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Discussion Paper

REFLECTIONS ON THE ENDOGENIZATION OF THE  
SCIENTIFIC-TECHNOLOGICAL REVOLUTION IN  
UNDERDEVELOPED COUNTRIES

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"Nam et ipsa scientia potestas est"  
Francis Bacon

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Introduction

Throughout the history of mankind, and particularly during the last five centuries, it has been possible to observe an evolution in the way in which natural and social phenomena have been assessed. The prevailing perspective from which men have examined and explained the world they live in has moved from magic to religion and then to science; although this evolution has not been linear and complete and it is still possible to find magic and religion coexisting and competing with the scientific perspective.\*\* In this process of evolution of thought the main contribution from the West has been the use of reason, and specifically the scientific method deriving from it, to contrast mental schemes with the evidence of the senses, thus building a cumulative fabric of knowledge whose weft are abstract concepts

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\*\* See J. Frazer The Golden Bough (edited by T. Gaster), New York, Mentor Books, 1964. For a slightly different interpretation of this evolution see B. Malinowski Una teoría científica de la cultura, Buenos Aires, Ed. Sudamérica, 1976. (Translation of "A scientific theory of culture and other essays", first published in 1948).

and whose warp are empiric observations.

The pursuit of science, considered as an organized, continuous and self-correcting process of knowledge generation, plays at present a most significant role in the progress of productive and social activities; to the extent that it can be considered as the main driving force for growth, particularly in the developed countries. We live in an age which can be characterized by the predominance of technology which is in some way or other related to scientific findings.

In international relations this is reflected in the fact that a few developed countries currently control the generation of, and access to, modern technology. Furthermore, these countries count with a surplus of food and capital which they interchange with the underdeveloped countries for natural resources and energy. Under exceptional circumstances the latter may have sufficient food or capital, but as it has been demonstrated in several occasions (and recently after the price increase of oil in 1973-74, which originated a massive transfer of financial resources to the OPEP member countries, but clearly highlighted their technological dependence), the developed countries are the only ones capable of fully linking a self-sustaining base of scientific activities with production. As a consequence, they control the access to modern technology and are thus capable of inclining the balance in their favour.\*

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\* On these issues see F. Sagasti "Technological self-reliance and cooperation among Third World countries", World Development", Vol. 4 (1976) pp. 939-946, and M. Halty Towards a new technological order? paper presented at the OECD seminar on Science, Technology and Development Changing World; Paris, April 1975.

Let us also note that food surpluses in these countries are a result of the application of technologies based on, or related to, scientific findings (fertilizers, pesticides, mechanical equipment), and that their capital surplus arises from the use of high-productivity techniques which lead to a process of accumulation that goes well beyond the needs of capital replacement. In this way, science-related technologies have been and are at the root of an international order which divides nations into developed and underdeveloped.

For the purpose of these notes, two types of countries will be distinguished; those where the evolution of scientific activity led directly to, or was clearly linked with, advances in production techniques; and those in which the knowledge generating activity was not related in any significant way to productive activities. We shall refer to the first as countries with an endogenous scientific and technological base, and to the second as countries with an exogenous scientific and technological base, noting that this division corresponds to that made between "developed" and "underdeveloped" countries.

#### Countries with an endogenous scientific and technological base

Whether as result of an internal cumulative process (Western Europe), or of a transplant which later on grew its own roots (United States, Japan), in these parts of the world the systematic generation of knowledge and the production of goods and services were linked organically through the development of techniques related to scientific findings. New knowledge was transformed into products without the need of resorting to substantial

external assistance, except for the normal process of contrasting scientific findings. The emergence of scientific and technological capabilities in the West can be understood by examining the evolution of ideas that led to science, the successive transformations of productive techniques, and the merging of these two currents.

