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THE SISYPHUS CHALLENGE:

Knowledge, Innovation and the Human Condition in the 21st Century

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(with the collaboration of Fernando Prada, Ursula Casabonne and Mario Bazán)

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Francisco Sagasti[1]

> *The gods condemned Sisyphus to eternally push a rock to the top of a mountain, whence the stone would fall back of its own weight. They had thought, with some reason, that there is no more dreadful punishment than futile and hopeless labor…*
>
> Albert Camus, *The Myth of Sisyphus* (1942)

Prologue

Sisyphus was "the craftiest of men" according to the ancient Greeks. His cunning, his lack of scruples, and the ingenuity of his deceptions infuriated the gods, who punished him for his trickery by endless labor in the underworld. Raising a stone towards the top of a hill only to see it roll backwards seems the epitome of futility, yet Camus' essay —written as World War II was raging— raises the intriguing possibility that, ultimately, Sisyphus was a happy man, identified with and fully accepting his hopeless task.

Building science and technology capabilities in developing countries appears to be a Sisyphean task. Time and again investments are made, people are trained, institutions are built, and policies are designed and implemented —often with considerable effort— only to see them fall apart and disappear without trace. Jorge Sábato, the Argentinian physicist who pioneered science and technology policy studies in Latin America, used to say that "it takes 15 years of hard work to build a world class research facility, but only two years to destroy it". Developing country policy makers and politicians, many of whom are unaware of the ways in which science and technology contribute to improve the human condition, have frequently adopted policies and taken decisions that destroyed research and innovation capabilities built over many years of hard work.

Thus the pertinence of the Sisyphus myth to characterize what has happened and is happening in Africa, Latin America, the Middle East, South and South-East Asia, and even countries in Eastern Europe and the former Soviet Union, as science and technology capabilities built over decades erode and even vanish.

But there is more. Even if our scientific and technological Sisyphus were to reach the top of the hill and, resolutely defying the Gods, managed to stay there, he would only see other hills to climb awaiting him. Hard won achievements in building science, technology and innovation capabilities appear diminished —even insignificant— as the furious pace of advance at the frontiers of scientific research and technological innovation makes evident the widening chasm between what most developing country researchers and innovators accomplish with great effort, and what their developed country counterparts appear to do with relative ease.

Perhaps, as Camus has suggested, attempting an impossible task makes Sisyphus proud and even happy. Indeed, the manifest futility of the attempt to catch up with the advanced scientific and technological nations liberates us from the fear of failure. Moreover, what may appear to be minor achievements against the backdrop of the swift displacement of the science and technology frontier can yield substantive benefits for people in the developing regions. It is in this sense that efforts to build domestic capabilities to generate, acquire and utilize knowledge become crucial for attempts to improve the human condition. In addition, the fact that a handful of developing countries have managed to build world-class research and innovation capabilities in just a few decades is a source both of comfort and inspiration.

This Sisyphean challenge is the subject of the present essay. The main argument is that developing countries —where more than three quarters of humanity lives, mostly in poverty— must judiciously invest scarce resources to build their capacities for creating, acquiring and utilizing scientific and technological knowledge, and this should be done without ignoring their heritage of indigenous knowledge and techniques. As the scientific and technological hills to climb will continue to proliferate —making Sisyphus' task even

[1] This essay has been prepared with the collaboration of Fernando Prada, Ursula Casabonne and Mario Bazán.

more daunting— it is also essential to devise ways of keeping the rock on the top of the hill, of preventing the results of past capacity building efforts from being wiped out.

But, how to mobilize knowledge to improve the human condition? How to face this Sisyphean task with aplomb and a sense of —why not?— resigned and even fatalistic optimism?. This essay attempts to answer these questions. It offers a set of concepts for examining the interactions between knowledge, innovation and development, for exploring how to create science and technology capabilities in different types of developing countries, and for placing the role of international science and technology cooperation in perspective. It builds on a large body of work of literature accumulated during the last several decades, and particularly on a series of papers, monographs and books written by the author since the early 1970s.[2]

The essay is aimed at all persons interested in the role that modern science and technology play in human affairs, and particularly at policy and decision makers in the public, private, civil society and academic sectors concerned with the disparities between rich and poor countries. The approach adopted has been highly eclectic, drawing from many disciplines (history, economics, sociology, engineering, political science, philosophy), from personal experience (as researcher, advisor, consultant, manager, policy maker, teacher), and from the contribution of many colleagues from around the world.

Following this introduction, the first section presents a conceptual model that, starting from an account of the diffusion of Western science, provides an integrative framework for relating knowledge, technology and production, and also for attempting a redefinition of what is meant by "development". The second section contains a historical overview of the interactions between knowledge, technology and production during the last several centuries, as well as a brief account of the way they relate to each other at the beginning of the 21st century. The third section characterizes the main features of the "knowledge explosion" that has taken place during the last three decades, focusing on the way in which research, innovation and the techno-economic paradigm have evolved recently.

[2] See Annex A for a bibliography of this material.

The fourth section deals with the "knowledge divide" that has emerged between rich and poor countries and, using the material of the preceding sections and together with statistical information, develops a composite index of "scientific and technological capacity" that is used to place countries along a continuum and in four broad categories. The fifth section focuses on the strategies and policies appropriate to create and consolidate science and technology capacities in developing countries and on the role of international cooperation. A few concluding remarks and suggestions for future research complete the essay, which is complemented by several annexes, a bibliography and a note acknowledging the contributions of many persons with whom the author has been associated with during the last three and a half decades.

As the sources of material for this essay are quite numerous, references have been kept to a minimum and are provided in the text only when the ideas can be traced specifically and exclusively to a particular author. The bibliography contains the main sources consulted during the preparation of this essay.

