselves with an occasional comment concerning relevant intra-LDC differences.

Both Brazil and Ghana begin as colonial entities, with much of the observed pattern of resource allocation and growth dictated by the needs of that system. Pastore and Ayensu report on the almost exclusive public sector emphasis of science during this period and the concentration on flora, fauna and geological surveys--mainly aimed at the location and exploitation of primary raw materials. It was gold, then mainly cotton, sugar and coffee in Brazil; gold, then cocoa, in Ghana. But the patterns were the same. In both cases we witness not only a neglect of industry--in fact, some destruction of artisan production by industrial imports--but also of food-producing domestically-oriented agriculture.¹⁷ And in both cases the concern with the exportable cash crop is supplemented mainly by an interest in health, and the required adaptation of medical science to the overseas territory. Colonial governments thus clearly recognized that some indigenous scientific capacity was required in agriculture and health where local conditions with respect to soil, climate and disease potentials are likely to vary substantially.

¹⁷ This, incidentally, differentiates the Japanese colonial system, e.g., in Korea and Taiwan, from others. But that is because, once domestic Japanese agriculture ran out of steam early in this century, it was food which the mother country wanted from her colonies in this case.

Political independence, of course, came much earlier to Brazil, which emerged from its "Iberian period" in the early 19th century, than to Ghana which did not become independent of England until the 1950's. Nevertheless, as Pastore is at pains to point out, political independence did not alter the basic triangular colonial pattern of resource flows in Brazil until the 1930's. Both systems, Brazil's in response to the international vagaries of the Great Depression, Ghana's in pursuit of domestically-oriented national development goals under Nkrumah, embarked on a fairly standard type of import-substitution industrialization strategy. Abstracting from the differences in the sizes of the two domestic markets, the sheer volume of natural resources available, the extent of regional diversity and the educational base achieved, import substitution in both cases meant a rather determined effort to import advanced country industrial technology without much emphasis on indigenous science, on the one hand, or technology adaptation, on the other, and with a continuation--if now for somewhat different reasons--of the policy of relative neglect of food producing domestic agriculture.

Since the agricultural hinterland remains the large and crucial sector in most LDC's, whether measured in terms of people, output, or the potential for the application of science-based technology, this continuation of colonial neglect under independent national governments is of great concern. Rice and maize research in Ghana received as scant attention as beans and rice in Brazil. Cocoa and coffee, on the other hand, continued to be viewed as the major source of fuel for the operation of the system and thus received most of the

attention of agricultural research concerned with variety improvements, new fertilizer combinations, resistance to plant disease, etc. Pastore records some recent changes in Brazil in this respect; the situation is less clear in Ghana--certainly the institution of the state farm system there did not encourage cultivator pressure or receptivity.

With respect to industry, Pastore finds not only Brazilian technology but the entire pattern of growth still heavily influenced by foreigners--if now via the multi-national corporation--even during the import substitution sub-phase of development. He notes that "domestic technological and scientific establishments were not encouraged to innovate," and that a surprising 62% of industrial know-how still emanates from abroad, with half of large-scale Brazilian firms holding permanent foreign technical contracts. Science, until quite recently, apparently remained a highly individualistic Europe-oriented art form. The first science or technology oriented University level training programs did not begin until the 1930's, and then with a still expressly abstract slant. It should not surprise us that the portion of Brazilian output growth not attributable to increases in physical inputs--which, with all its shortcomings, is called "technology change"--has been measured in the vicinity of 20%, as opposed to 40% to 80% for the advanced countries. Pastore is undoubtedly correct in concluding that the development of science cannot be left to laissez faire forces if the requisite critical mass of human and physical resources is to become available.

On the other hand, we note that heavy government intervention in science

(and technology)--which certainly was the situation in Ghana during the Nkrumah period--by no means guarantees a more favorable outcome. Ayensu is kinder than this observer in his evaluation of the long-term developmental impact of Nkrumah's Science City, the Volta River project, and other large-scale government efforts aimed at forcing Ghana into modernity, without the benefits of a fully socialist institutional structure. He nevertheless recognizes that the increasingly heavy government participation in directly productive activities during the First and Second Plans could not solve (I would say probably worsened) the middle-level management capacity shortage in the country. In fact, there should be little surprise, given Ayensu's own figures of only 1.4% of school-going males and .7% of school-going females getting even a modest technical or commercial education, that the Ghana Council of Scientific and Industrial Research (CSIR) has performed as badly as he reports.