Considering briefly the evolution of Western thought, it is necessary to go back as far as the Hellenic period. Starting with the pre-socratic philosophers, who began to elaborate abstractions of the world surrounding them; going through Plato, who invented the concept of idea; and continuing with Aristotle, who formalized logic and the concept of method, the ability to build and relate concepts abstracted from reality was first developed in Greece. During the Roman and the Middle Ages no new elements were added to the Greek conceptual edifice, and this was to a large extent related to the prevailing view of a certain divine order imposed on mankind and to the predominance of dogmatic disquisitions. However, the influence that the Arab world had on Europe towards the end of the Middle Ages helped in the development of schemes for manipulating concepts and symbols (e.g. algebra), and motivated a return to the examination of natural phenomena (witness the concerns of the alchemists).\*

The Renaissance brought a revaluation of manual labour and of detailed

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\* On these issues see, among others, C. Singer From magic to Science, New York, Dover, 1958

observation, which would facilitate the full contrast between abstract concepts and physical phenomena, thus paving the road for modern science. Philosophers began to worry about machines, systematic astronomical observations helped navigation, and the reinstatement of manual labour (which had been looked down upon during the Middle Ages) reached its culmination with the work of great artists such as Da Vinci. The contributions of Copernicus and Galileo on the celestial order led to the triumph of reason over dogma, and constituted a milestone in the transition from religion to science as a way of explaining natural phenomena. Lastly, Newton's contribution, who introduced the idea that the universe was predictable and obeyed certain laws which could be known and tested, changed radically man's conception of the world, giving sense to the Baconian statement that man can master and control nature through understanding.

Considering now the techniques used in productive activities, the Middle Ages and the Renaissance saw a cumulative evolution of the crafts practiced by artisans, which were gradually transformed into manufacturing activities, and later, during the 17th Century, into industrial activities proper. The milestone marking this transition was the use of machines to manufacture machines, referred to by Marx as the "emergence of large-scale industry".\* This took place concurrently with a gradual but relentless shift from a poly-

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\* K. Marx. Capital (Vol. 1, Chapter 15), Middlesex, Penguin Books, 1976.

technic era of varied local technological responses, usually in harmony with the environment (although there were exceptions such as the environmental contamination in London due to coal utilization during the 13th and 14th centuries), towards a monotechic era in which the variety of responses is reduced and a few specific production technologies predominate in each field of activity.\*

The merger of both currents --the evolution of thinking and the evolution of technology--constituted what has been referred to as the scientific and technological revolution . This was a complex process, full of sinuosities and blind alleys, where science on the one hand and productive techniques on the other, interacted strongly and conditioned each other. This process lasted approximately 200 years, starting in mid-17th century, and has originated strong debates on the relative contribution of both currents. \*\* Broadly speaking, it appears that during a first stage craftsmen and manufacturers made a greater contribution to the growth of science (especially to its experimental aspects through the construction of instruments), than that made by scientists to the productive activities of artisans and industrialists. However, towards the end of the period mentioned, the findings related to mechanics, chemistry, optics, thermodynamics and other areas of knowledge were making an equal

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\* L. Mumford The Myth of the Machine, New York, Harcourt Brace, 1972, Chapter 6

\*\* See, among others, A.E. Musson (Ed.) Science, Technology and Economic Growth in the 18th Century, Cambridge, Cambridge University Press, 1972; D. Landes The Unbound Prometheus, Cambridge, Cambridge University Press, 1969; and J.D. Bernal Science in History, Cambridge, Mass. MIT Press, 1971.

or perhaps larger contribution to the development of production techniques, than the latter to the development of science.

The point of inflexion marking the beginning of the predominance of science-related technologies over the techniques that evolved in a gradual and autonomous way, was the emergence of the first productive activities based on scientific findings: the electric and chemical industries. Since then, the contributions of science to production have been growing at an accelerated pace.

This merger took place among considerable social upheavals, concurrently with the emergence of capitalism as the dominant mode of production, and with the spread of the market economy at the European and international levels.\* There is no need to reproduce here the debate on whether progress in science and technology was a key contributing factor in the rise of capitalism, or whether capitalism led to the rapid growth of scientific-technological activities. The important issue is that both phenomena were closely intertwined and were exclusive to the development of the West.