Although it builds on a large body of previous work by the author, this essay has been prepared during 2002 as part of a joint project between FORO Nacional/Internacional-Agenda: PERU in Lima, Peru, and the Center for Global Studies (CGS) at the University of Victoria, British Columbia, Canada. The Rockefeller Foundation provided support for the joint project, which led to the preparation of this essay and to the compilation of a large inventory of international science and technology cooperation programs.[3] The participants in a technical workshop held in Lima and Urubamba in early October 2002 provided most valuable suggestions and comments on a first version of this report (see the acknowledgements section at the end of this essay).

The challenge of pulling together a large body of work into a single essay has been most difficult and stimulating. I hope the result offers some ideas and encouragement to those facing the Sisyphean challenge of mobilizing knowledge and innovation to improve the human condition in the 21st century.

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[3] The inventory can be found at http://www.globalcentres.org/html/project1.html

1. Knowledge, technology and production: a conceptual framework

This section introduces a set of basic concepts that will be used throughout the essay. It begins with a discussion of prevailing views regarding the diffusion of Western science and then proposes an integrative framework to view the interactions between knowledge, technology and production and service activities.

1.1 The diffusion of Western science

In a well-known and still quite influential paper George Basalla[4] proposed a conceptual framework to explain the spread of Western science throughout the world. His model consists of three partly overlapping stages: in the first stage, the non-scientific or pre-scientific society of the developing world constitutes a source of problems for European science to delve into; in the second, there is an incipient development of what Basalla calls “colonial science”; and in the third stage developing countries struggle to establish an independent scientific tradition of their own.

During the first stage, a few European scientists visit the new lands, explore and collect fauna and flora, study the geographical and physical characteristics of unexplored areas, and then return to their place of origin to complete their scientific work. In their relatively tranquil home academic settings, they put forward their theories and describe their empirical findings.

A dependent “colonial science” emerges in the second stage. Natural history continues to be the main focus of interest and attention, but the range of scientific activities and problems studied begins to expand until it almost coincides with that of the colonizing power. The colonial scientist is dependent in the sense that the sources of his education and training, the origin of the scientific traditions that he adheres to, the orientation of his activities, and the ways of obtaining recognition for his work are all defined in the metropolitan scientific power and not in the country or region in which he lives and works.

The transition from the second to the third stage is more complex and difficult to characterize. Basalla suggest that the stage of colonial science contains, in embryonic form,

[4] See: Basalla (1967).

some of the essentials aspects of the third phase. During this transition, the colonial scientist —even though he still gets support from outside— begins to create institutions and traditions that eventually will be the base for an independent scientific culture. Thus, in the third stage, colonial scientists are gradually transformed into scientists whose main allegiance is to their country of origin.

Basalla's model has been rather attractive and widely known, but has two important limitations. First, the use of the concept of "dissemination" of Western science as the exclusive focus of his analysis, without giving sufficient attention to the processes of "absorption" and "internalization" of scientific activities in developing countries. Second, it centers attention mainly on the diffusion of Western science, without examining the worldwide expansion of the technological base and the internationalization of production activities.

To privilege the concept of dissemination or diffusion entails adopting an exceedingly Eurocentric perspective, in which Western science, nurtured by different currents of speculative, theoretical and empirical thought that converge upon it from various regions, irradiates the whole world until it displaces the local "pre-scientific" forms of thought. In reality, what happened —and continues to happen— in different parts of the world, each of them with their own tradition and culture, has been a process of interaction between the imported scientific knowledge and the traditional modes of speculative thought. The permanence of non-scientific forms of speculative thought is a constant in the history of Africa, India, China, Latin America, the Middle East and even in Japan, and the interactions between the Western view of the world and a variety of traditional perspectives has taken a multiplicity of forms.

For these reasons, rather than focusing just on the "diffusion", it would be more appropriate to refer to the "diffusion, absorption, and reinterpretation" of modern science, admitting that this is a process still under way, that in many parts of the developing world it remains at an incipient stage and is proceeding rather slowly, and that in some instances there has been little "interaction", but rather a juxtaposition of two different and independent forms of speculative thought: the scientific Western view and the traditional indigenous perspectives of developing regions.

Furthermore, if the diffusion of modern science is examined without taking into account the parallel processes of dissemination, absorption and adaptation of modern techniques and technologies (in which there were complex and rich interaction between the Western and the indigenous traditions), and without considering the worldwide spread of European production activities (which accompanied the expansion of the capitalist system at the world level), there is the risk of presenting a partial vision, in which the "diffusion of Western science" is perceived as an independent phenomenon, conditioned only by its own internal logic, and mostly unaffected by the wider social, economic and political forces at play.

1.2 Elements of an integrative conceptual framework

In order to offer an alternative and comprehensive view of the emergence and diffusion of modern science in the developing countries, it is necessary to consider the process of generation, transmission and utilization of knowledge in an integral manner. For this purpose, it is possible to distinguish a set of three components that, together with their interrelations, configure an integrative conceptual framework to account for the way in which modern knowledge, technology and production activities spread throughout the world.

The first component is the *evolution of speculative thought* which seeks to generate knowledge to understand natural and social phenomena, and also to offer explanations that give sense to human existence. The second component is the *transformation of the technological base* that provides every human group with a set of organized responses to confront the challenges posed by the physical and social environment, and also with the criteria to select the most appropriate among these responses. The third component is the *expansion and modification of production activities*, which provide goods and services to satisfy the needs of a community and of the individuals that compose it. These three components, considered in a dynamic fashion as currents in constant change, are linked to each other through a set of institutional arrangements, and are immersed in the broader social, cultural and political context that envelopes human societies.

At a given time and place, a social group can be characterized by the way in which these three currents unfold and relate to each other, by the form in which these currents are linked with their counterparts in other societies, and by the specific nature of the interactions between these three currents and the institutional and social environment in which they are immersed.