Even where the effort is less extreme, and the economy remains more "mixed," there seems to be ample evidence that "in general, import substitution policy and full-scale protection of consumer goods industry have tended to promote a passive attitude to the utilization and development of indigenous R & D efforts, during the early phase of industrial development."¹⁸ The distortions affecting output and technology choice, both in terms of relative prices and lack of competitive pressures, in

¹⁸Nam Kee Lee, "Technological Development and the Role of R & D Institutes in Developing Countries," I.L.O. Working Paper, p. 19.

favor of modern "engineering" and against appropriate "economic" choices, are well known. The relevant issue rather is how severe are the import substitution policies and for how long are they maintained? For, while it is generally acknowledged that they have a valid and important role to play in the early post-colonial life of an LDC still lacking in industrial entrepreneurial capacity, the fact is that they as often convert themselves into ballast which is later politically difficult to discard. While Ghana remains in the fairly early stages of non-durable consumer goods (primary) import substitution, it is, we believe, accurate to say that Brazil, except for a brief 1963-68 interlude, has intensified her import substitution policies, moving into the technically more complicated (secondary import substitution) industries,, i.e., durable consumer goods, capital goods and raw material processing. Such a shift, if anything, is yet more dependent on foreign technology and yet more dissociated from domestic scientific or adaptive technological ingenuity. We agree with Pastore that "a strong scientific establishment is necessary in order to understand trans-national knowledge, both in science and technology." We would only add that the dimension of "strength" involved includes the capacity to choose, and to reject, to adapt and to diffuse; the contrast in performance between a relatively small natural resources poor island nation, Japan, which proceeded to turn outward after a period of relatively mild import substitution, and large, natural resources abundant Brazil, is bound to be instructive in these respects.

VI. Findings and Conclusions

In these last few pages we will attempt to record some of the findings and insights that seem to have emerged with respect to the many complicated questions raised--focussing mainly on those facets of historical experience which may serve to illuminate basic contemporary developing country concerns. These are personal conclusions drawn from the seven country papers as well as other sources and--just as the rest of this effort--do not implicate the individual authors in any way. Almost all countries today accept the importance of the impact of technology on growth--as well as on distribution and other important dimensions of development. But they are profoundly uneasy as to how much of their technology can be, or should be, home-grown, imported and/or imported and adapted. They are even more uneasy with respect to the volume of resources and energy they should commit to basic science as the underpinning for technology change. Waiving other motivations and considerations, in other words, they are concerned about the price of the "ticket of admission" to the community of science.

Our analysis of the role of science and technology in the history of the now developed countries led us to conclude that to divide technology into empirically-based and science-based categories is likely to be off the mark. Epochal technological change of the type we have become accustomed to in the 20th century is likely to be more directly related to major scientific breakthroughs than in the past. We need only

think of electronics, plastics, the computer, atomic energy, to make the point.¹⁹ In the 18th and 19th centuries, on the other hand, the pace of science was slower--some would say "big science" had not as yet arrived--and consequently any epochal technology change such as the steam engine, equally based on a major scientific discovery, might yield its technological impacts and applications over a longer period and in more diffuse ways. This does not make the sum of such innovations less science-based, but rather less science-intensive.

Second, keeping the United States and Japanese experiences particularly in mind, these systems were admittedly not pioneers in frontier science; but they developed a definite capacity to absorb science as a necessary basis for their own very substantial achievements in importing and adapting technology. As Kuznets has pointed out,²⁰ this capacity to use science wisely is more likely to be national rather than supra-national. But it does not just happen. It is related to the educational system, to the national ethos, as well as to the types of interventions, direct or indirect, practiced by governments. An educational system which imparts a modicum of scientific understanding to a substantial portion of the population, a pragmatic "catch-up" philosophy which accompanies "late-comer"

¹⁹ As a recent OECD study (The Conditions for Success in Technological Innovation, OECD, Paris, 1971) noted: "Technological innovation is as old as man, but it is only in the 20th century that science, technology and industrial firms have come together to play such an important role in it."

²⁰ In private correspondence with the author.

status, and national governments' willingness to move away from dirigiste mercantilist interventions can provide basic building blocks for this type of science capacity at a relatively early stage of a country's development. As the experience of both Japan and (especially) the U. S. also illustrates, the same country may later, in its modern growth phase, acquire the capacity to advance the international frontiers of science.

The "typical" contemporary LDC thus cannot afford to "sit back" and let the advanced countries incur all the expenditures attached to the trials and errors of international science--especially not now in the twentieth century when the pace of science has much accelerated and the gap between it and technology narrowed. Yet it cannot afford, and should not try, to "show the flag" in every field of basic scientific endeavor; the less developed world is strewn with scientific institutes and other expensive white elephants which contribute neither to science nor to technology. Most observers agree that the biggest waste of all is second-rate basic research. The "middle road" points in the direction of a broad enough spread of science and technical education and a flexible enough economic environment to permit both appropriate scientific and technological choices as well as indigenous improvements and adaptations. International science is only slightly more a "free

good" than technology; there are important search, identification, transfer and assimilation costs involved.