The marriage of science and production, as well as the concurrent social upheavals, took place while techniques of lower relative efficiency were being abandoned, in accordance with the economist criteria prevailing at the time. The process of reduction in the variety of technological responses, which started towards the end of the Middle Ages, was suddenly accelerated, to the extent that in many cases it totally disrupted the cumulative develop-

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\* See K. Polanyi The Great Transformation, New York, Harper Torchbooks, 1969

ment of traditional technologies, and led to what Mumford called "the loss of the polytechnic heritage".

The subsequent evolution of the interactions among science, technology and production in the countries with an endogenous scientific-technological base is well known. The accelerated pace of technological progress during the last 100 years has been extensively documented and we shall only point out some milestones, such as the replacement of the individual researcher by organized laboratories (referred to by Sabato as the emergence of "technology factories" ),\* which started towards 1890 and is now widely spread; the incipient use of warfare technologies based on scientific findings during the First World War (e.g. mustard gas); and the diffusion of technological knowledge and values brought about by the improvement of the internal combustion engine and the massive production of automobiles. The period between the two World Wars witnessed the great advances in physics, which culminated with the development of the atomic bomb, and in chemistry, which led to the widespread production of new synthetic materials. Finally, the World War II and post-war periods may be characterized as the age of the scientific explosion, in which the advances in electronics, biology, chemistry, cybernetics, and many other fields, transformed science into the key source of changes and improvements in production techniques. In countries with an endogenous scientific-technological basis, this was associated with an increase in the mi-

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\* J. Sabato Empresas y fábricas de tecnología , Dept. of Scientific Affairs, OAS , Washington 1972.

nimum critical mass of resources required to do science and by an unprecedented expansion in the scientific-technological effort, to the extent that Machlup could state that in 1960 more than one third of the economically active population of the United States was linked in one way or other to the "knowledge industry" (research, teaching, information, etc) \*.

Retrospectively, in those countries with an endogenous scientific-technological base the last 400 years have witnessed the emergence of the profession of generating knowledge in an organized and cumulative way, and have seen the evolution from science as practiced by individuals, to that carried out by an incipient collectivity of scientists, and to that currently undertaken by a fully-fledged scientific community. This community acquired legitimacy not only because of the increasingly coherent explanations it gave to natural and, to a lesser extent, social phenomena, but mainly because it demonstrated its usefulness for the development of production techniques, a usefulness anticipated by Bacon in the early 17th century when he stated that knowledge in itself is the source of power. It is appropriate to add that the scientific community has not remained static in one place. Ben-David has pointed out the shift of the center of gravity of the scientific activity from Italy to the Netherlands, England, France, Germany and later to the United

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\* F. Machlup The production and distribution of Knowledge in the United States, Princeton, Princeton University Press, 1962.

\*\* J. Ben-David The Scientists' Role in Society, New York, Prentice Hall 1972.

States of America , over a period of four centuries and without loss of continuity.

Perhaps the most important feature of the scientific-technological revolution, referred to by Kuznets as an "epoch-making innovation"\*, was the discovery and improvement of the methodology of invention, which, building on the foundations initially laid by the Greeks, allowed to transcend the limitations of the materials and procedures resulting from the slow and gradual process of technological evolution. Once this barrier was crossed, the possibilities open were enormous and are bounded primarily by the advances of knowledge and the limitations of the human mind.

However, the illusion that this was a conscious, orderly and planned undertaking must be dispelled. It rather took place in an spontaneous fashion, covering a wide spectrum of areas, duplicating efforts, with many false starts, and showing a series of contradictions. Notwithstanding that, the self-corrective nature of science allowed for changes in course to be effected; although always within the broad directions determined by the conjunction of the interests of scientists and those of states and institutions financing scientific activities. Incidentally, it is in response to these interests that at present more than half of the world resources channelled to science and technology are devoted to the improvement of warfare technologies.