Although the Western worldview cannot be considered as the privileged or unique frame of reference to examine the achievements of the great diversity of human societies, it is impossible to deny that, because of its success in the material and intellectual realms, the West wields enormous influence throughout the world —to the extent that it implicitly provides a yardstick to view the relative standing of other societies. However, in order to highlight the extraordinarily diverse ways in which human beings think and act, and also the enormous potential that this diversity embodies for the future of humanity, it is necessary to move away from the powerful shadow cast by the dominance of Western concepts and things.

The development of the different civilizations and societies in the last several centuries should be seen as a complex whole, whose components are in continuous action and transformation, and in which a perspective —the Western one— came to influence all others during several centuries. At the same time, other cultures preserved their individuality, influenced Western civilization, and gave rise to new hybrid forms of conceiving the world and relating to it. The image of all civilizations and cultures of the world converging to the culmination and greater glory of the West, implicit in the metaphor of different cultures as tributary rivers that converge on the sea of Western civilization, is rather biased and even suspect.[5]

When displacing the perspective of Western civilization as the privileged frame of reference to appreciate the march of other cultures, there still remains the problem of posing a

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[5] In this sense, it is convenient to recall what Alvarez (1979, p.2) has stated:

> "... Human history may be better described not as a movement of different peoples towards some convergent mythical future (although at different speeds and in distinct groups), but as the experience of many discontinuous cultures, each in itself equally important as exhibiting the variability of products of human inventiveness, each crystallizing a system of meanings irreducible to the others."

Ortega y Gasset (1968, p. 77) has argued along the same lines, with particular reference to techniques when he opposes:

> "… [the tendency] as spontaneous as excessive, reigning in our time, to believe that in the last analysis there is truly no more than one technique, which is the actual European American technique, and that everything else was just clumsy babble towards it.
> [It is necessary] to counteract this tendency, and to submerge the technique of the present time as one of the many in a vast and multiform panorama of human techniques, revaluing in this way their sense and showing how to each project and model of humanity there corresponds a particular technique."

direction for the process of social evolution that could provide, at least to some extent, a backdrop for comparative studies and for avoiding the potential excesses of cultural relativism. Two options emerge in this regard. The first is to posit a broad vision of the future direction for the evolution of humanity, which should be acceptable to many different cultures and societies. One leading candidate is the process of "emancipation" from the forces of nature and from the dominance of other individuals, which could be considered as the capacity of human beings —both as individuals and groups— to forge their own destiny and to realize fully their own potential. From this perspective, emancipation could be considered as a key value and as an end in itself, and the process of development as the gradual, but not necessarily linear, advancement towards this end.[6]

A second option is to view human evolution as the open-ended process of creating and realizing new values (as well as reinterpreting and realizing old ones), and of seeking to articulate shared perceptions of what humanity is and should be. Implicit in this approach is the acceptance of human diversity as a source of potential new values, and the need to agree on ways to articulate those shared perceptions. This, in turn, requires recognizing that values can be in contradiction, that there is a need for conflict resolution procedures, and that openness, tolerance and respect for the views of others are a prerequisite for shared value creation and realization. From this perspective, development may be seen as the complex and arduous process of devising the means for advancing towards creating and putting shared values in practice.

Development, whether conceived as advancing towards emancipation or towards the creation and realization of values, requires that human societies continuously improve their understanding and mastery of the phenomena that affect them. For more than three centuries, and in spite of limitations that have become evident as we enter the 21st century, modern science has shown to be the most efficient way of generating knowledge to improve our understanding. Research and the systematic examination (*logos*) of the repertoire of responses available to act upon natural and social phenomena (*techné*) have given rise to a

[6] Wertheim (1974, pp. 40-41) suggests that "… the general tendency of human evolution... consists in a growing emancipation from the forces of nature… [and]…the emancipation from the domination of privileged individuals or groups". This is similar to Sen's (1999) idea of "development as freedom". This concept was used in the Agenda: PERÚ project, which defined the "common good" in the following terms: "Expand as much as possible the options which all Peruvians possess to freely imagine, design, choose and realize their own life projects" (Sagasti, 2001).

vast array of technologies to confront the challenges posed by these phenomena. Production and service activities associated with modern science-based technologies have acquired an enormous potential to satisfy all kinds of human needs.

As a consequence, development becomes a nearly impossible task without a minimum level of autonomous capabilities to generate scientific knowledge, to transform it into technologies, and to incorporate these science-related technologies into production and service activities.