Julian Engel sees "little justification [in LDC's] for basic research except for sustaining a viable teaching effort and keeping your best brains at home." This is in general accord with our above position except that it may go too far. There are fields of scientific endeavor which must be strongly represented within the LDC's because of their country- or region-specific character. The best examples are in agriculture and health. Without basic agricultural science-oriented research on a country or at least regional basis, the recent chemistry and Mendelian law-based innovations which have gone under the name of the Green Revolution do not, as we are now finding out, have the necessary sustaining power and the necessary defense against specific local (e.g., pest and disease) problems. Similarly, in the field of health, few people would argue that one trans-national science can really be equally responsive to the very differentiated conditions around the globe. It is in such areas that the "puzzle"-solving capacity of science in response to technological problems clearly requires a first-rate scientific establishment.

Are there other areas in which the same criteria apply? This is perhaps the most difficult question of all. In one sense, all human activity is affected, to a larger or smaller extent, by the particular soil, climate and other conditions under which it is carried out. It is, for example, relevant even in industry--think of the relationship of fertilizer and agricultural implements to the conditions of

the soil, and of the importance of humidity and temperature conditions-- as well as natural fiber quality--to spinning and weaving operations. Where then does the need for individual LDC basic research end--and the caveats against a wasteful buck-shot approach take hold?

This is by no means an easy matter on which to pontificate in an abstract way. This observer would insist, nevertheless, that the burden of proof be on those who would like to initiate advanced university training and basic research, including some obligation to demonstrate a flexible, time-phased relevance to technology changes-- which, in turn, can be expected to affect the productive system. This may seem like the typical hard-headed, narrow economist's prescription. What about the importance of those many possible chance inter-connections, decades apart, which may flow, in some entirely unpredictable way, from what looks like some unconnected intellectual pursuit? Without disparaging these possibilities in any way, we would respond--if we are indeed offended by the spectacle of open heart research in countries where malnutrition is a prevalent phenomenon--that science really should not expect to be entirely outside the realm of some flexible, sophisticated version of cost-benefit analysis. Such analysis must try to balance the potential benefits against the possible alternative allocations of scarce financial and (perhaps more important) human resources. The higher risks of science--partly due to the uncertainty of predicting future two-way interactions between science and technology, and partly to the likely inappropriability nationally of any such "returns"--render this task unusually difficult. But analysis must still be done; an act of faith does not suffice.

In addition to placing the burden of proof on those who would like to have LDC's purchase the "price of admission" in a given field of basic scientific endeavor, it might be possible--although admittedly difficult--to encourage much more specialization, at least within, and possibly also among LDC's on a regional basis. This type of agreement has been reached, for example, in the case of European atomic energy and ballistics research and African efforts to combat yellow fever and rinderpest, i.e., where the required scale and the need to avoid expensive duplication were sufficient to overcome nationalistic jealousies. Although the record on similar inter-LDC agreements in the field of common market investment allocations, etc., has not been terribly encouraging, it has been somewhat better with respect to the use of regional training institutes and research organizations-- whenever regionalism is not forced but flows from the recognition of mutual self-interest.

If we agree that no country can really afford to be either a full-time borrower of science or an across-the-board contributor to it-- what about technology? First of all, our historical forays seem to clearly indicate support for the Bernal-Kuznets position that technology gives rise to as many leading "puzzles" required for further scientific progress as the other way around. Consequently, much of what we had to say above applies to technology as well. When we are speaking about a society's national capacity to utilize and modify international science creatively, we are also referring to a kindred capacity to select appropriate technology and adapt it to differing

environments. If we but keep in mind that contributions to human knowledge which break new ground and provide scope for major new technological breakthroughs will, with few exceptions, remain the province of the leading mature countries, what can we say about the direction new science-intensive and engineering-intensive technology change is likely to take?

The two elements which seem most responsible for this direction are changing resource endowments and public policy. The very different behavior of the natural-resources-rich labor-scarce United States relative to a relatively capital-scarce England and a Germany which felt cramped for natural resources should be instructive in this respect. Engineering-intensive technology took a different, more capital-intensive path in the wide open spaces of the U.S. than in England. And, in Germany, metallurgical science responded to the needs of a high phosphoric iron ore content; official encouragement of the entire chemical industry was based on the felt need to overcome, by artificial or synthetic short-cuts, the relative unkindness of nature. Japan, after first exploring her abundant labor resources-- and taking an engineering-intensive route analogous to that of the U.S., but capital-saving--has, with the disappearance of that labor surplus, tended to place more of her eggs in electronics and other high technology baskets.