Another feature associated to the symbiosis of scientific and productive activities was the diffusion through society of the values and modes of

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\* S. Kuznets Population, Capital and Growth, New York, W.W. Norton, 1971, pp 165-185.

thinking related to the scientific-technological revolution. The idea that it is possible to understand, predict and control the phenomena surrounding us, and that men are able to overcome the limitations imposed by nature, has influenced greatly the development of countries with an endogenous scientific and technological base, in contrast to those in which traditional concepts and values, linked to magical or religious perspectives, have hampered the full utilization of man's faculties and potentialities.

#### Countries with an exogenous scientific-technological base

The majority of the underdeveloped countries, in contrast with Western-European nations and others such as the United States and Japan, did not establish a basis of productive technologies related to scientific findings of their own. There was no linkage between the development of activities devoted to the generation of knowledge and the evolution of production techniques, with these two areas remaining completely isolated from each other.

The diffusion of western science to countries with an exogenous scientific-technological base was an irregular process, entailing a partial acceptance of results, but without full awareness of the cumulative processes that originated them. The conduct of science in these countries, even to a greater extent than in countries with an endogenous scientific-technological base, was an activity limited to the elites and isolated pioneers who lacked organic links with their social environment, at least in what refers to their scientific-technological activity. Their efforts were inherently out of phase

in time, since the frontiers of knowledge were being explored in other parts of the world and they received information on advances and findings with unavoidable delays.

Thus, the pursuit of science does not grow roots in the majority of these countries until the first decades of the 20th century, and even then it acquires a fragmentary, reflex and imitative character, divorced from the productive sphere. In some cases, such as India in the 19th century, the colonial power deliberately excluded the potential local scientists from research undertaken by the colonizers, thus preventing the development of indigenous scientific-technological capabilities \*. Science was mainly oriented towards the knowledge-generating world centers, and the concern for local scientific activities arose in so far as it was necessary to know better the environment for a more intensive exploitation of resources, or in so far as curiosity and the possibility of contributing to the advancement of world knowledge would motivate scientists to focus their efforts on specific regional problems.

The nature of productive activities was conditioned first by the interests of the colonial powers and then, after some regions became independent (particularly Latin America), by the way in which their economies were incorporated into the international division of labour accompanying the expansion of the capitalist system. Due to this, productive activities in these countries were oriented primarily towards the extraction of natural resources of interest to the colonizers or capitalists, or to the generation of surpluses to be transferred abroad.

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\* See S.N. Sen. "The introduction of Western Science in India during the 18th and the 19th century" in S. Sinha (Editor), Science, Technology and Culture New Delhi, India International Centre, 1970

Most of the techniques used in productive activities were imported, and this meant that the associated technological base was alien to the local environment. When the implanted extractive and manufacturing activities began to acquire greater relative importance in the local economy, the corresponding technological capabilities were expanded through new technology imports. As a result these countries acquired a reflex and superficial layer of technical knowledge, disconnected from their physical and social reality, and which depended from abroad for its maintenance and renovation.

Considering now the traditional technological base, it is possible to say that after a relatively short lapse at the beginning of the colonial period during which colonizers learned to operate in an alien environment, the indigenous non-western technological tradition, which had been developing slowly and cumulatively for a long time (through a process similar to that which took place in Europe during the Middle-Ages), was eliminated or left aside, primarily because it did not serve directly the interests of colonizers and later of capitalists. This elimination process was particularly drastic in those regions that had achieved considerable progress independently of the West (e.g. the Andean World), and its social consequences were disastrous.\* Nevertheless, some of these traditional activities remained at periphery of economic life, to the extent that they supplied in part the means of subsistence to those involved in the productive activities that were implanted.

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\* For example, the drop in population in Latin America, which followed the Spanish conquest. See R. Konezke America Latina : La época Colonial, Mexico, Siglo XXI, 1972 ( pp. 93-98)

The demise and substitution of traditional productive activities implied a reduction in the variety of indigenous technological responses developed through time, and led to the total disappearance of many of them. Since in these regions the European counterpoint between traditional techniques and those related to scientific knowledge did not take place, but rather the new techniques were implanted once they were highly perfected, the disappearance of traditional techniques took a more radical character than in Europe. The shift from what Mumford called the "polytechnic age" to the "monotechnic age" was particularly violent in those countries with an exogenous scientific-technological base.