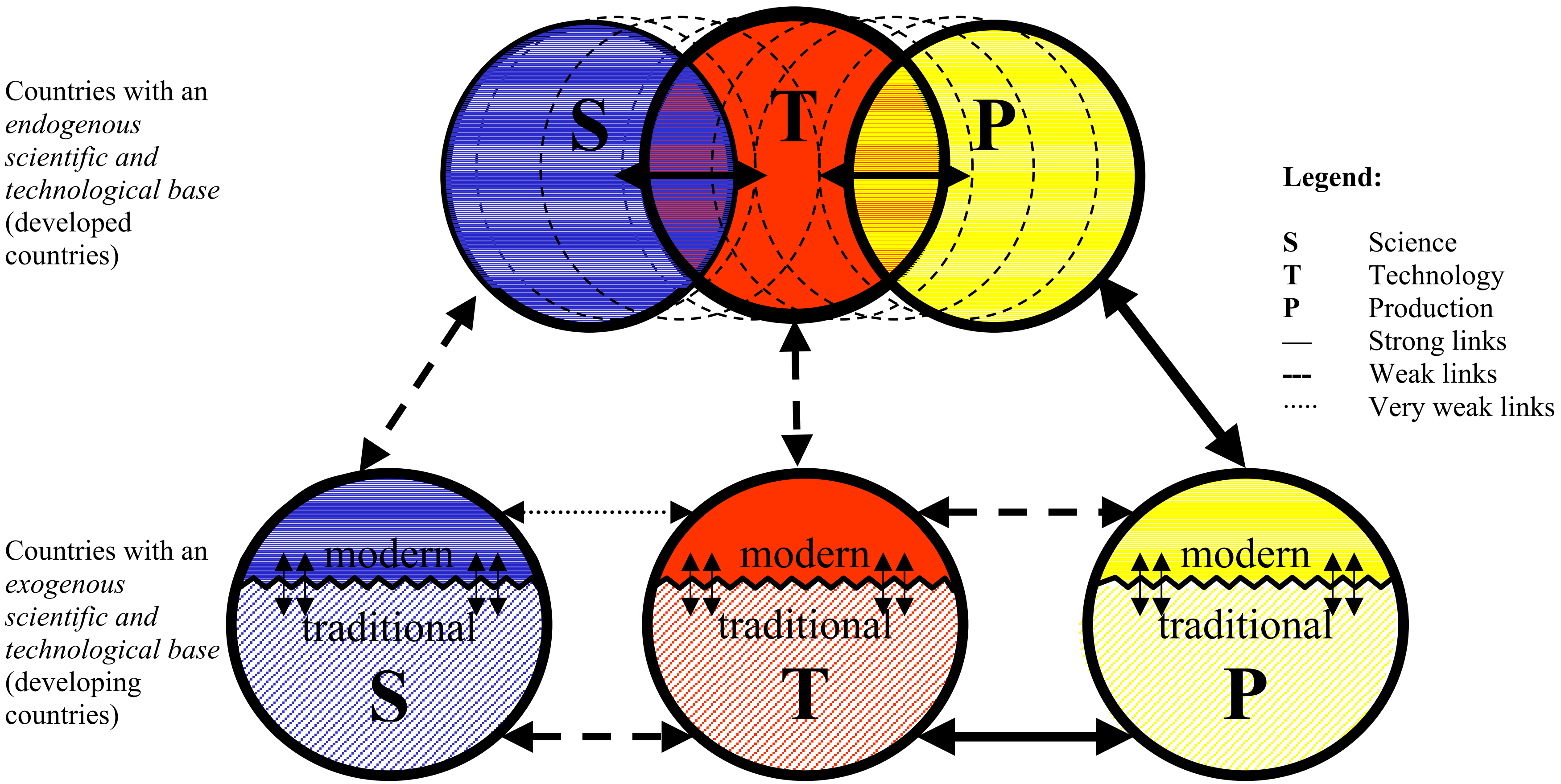
From this perspective, it is possible to distinguish between two types of societies. First, those where the evolution of speculative thought led to or embraced modern science, where scientific activities were directly linked with technological advances, and where such advancements led to improvements in production and service activities. Second, those in which the process of knowledge generation was not associated with modern science to any significant extent, where the technical base remained largely isolated from modern science, and where production and service activities did not depend on domestic scientific research or technological advance.

Figure 1 indicates that a close interaction between science and technology in developed countries nurtured and underpinned the evolution of production activities. Without the capacity to generate scientific knowledge, to transform it into technologies that were used in the production of improved goods and services, these countries could have not achieved their high rates of economic growth and of improvement in living standards. The close and continuous interaction between science, technology and production led to the creation of an *endogenous scientific and technological base*. This consists in the accumulation of scientific research and technological development capabilities that make it possible to generate new knowledge, and also to modify, adapt and recombine existing knowledge, which is then deployed to produce goods and services. In turn, through learning-by-doing and learning-by-using, the utilization of knowledge and technologies in the productive sector leads to incremental technical innovations, to the further accumulation of technological capabilities and to new areas for scientific research.

Developing countries were not successful in generating such an endogenous scientific and technological base. Their worldviews differed from those of Western societies where

FIGURE 1

Relations between science, technology and production in developed and developing countries



Source: adapted from Sagasti (1979a), p. 13.

science superseded religion and myth as means to generate knowledge for explaining and natural and social phenomena. In these countries, God's will and divine interventions, as well as mysterious and mystical forces, continued to structure the relationships between human beings and the natural and social phenomena that affected them. The evolution of their technical base was the largely a result of localized trial and error processes, and the transformations experienced by the production system were also the result of slow changes made to adapt to local conditions and demands.

To the extent that developing countries interacted with their Western counterparts during the last four centuries, they acquired a thin layer of modern scientific, technological and production activities that usually remained isolated from each other. Traditional practices were employed in most production activities, many of which were location specific. With few interactions between modern science and both indigenous and modern technologies, and with very little relation between their modern technological activities and their traditional and modern productive systems, these countries evolved an *exogenous scientific and technological base*.

The elements or components of the proposed conceptual framework can be summarized as follows: three currents of human activities (evolution of speculative thought, transformation of the technological base, and modification of production and service activities); the social, cultural and political context, together with the institutional arrangements, in which these three currents unfold; the interactions among these three currents, and between these currents and their counterparts in other societies; a direction for the evolution of human activities (emancipation, value creation and realization, development); and an instrumental condition (to acquire an endogenous scientific and technological base). Box 1 summarizes the definition of these elements.

The unfolding and deployment of these components over time characterize the historical development of societies, help to understand the current worldwide distribution of scientific and technological capabilities, and suggest possible avenues towards development and the acquisition of an endogenous scientific and technological base. The next section summarizes briefly the evolution of speculative

BOX 1: **Some terms used in the description of the integrative conceptual framework**
(See Figure 1)

Speculative thought refers to a set of concepts, ideas, metaphors, myths and other mental constructs that aim at understanding natural and social phenomena, and also at offering explanations that give sense to human existence. It comprises ***scientific knowledge***, which is the result of the rigorous contrast between theoretical constructions and systematic experimentation, and ***traditional knowledge***, which emerges out of mythical, magic, religious and non-scientific accounts of natural and social phenomena, is anchored in deep beliefs and is usually not amenable to rigorous and systematic empirical testing.