But, as has also been pointed out, while government policies cannot legislate away the basic endowment of a society, they can, if flexible and able to overcome narrow sectional interests,

provide an important assist to the transition effort of a developing economy as its endowment changes with time. Analogously, if dominated by narrow vested interests and/or lacking in historical perspective, such policies can attempt to draw a veil over the endowment and lead the system into expensive scientific/technological dead-ends and economic stagnation. While there is no rigid uni-directional sequence of phases which every LDC must somehow traverse on the path to mature growth, some attention to the changing roles of science and technology in terms of a changing resource endowment and, especially, changing human capacities is essential in all but the most unusual cases.²¹

At the micro and institution-building level, the appropriate role of government in the mixed economy context is, of course, not unrelated to the appropriability or non-appropriability of the new knowledge acquired. Investment in basic science carries a high risk, in part because of its, at best, indirect and long-term relationship with technology and growth, but partly also because it is generally an international good not even appropriable by a country, not to speak of any private party within the country. As we move from basic international science to changes in technology, risks are reduced and private appropriability becomes much more important. As the extent of appropriability rises, so, normally, does the level of private R & D expenditures.

²¹ A country like Kuwait, for example, may be able to buy its way into the charmed circle with turn-key oil-oriented technology but, even there, there is some doubt as to whether it qualifies as a mature economy. It certainly does not meet all the Kuznetsian stylized attributes of a system under modern growth.

Appropriability, of course, depends not only on how basic the research effort but also on the overall state of competitiveness or non-competitiveness of the system. This is partly a function of the overall policy environment; for example, during periods of intense import substituting industrial protection and large unearned profits, there would seem to be less interest on the part of industrialists to search for the best technology; instead, satisficing behavior and the use of inappropriate (often prestige) technology seems to frequently displace maximizing behavior.²² But, for any given industry or sector, the state of competitiveness also depends on conditions peculiar to the particular market, with respect to goods, information or technology. Agriculture, for example, is typically the most competitive field, therefore exhibiting the least private appropriability possibilities and the least willingness (or capacity) by individual farmers to incur R & D expenditures. Consequently, not only basic scientific agricultural research but also the search for appropriate adaptive technology and even its dissemination to individual farmers usually represents activities (and costs) which fall to the public sector. Ditto for health--except perhaps even more so. This is fairly well recognized. But what is perhaps less well understood is the fact that there exist other industries--again on a continuum moving through agricultural processing and input industries to light consumer goods, some services, and beyond--where similar characteristics abound, i.e.,

²² For more on this, see the author's "Appropriate Technology in the Dual Economy: Reflections on Philippine and Taiwanese Experience," International Economic Association, 1976.

a competitive market structure, the relative absence of scale advantages, and thus the need for possible government involvement in R & D, education and extension. If, in the absence of pronounced market imperfections, new technology can be selectively borrowed from abroad, the burden on high cost domestic R & D is reduced and a minimum of government support can lead to rapid diffusion of technology change. This certainly was the case for Japan. Here the profound technology change associated with the switch from mule to ring cotton spindling in the late nineteenth century was diffused as rapidly as the agricultural practices of the "Veteran Farmers."

Whether or not, in mature market economies, competitive or non-competitive industrial configurations yield relatively more private R & D activity remains an as yet unresolved empirical issue. Competitive industries have more incentive but less capacity. With respect to the LDC's, it seems to us, any viable science and technology policy must begin with an examination of the extent of the overall competitive pressures felt by individual decision-makers with respect to economic versus engineering choices. It must include sensitivity to differences in the market structures of specific industries, and consideration of selective government action in creating social overheads in the science and technology arena. Such interventions may be addressed to ensuring that existing technological alternatives are known to all sizes of firms, or to helping expand the range of alternatives via the support of university or R & D institute activity. In either case it is, however, important to ensure not only that the areas of activity are selected with some of the (flexible) cost/benefit

considerations previously referred to in mind, but also that the specific activities supported within these fields carry built-in devices to ensure that the criteria of ultimate contributions to social and economic development and not any exclusively internal criteria of the "invisible college" are addressed. One such device, frequently referred to, is that government subsidy of R & D institutes be set on a long-term declining basis, with private sector contracts forced to fill the widening gap. Another is to concentrate scarce attention on the more competitive "non-appropriable" sectors and, in fact, to ensure that access to information as well as to the required complementary inputs is relatively equal across firms.