These three components--the scientific activity generating knowledge, the technological capabilities associated to implanted productive activities, and the traditional or indigenous technological capacity--have practically had no interactions among themselves in the countries with an exogenous scientific and technological base. Their evolution (involution in the case of the traditional technological capabilities) has taken place in isolation, and the fusion of science and production, which characterized the countries with an endogenous scientific and technological base in the West, did not occur. Moreover, the elimination of traditional technological capabilities was more traumatic and disruptive in the countries that have an exogenous scientific and technological base, in comparison with those that have an endogenous one.

#### Towards a strategy for scientific and technological development

Accepting as a working hypothesis that the division between developed and underdeveloped countries corresponds to the proposed differentiation

between countries with an endogenous scientific-technological base and those with an exogenous scientific-technological base, one of the key problems in the design of an autonomous development strategy becomes how to relate in an organic fashion the conduct of scientific activities with the technological capabilities associated to both modern and traditional productive activities.

From this point of view a country will achieve a level of self-reliance or autonomous development \* to the extent that it acquires and expands its own scientific and technological base; this is, the degree to which it endogenizes the process of generating production technologies related to scientific discoveries. Let me caution that the problem is not one of reproducing in a mimetic way the experience of the countries which have an endogenous scientific-technological base at present. This is neither possible nor desirable, because to trod the same path followed by these countries would lead us to the same problems they are experiencing now, and would show that we are incapable of learning from history. On the contrary, it will be necessary to endogenize the scientific-technological revolution in a selective and gradual way, choosing consciously those areas and fields of activity in which the process can succeed and grow roots.

At the same time, and in contrast to what has happened in the countries that now have an endogenous scientific and technological base, the

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\* Which should not be confused with autarchic development. On this subject see F. Sagasti Tecnología, Planificación y Desarrollo Autónomo, Lima, Instituto de Estudios Peruanos, IEP, 1977.

indigenous technological tradition should not be discarded. This tradition, which usually remains diminished and lethargic (when it has avoided extinction), should be rescued and fully integrated with the development of scientific activities and the evolution of modern productive techniques. Let us make it clear that this does not imply an indiscriminate return to the technological past, not an illusory reappraisal of all traditional productive techniques. \*

Summarizing, at the core of an autonomous development strategy it is necessary to place the fusion of the current of activities generating knowledge, together with the evolution of technological capabilities linked to modern production, and with the discriminate and systematic rescue of the traditional technological base. These three components should be integrated around problem areas of critical importance for the country's development strategy, and should lead to the progressive substitution of the exogenous technological base, although accepting that this is a slow process viable only in the long-term. The identification of an initial set and a sequence of problem areas in which this integration could be obtained thus becomes one of the main issues to be settled.

In addition to linking the scientific activity to the technology involved in modern production and to traditional technologies, it is necessary to create the appropriate conditions for the harmonic coexistence of modern and traditional activities, and of their respective technological bases. This implies

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\* On this matter see A. Herrera Scientific and Traditional Technologies in Developing Countries, Science Policy Research Unit, Sussex University, April 1974.

a substantial revision and reformulation of economic concepts such as obsolescence and efficiency, and the experience of the People's Republic of China may prove to be valuable in this regard.\*

Given the magnitude of the effort required to put in practice the strategy for scientific-technological development suggested in these notes, it is obvious that its viability would be conditioned by the proper identification of problem areas in which the fusion of the three currents mentioned above can be accomplished. The experience of countries with an endogenous scientific-technological base is not very useful to this end; not only because of the differences in starting conditions, but also because they went through an erratic and slow process which involved a considerable waste of resources. At most, a study of their past experience should indicate mistakes to be avoided.