Technological base refers to the set of organized responses to confront challenges posed by the physical and social environment, and to the criteria and procedures to select the most appropriate among these responses. It comprises ***techniques***, which are those responses obtained by trial and error and of systematic but non-theoretical experimentation, and ***technologies***, which are those responses resulting from rigorous experiments based on prior theoretical constructions.

Production and service activities refer to those actions that lead to the provision of goods and services to satisfy the needs of a community and of the individuals in it. They comprise both ***traditional production and services***, which evolved in specific sites, are closely linked to local resource endowments, are based on *techniques* and have relatively low levels of productivity; and ***modern production and services***, which are logically codified, can be moved from one location to another with relative ease, are based on *technologies*, and have relatively high productivity levels.

Endogenous scientific and technological base refers to the set of usually well developed and closely interrelated scientific, technological and production capabilities that foster *innovation* and make it possible to provide goods and services in an efficient manner

Exogenous scientific and technological base refers to the set of usually rather limited scientific, technological and production capabilities that have little interaction with each other, which are seldom related to the stock of *traditional knowledge, techniques and production* in the country, which have relatively stronger ties with their counterparts in the developed countries, and which do not foster *innovation* or efficient production.

Innovation refers to the introduction of new approaches, methods, processes, inputs, resources and other elements —based in large measure on the results of recent or older scientific and technological research— into production and service activities. The adjective "new" may be assessed against the background of different geographical settings, giving rise to local, national, regional or international innovations.

Source: Section 1 of the present report.

thought, the transformation of the technological base, the expansion and modification of production activities, and the institutional arrangements that support them, highlighting the way in which they have interacted during the last several centuries.

2. A brief historical perspective

Each of the three currents of the conceptual framework interacts with the other two and with the institutional contexts in which they are embedded, and all of these currents and interactions experience change over time. Nevertheless, amidst this multiplicity of mutually conditioned alterations and considering a long historical period, the main transformation experienced by societies takes place when there are major qualitative changes in the nature of speculative thought and in the process of knowledge generation. These lead to fundamental shifts in the conceptions of humanity and its relation to the physical world, which, in turn, will diffuse and influence the evolution of the technological base and the expansion and modification of production activities. Therefore changes in the nature of speculative thought may be thought as being the *primus inter pares*, as the primary ordering component of the conceptual framework.

2.1 The challenge of the West

The evolution of the different societies in the world can be examined in a relatively independent way until the period between the 15th and 17th centuries, in which the knowledge generation process underwent a radical transformation. Before this period, it is possible to examine the historical evolution of the process of knowledge generation, of the technological base, and of production and service activities in the major civilizations —European, Indian, Chinese, Andean, Maya, Aztec, Islamic, among others— considered more or less as individual units.

However, the world experienced an irreversible transformation beginning with the scientific and industrial revolutions, which were accompanied by qualitative changes in the technological base and by the international expansion of the capitalist system of production that emerged in Western Europe. After those events it is not possible to consider the evolution of the non-European civilizations, cultures and societies in an independent manner: their study must take into account the challenges posed by the West to them and the responses they generated. The point of inflection coincided with the transformation of speculative thought and the changes that took place in the generation of knowledge as a consequence of the scientific revolution.

The transition towards a scientific conception of the world made it possible to link systematically abstract theories with practical experiments to study natural phenomena, to discover laws that organize and rule the physical world, and to derive postulates and norms that increased the power of human beings over nature to a previously unthinkable extent.

In parallel with these long-term conceptual changes and encompassed by them, there were transformations in the technological base, partly derived from an improved understanding of natural phenomena and partly from the systematization of empirical knowledge about techniques developed through trial and error. At the same time, influenced by and enfolded by these transformations in the technological base, production and service activities experienced significant changes during relatively short periods, at least in comparison with the transformations experienced by the two other currents.

2.2 The evolution of speculative thought

Throughout history, magic, myth, religion and science have provided different ways of generating knowledge about the physical and social contexts in which human societies evolve. These varieties of speculative thought have also attempted to explain the place that humanity occupies in the order of things. The knowledge and information they generated can also be considered as attempts to reduce the uncertainties faced by individual and social groups in their dealings with the physical and social environments.

All societies have had their own myths, especially creation myths, which usually explained the relation between human beings and deities, accounted for changes in the seasons and weather, and also provided guidance for the development of techniques and the organization of production. Myths codified knowledge, which before the advent of writing had to be transmitted orally from generation to generation.

Religion superseded myth and provided a more orderly way of accounting for natural phenomena and for explaining the place of human beings in the universe.

God's will and divine interventions, which were to be interpreted by shamans and priests acting as intermediaries between deities and humanity, structured the relations between societies and their physical environment, as well as the relations between individuals. The assumption that there exists a natural hidden order, established by divine fiat, would become a motivating force for engaging in speculative thought and for generating knowledge to unveil the mysteries of the universe.

As magic, myth and religion evolved, abstract conceptions began to emerge to account for a variety of natural events and phenomena that were recorded by the senses. For example, since Plato (430-350 BC) and Aristotle (384-322 BC), in the West our changing views of physical reality have evolved largely as a result of the interplay between two realms: an abstract one of ideas and forms, associated with our mental faculties, and a tangible one of matter and substances, associated with our sensory perceptions.

About this time, Chinese scholars and Indian thinkers offered rather elaborate accounts of the structure of matter —the first with five elements, two fundamental forces and a variety of interactions among them, and the second with a more complex and subtle schemes involving minute particles and causal effects—, but these conceptions would not affect in a major way the subsequent evolution of Western accounts of physical reality. The Middle Ages added relatively little to the conceptions inherited from Aristotle, and linked them to the designs of an omnipotent God that exerted a continuous influence upon his creatures on earth. Islamic scholars and alchemists would build on Aristotle's conception of matter and forms, developed a scheme that linked cosmic and earthly forces, and gave an account of the transformations experienced by minerals and metals.