One dimension of this general problem which has been mentioned only fleetingly thus far is that of process versus product innovation. Economists, as this paper well demonstrates, spend most of their time discussing technique or process change while industrialists and R & D allocators spend most of their energies and resources on product change. When technology change is of the cataclysmic or epochal type, e.g., the invention of the automobile based on the principle of combustion, it is more of a semantic issue whether we call this a change in the transportation process or a change in product (from the horse and buggy); but when we are dealing with more common sequential and adaptive innovations, the distinction may be more real and related to the competitiveness of markets. It seems clear, for example, that product differentiation is of greater importance in less competitive markets and

process differentiation more important in competitive markets. If we apply, if loosely (and briefly), the product cycle idea, it is clear that patents and trademarks may represent one device to extend the period of quasi-monopoly position beyond what would be possible via simple process and price considerations. The contrasting role in today's LDC's, of the contemporary Japanese multi-national corporation, which is largely process and price oriented, and that of the U. S. multi-national which is largely product and quality oriented, is rather startling in this regard. It is no accident that the distribution of domestic patents as between process and product innovations today is overwhelmingly in favor of process in Japan and of product in the U. S. In an earlier day the U.S. was process oriented relative to the product orientation of the U.K. In recent years, Japan is itself shifting towards product innovation. It thus appears, ceteris paribus, that the richer and more scale-dominated the mature economy becomes, the more important is the relative role of product innovations.

This question of competitiveness is, of course, of importance for the developing economy subject to the blandishments of domestic as well as foreign technology salesmen, with respect to both process and product. Schmookler long ago pointed to the importance of demand factors in technology change. Whether the change in product quality is real or imagined, carries additional real benefits or not, is another question. The fact is that the absence of competitive pressures and adequate information often do not give LDC consumers an unimpaired choice, at realistic relative prices. Much of the (we believe quantitatively important) misallocation of LDC resources on inappropriate (e.g.,

overspecified) goods as well as inappropriate technologies is related to the presence of proprietary and non-competitive elements in areas not warranted by the basic scale relative to the size of the market, e.g. in soft drinks and drugs. The evolution of modern appropriate goods for local markets, at prices which reflect quality differentials, is similar to the adaptive changes in processes arising from "blue collar" R & D, practiced on the factory floor and in the machine shops, as contrasted to the more visible "white collar" variety carried on in corporate and university labs. It is similarly linked to empirical learning by doing and experimenting processes. While some scientists, some economists, and many engineers may well disdain to call both of these related types of activity technology change--and may be especially reluctant to admit of any relationship to science--we would argue not only that they are important for LDC social and economic growth but also that they are but one step removed from the mechanical or engineering intensive innovations of 19th century labor surplus Japan, and two steps from those of the 19th century labor scarce United States.

It is, in summary, admittedly futile to attempt to manipulate basic science in any particular direction; the relationships and feed-backs are much too diffuse and complicated. But LDC's can, and we might add, must, exercise restraint as to the fields in which they decide to maintain a first-rate scientific establishment. They must make a serious effort at reorienting their educational structures towards the very ability to make these selections, i.e., via the achievement of a broadly based scientific literacy which not only

conveys the ability to perceive where indigenous frontier capacity should be installed but also guarantees the necessary access to the international networks.

With respect to technology, the task of public policy is perhaps easier, but by no means simple. Internationally, there exists a substantially larger number of borrowing options by country and by type than we used to believe, but many remain obscured by a lack of information and other institutional impediments, some related to the public and private capital transfer mechanism. The options which exist, in nature, with respect to indigenous or adaptive technology change, new or derived, are much more numerous yet. Governments can do much at the aggregative level to ensure that the veil between relative prices and endowments which must sometimes be drawn is neither excessively thick or kept excessively long; governments can help ensure that sufficient workable competition exists so that entrepreneurs are interested in finding the most appropriate technology in the first place, rather than being in a position to indulge their preference for prestige and the "quiet life." And, perhaps most important, as a complement to these aggregative measures is the possible intervention of the public sector in institutional areas, in ensuring a freer flow of information on market, quality and technology options and in providing support to technical education and R & D, especially of the unspectacular adaptive non-appropriable type.

The interactions between science, technology and development are potentially of very great benefit to the transition effort of the developing

country--which typically finds itself more restricted than the rich in terms of its ability to rely on the contribution of more physical capital and other conventional inputs. But the opportunities of participating within an interdependent global system will not be realized if national policies are not more realistically geared to our gradually improving understanding of the fundamental behavioral relationships involved. It is hoped that the work of this Symposium has carried us a small step forward in this direction.