As an initial approximation I shall suggest five criteria for the identification of problem areas around which to center efforts. The first criterion derives from the need to secure a critical mass to undertake scientific activities, and this should be examined from the quantitative, qualitative and interfacial points of view. Considering the quantitative aspect, the question is to ensure the availability of human, physical and financial resources above the minimum level required to generate scientific knowledge of direct interest to the problem area. From the qualitative point of view, the resources available should have the characteristics that make them suitable for the selected

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\* On this matter see G. Dean Technology and Industrialization in the People's Republic of China, Office of the Field coordinator, STPI Project, Lima, July 1976.

activity (trained and experienced scientists, equipment satisfying certain specifications, etc). From the interface point of view, it is necessary to gather a qualitative and quantitative base of resources, not only in the scientific field of immediate interest for the problem area, but also in those neighbouring fields which interact strongly with that which constitutes the main axis, since advances in science arise frequently from the combination of knowledge generated in adjoining fields.

The second criterion derives from the fact that problem areas in which to promote the merger of scientific advances with traditional and modern technological capabilities must be country-specific, and determined taking into account the social and historical context, as well as the availability of natural and human resources. The identification of problem areas should also be country-specific in the sense of being closely linked to the style of development chosen and designed.

The third criterion for the identification of a problem area would stem from the possible societal impact of the fusion of the three currents. The idea is to ensure the largest possible multiplying effect of the integration of science with modern and traditional technological capabilities, both in what refers to the possibility of facilitating their integration in other problem areas, as well as in what refers to the diffusion through society of the values and points of views related to the endogenization of the scientific and technological base.

The fourth criterion to be considered should be the possibility and the opportunity of exercising world leadership, so that the country would

become an internationally recognized center of scientific excellence in a particular problem area. This would be achieved through the concentration of efforts, and could eventually pave the road for a more balanced exchange of scientific knowledge and technologies with other countries.

The last criterion would lead to the selection of problem areas based on the possibility of obtaining concrete results in a reasonable period of time, expressed in terms of producing and utilizing technologies related to scientific findings and of linking the scientific activity with traditional technological capabilities. Moreover, the merger of the three currents in a specific problem area should serve as a starting point to undertake the integration process in other areas, thus generating a cumulative sequence which would facilitate the growth of an endogenous scientific and technological base.

It is clear that the strategy outlined in these notes should be complemented by the development of a capacity for regulating technology imports, primarily because it would take a long time for the endogenization process to acquire a significant magnitude. This implies the need to increase the country's bargaining power, to be informed about the scientific advances in other parts of the world and the technologies derived from them, and to improve the technology absorption capacity of the productive sector. At the same time, and given the limitations of all types faced by the underdeveloped countries, it will be also necessary to promote international collaboration agreements, particularly among underdeveloped countries with similar problem areas. \*

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\* On this matter see F. Sagasti "Technological self-reliance and cooperation among Third-World countries" World development Vol. 4 (1976) pp 939-946; and F. Sagasti and M. Guerrero El Desarrollo científico y tecnológico de América Latina, Buenos Aires, BID/INTAC, 1974, chapter 3.

### Final Remarks

The purpose of these notes has been to contrast the situation of the countries in which productive technologies were developed on the basis of scientific discoveries with that of those where the symbiosis between science and production did not occur. This differentiation coincides with the division between developed and underdeveloped countries, and an analysis of their historical experiences moves us to reflect on the possible way in which the underdeveloped countries could internalize the processes associated with the scientific-technological revolution and its effects.

The brief analysis of the way in which scientific advances were united with the evolution of productive techniques in the West shows that this was a long maturing process. Resource constraints and the limited room for maneuver inherent to the condition of underdevelopment makes the internalization of the scientific-technological revolution an improbable and difficult task.

However, history shows us that to rely on an endogenous scientific and technological base is a necessary condition to satisfy the basic needs of the population in an autonomous way and to allow for the full development of human potentialities, whichever the style or model of development chosen. For this reason, the endogenization of the scientific-technological revolution is a task which should be initiated without delay in the underdeveloped countries, particularly considering the slowness of the process and the difficulties involved.