Abstract thinking led to the development of symbolic logic, geometry, algebra and various branches of mathematics in ancient Greece, India, Islam and other civilizations. Although unevenly developed in different parts of the world,< as a whole these advances provided a set of rules for the manipulation of concepts, ideas and other abstract products of the human mind. As a result, it became possible to develop theories and theoretical constructions. With the passage of time the capacity to manipulate abstract symbols would eventually lead to the invention of differential calculus and of other mathematical tools that became essential to the development of modern science in the West.

A variety of institutional arrangements —which took the form of organizations, rituals, social habits, patronage, among many others— were devised by different societies to engage in the production of speculative thought and to generate abstract knowledge. Shamans, priests and clerics, working individually or in sects and churches, applied themselves to the creation, organization and dissemination of abstract notions and concepts that provided accounts of natural phenomena. Kings, tyrants, feudal lords and rulers of all types, as well as public officials and wealthy merchants, gave patronage to those (mostly men) who engaged in the production of knowledge.

The Medieval outlook, which was characterized by the belief that divine will had imposed a hidden order in the workings of the universe, an order which could be uncovered by his creatures, allowed natural phenomena to be seen as following predictable —albeit unknown— rules, rather than as capricious events. Many contributions of the late Middle Ages and the Renaissance laid the foundations for the emergence of modern science in the 16^{th}-17^{th} centuries. These included: the work of Roger Bacon on the importance of rigorous experimentation as a source of knowledge; the rudimentary experiments of alchemists to manipulate the constituent elements of matter; the rediscovery of Aristotle’s works through the mediation of Islamic scholars (which would help to break the static, non experimental hold of Platonic ideas); developments in the plastic arts, which stressed the importance of careful observation and led to the rediscovery of geometry; the invention of Guttenberg’s movable type printing press, which allowed a wider distribution of texts that codified existing knowledge; improved techniques of celestial observation (including the invention of the telescope) that, together with advances in mathematics (algebra and geometry), helped to reinterpret existing records and allowed to develop new conceptions of the movements of planets and stars (best exemplified by Copernicus’ heliocentric ellipses superseding Ptolemy’s geocentric circles with a profusion of cycles and epicycles). All of this laid the groundwork for the emergence of the scientific method, which would be later developed by Bacon, Descartes, Galileo and Newton.

In the non-Western parts of the world, traditional speculative knowledge confronted the challenge of religious ideas and the intellectual outlook of European missionaries (often with deadly results, as indicated by the movements to "extirpate idolatries" in Latin America). The interests and preoccupations of European researchers would eventually lead to the emergence of "colonial science" in various parts of the non-Western world.

The emergence of the modern scientific method during the 16th and 17th centuries, which would culminate in "the Newtonian synthesis," allowed to systematically relate the realm of ideas with that of tangible biophysical phenomena. The scientific method —characterized by a set of procedures to link the manipulation of abstract concepts and symbols with observations and experiments— led to major advances in all branches of science, from astronomy and mathematics, to physics and biology. The increasing stock of knowledge, a result of the growth of scientific research, generated the need to classify the rapidly growing amount of information and led to the first attempt of French Encyclopedists.

In the two centuries following the scientific revolution science became firmly entrenched as the principal means of generating knowledge. By the end of the 19th century advances in physics had left prominent members of the scientific community wondering if there was anything else of fundamental nature left to discover. Darwinian evolutionary theory, enriched with Mendel's contributions on genetic factors in inheritance, reigned in the biological sciences and would supply a powerful metaphor for all fields of human activity.

Two major advances in physics in the early decades of the 20th century —general relativity and quantum physics— would alter the prevailing conceptions of the physical world in a fundamental manner. In Einstein's recasting of physical reality, space and time were no longer considered as an immutable, all-encompassing universal stage, independent of the forces and bodies that dwell on it. They were rather conceived as space-time, a four-dimensional construct that interacts with mass and energy. These interactions distort the fabric of space-time and gravity is no longer considered as a force acting between masses at a distance, as Newton had postulated, but as a curvature of space-time caused by the presence of bodies and forces in it.

Quantum mechanics would modify our conceptions of physical reality in an even more radical way. Classical physicists, including Newton and Einstein, considered that it was possible, at least in principle, to define the state of a mechanical system with precision, subject only to measurement errors. The quantum conception of the universe introduced the idea of probability into the basic structure of matter and energy. It was no longer possible —not even in principle— to know with certainty both the position and the momentum of a particle at a given instant in time: Heisenberg's uncertainty principle states that the more precise the measurement of the position, the less exact the measurement of its momentum must be.

However, it would take several decades until these two scientific discoveries would encounter practical applications. Einstein's formulations, complemented with contributions from many other physicists, would eventually lead to the construction of the atomic bomb during World War II, and quantum mechanics would provide the theoretical foundations for the invention of semiconductor devices, which in turn would pave the way for advances in microelectronics and the information revolution in the second half of the 20th century.

During the early decades of the 20th century there were also significant advances in the medical sciences, which included the discovery of antibiotics to treat infections, the use of safe procedures for blood transfusion, and the discovery of painkillers such as Novocain. In addition, modern statistical methods were developed starting in the second decade of the 20th century to extract information from physical, biological and social data. These included sampling methods, test of hypothesis and the development of mathematical functions to describe the various properties of statistical distributions. These methods became indispensable tools for scientific research, for they allowed researchers to extract the maximum possible amount of information from limited data, thus facilitating the process of accepting or rejecting hypotheses in scientific experiments and tests.

This brief examination of the evolution of speculative thought suggests that every civilization and culture has its own characteristic way of generating and acquiring knowledge. However, in general and over a long time, a transition can be observed from the contemplation and passive acceptance of the manifestations of nature towards greater interaction between man and the phenomena that surround him. Although there are great variations in approach, rate of advance and emphasis (e.g. relative weight of abstract theories versus empirical aspects), it can thus be said that changes in speculative thought and in the way of generating knowledge in different societies exhibit certain commonalities. Whichever the scheme employed to explain this process, it is possible to perceive a gradual if uneven progression towards the use of reason as the principal means to structure the human vision of the physical, social, intellectual and, to a much lesser extent, spiritual world. This predominance of reason, together with the recognition of its limitations, led to a revaluation of traditional and indigenous ways of generating knowledge at the end of the 20th century. Human reason can adopt a multiplicity of forms and should be seen from a broad perspective —and not only from the narrow vantage point of Western science.

2.3 Changes in the Technological Base

Throughout history each society has developed a distinctive set of responses to relate to its biophysical environment. Agricultural practices, irrigation schemes, animal husbandry, metal working, pottery making, manufacture of textiles, stone cutting, means of transport, production of artifacts, construction methods and health care procedures, among many others, have evolved gradually over long periods of time as social responses to the specific demands imposed by the biophysical context.

Technical responses can be seen as evolving through a series of steps. Initially, a social group has at its disposal a layer of passive empirical knowledge that offers responses only to specific challenges and situations one by one; later it acquires a base of empirical knowledge that begins to detect variations in the efficacy of such responses and to register them through trial and error. At a following stage, it develops a base of active empirical knowledge in which there is the beginnings of systematic experimentation, but without theoretical knowledge to orient the experiments. While advancing in the transition towards more complex and richly endowed sets of techniques, the variety of available responses increases continuously and creates a vast "genetic reservoir" of technical knowledge.

A subsequent stage is characterized by the evolution of technical responses based on theoretical constructions, heralding the transition from "technique" to "technology." At first such abstract theories are quite rudimentary, and the incipient technologies associated with them are not much different from those derived from the systematization of active empirical knowledge. Gradually, starting in the 15th-17th centuries, theories begin to explain the workings of techniques and anticipate their evolution. Much later, and particularly in the Western world, theory would take precedence over practice. The manipulation of abstract symbols would eventually lead to the development of new technologies lying outside the scope of prior empirical knowledge or experience, and also to their validation through scientific experimentation. The rise of engineering practices and the institutionalization of the engineering profession, particularly after the 17th century, are associated with the triumph of "technology" over "technique."

The institutional arrangements for the transformation of the technological base in the Ancient World and the Middle Ages were closely tied to the organizations involved in the modification and expansion of production activities, for evolution through trial and error requires engaging in actual production. In addition, as technique began to metamorphose into technology, a set of "common sense" habits of thought and social practices provided criteria for selecting among the rapidly increasing set of potential technological responses. Faced with a growing stock of information about possible ways of dealing with the challenges of the physical and biological environment, societies developed institutional mechanisms — organizations, rules and regulations, selection criteria— that provided guidance in the process of transforming potential into actual responses, thus guiding the evolution of technologies and by extension of production activities.

Technical knowledge, which by the late Middle Ages had been accumulating mostly as a result of trial and error and of systematic but non-theoretical experimentation, began to grow and diffuse rapidly throughout the world. The European discovery of new lands, peoples, plants, animals and products stimulated the search for and exchange of knowledge about techniques and products, and in the late 16th century, Francis Bacon would argue that three technological breakthroughs —gunpowder, the compass and the printing press— had changed the course of human history. Advances in military engineering, with the construction of fortresses, bridges and mechanical weapons, and in civil engineering, with the construction of palaces, churches, houses, irrigation schemes and water supply systems, spread rapidly as designs and blueprints became widely available and as engineers began to travel extensively.

Several treatises on agriculture, mechanics, metallurgy, medicine and alchemy (the precursor of chemistry) circulated extensively among practitioners and made knowledge and information, once jealously guarded, available to a growing number of practitioners. As the economic value of such technological advances became evident, the first attempts at creating what are now know as "industrial property rights" emerged with the establishment of a rudimentary patent system, first in Venice and then in other Italian and European cities. At the same time, a gradual replacement of sources of power took place as advances in technological knowledge led to the development of windmills and watermills that replaced human and animal power, and eventually to the steam engine and various mechanical devices that increased the efficiency of motor power in the 18th century.

The first ideas for the design of calculating machines —which would replace routine human intellectual labor— were put forward by Blas Pascal in the 1640s, and a rough design for the construction of a general purpose computing machine was advanced by Charles Babbage in the 1830s. Yet, although mechanical calculating machines became a common sight in the late 19th century, it would take another hundred years before Babbage's designs could be realized and a programmable computer would become a practical proposition.

Progress in military, naval, civil and mechanical engineering would gradually become associated with advances in physics and mathematics. The invention of infinitesimal calculus by Gottfried Leibniz and Isaac Newton provided the mathematical tools for solving complex problems, such as computing the trajectories of moving bodies subject to acceleration. The rise of engineering sciences would expand considerably the range of technological knowledge in European empires and in some of their colonies. The importance awarded to modern science and technology was underscored by the privileged position they were awarded by the Founding Fathers of the United States of America at the time of independence.

Thus, between the 17th and 19th centuries, advances in technological knowledge led to a variety of ways of augmenting human capabilities, both physical and intellectual. To a growing extent, progress in technology during this period began to be linked to advances in the sciences, thus laying the ground for the full emergence of science-based technologies in the late 19th and 20th centuries.

By the end of the 19th century, the new applications of electricity and of chemical synthesis were rapidly transforming the technological base in the more advanced industrial nations. The interpenetration of science and technology continued at a rapid pace, particularly in the chemical industry, as advances in organic chemistry led to the development of plastics, pesticides, synthetic fibers, many of them derived from oil (whose production increased significantly). Advances in physics and metallurgy led to improved steel making and metal working technologies.

During the first decades of the 20th century deliberate research efforts transformed knowledge into a critical factor of industrial production, and industrial laboratories began to produce a stream of inventions that soon found their way to mechanical shop floors and chemical plants. Standardization and manufacturing with interchangeable components led to major increases in productivity, and industrial organization methods —pioneered by Frederick Taylor and his "scientific management"— made further efficiency improvements possible.

Electricity and hydrocarbons became the main sources of power for industry, transportation and households. The increased availability of electric motors, which became smaller, cheaper and more efficient, together with improvements in transmission networks, allowed to distribute electric power widely at low cost. A similar development took place with the internal combustion engine, which together with the increased availability of oil and gasoline, led to the spectacular growth of the automobile industry in the second and third decades of the 20th century. In turn, this led to major changes in the production and distribution of all types of goods, in the organization of private life, and in war making.

The rise of the automobile industry, which was dependent on the almost limitless supply of oil and gasoline at rather low prices, led to the development of vast networks of roads, first in the United States, then in Europe and subsequently throughout the world. In turn, this required networks of gas stations, mechanical repair shops, and of suppliers of various ancillary goods and equipment for automobiles. As automobiles became more affordable but still exceeded the capacity of most households to pay for them in full, consumer credit lines began to be offered by financial institutions, an innovation that would soon extend to other consumer durable goods.

New equipment and machinery for industry (machine tools), agriculture (harvesters and tractors), construction (bulldozers and concrete mixers), mining and oil (drilling bits and tools) and administrative tasks (electric calculators and typewriters) led to major improvements in productivity in practically all sectors of the economy. The aircraft industry began in the early years of the 20th century and in a just few decades airplanes introduced fundamental changes in long-distance transport of mail, passengers and cargo, and also in the ways of fighting wars. Technological innovations in telecommunications and in the recording of voice, sounds and pictures transformed human interactions and provided new means for storing and transmitting vast amounts of information across time and space.

With the growth of science-based technologies, technological knowledge began to permeate production and service activities in the industrialized nations and to almost completely replace the technical knowledge acquired through trial and error. Yet, in most parts of the world outside Europe and North America, traditional techniques would still provide for many decades the means to ensure the livelihood of most people in the poor regions of Asia, Africa, Latin America and the Middle East. Even in the industrialized countries, pockets of artisan and "hand made" production activities remained highly valued and their products were sought after.

This brief review of the transformation of the technological base indicates that the challenges posed by the biophysical environment condition the demand for technical and technological responses and the organizational forms that societies adopt to confront them. Although the transition from technique to technology took place mainly and most successfully in the West, non-Western cultures and societies also acquired and evolved a set of technical and technological responses of their own, usually appropriate to their context, often based on mixes of indigenous and Western knowledge, and always processed by the social organization forms particular to them. As the predominant stock of Western technological responses begins to be questioned, largely on environmental and social sustainability grounds, it would be useful to study the alternative configurations of the technological base in societies that have not been completely Westernized, and where indigenous knowledge and techniques still play a significant role.

2.4 Changes in production and service activities

The modification and expansion of production activities has as its principal motivation the satisfaction of the needs of the members of a society. Over time, all social groups have increased the range of products and services provided to their members, enhanced their quality and improved production methods. The exchange of knowledge and information —primarily through trade, the displacement of persons and later the transmission of written information— has played a major role in the process of producing more goods and services of better quality and with less inputs. However, the definition of "needs" varies over time, with the degree of material development of a society and with income distribution patterns. At present a large number of needs are generated artificially by the logic of the accumulation process itself, particularly in highly industrialized market economies.

The expansion and modification of production activities was closely related to the evolution of the accumulation process, and to the way in which the economic surplus was appropriated, distributed and allocated to various social activities. The traditional uses of accumulation —characteristic of most civilizations and societies until the expansion of European capitalism— include securing food stocks and reserves; constructing temples, palaces and defense walls; waging war and maintaining armed forces; supporting religion and the priesthood; and providing patronage to the arts, crafts, and the pursuit of speculative knowledge. The new uses of accumulation began to spread during the late Middle Ages and the Renaissance, and were consolidated during the expansion of the European empires and of the capitalist mode of production. These included: opening commercial routes, discovering natural resources, increasing labor productivity, facilitating economic transactions, and creating or acquiring technological knowledge. The surplus accumulated in capitalist societies was invested to generate additional economic surplus, which would be used once more for furthering the accumulation process.

Production and service activities grew through the 15th-17th centuries in close connection with the evolution of the repertoire of technical and technological responses. Indeed, before the advent of "technology," the tightly joined evolution of these two currents —technical knowledge and production activities— made it rather difficult to distinguish between them. After the marriage of *logos* and *techné* the range of potential responses to the challenges of the biophysical and social environments increased to such an extent that only a gradually diminishing proportion of these responses were put in practice. A variety of institutional arrangements, mostly related to market forces and the allocation of financial resources, would filter the growing stock of potential technological responses and select those relatively more efficient or profitable to be put in practice.

A counterpoint between the range of products and services on the one hand, and of needs to be satisfied on the other, has been a integral feature of the expansion and modification of production in all societies. Needs have spurred human ingenuity to devise new products and services, together with the techniques and technologies associated with them. As new products and services became available, and as new knowledge and information increased the potential supply of goods and services, a corresponding growth and diversification of needs would transform itself into actual demand for such goods and services.

A wide variety of institutional arrangements were devised by different civilizations to organize the production and distribution of goods and services. While self-regulating markets have come to be seen in modern times as the natural way of engaging in such activities, for most of history and in most of the world, reciprocity and redistribution arrangements, usually articulated and mediated by hierarchical authorities, provided the institutional underpinnings for transactions in traditional economies.

The exchange of goods and services began to be structured through markets, which evolved from bazaars and exchanges along trade routes, towards the convergence of sellers and buyers at specific places, and towards the creation of self-regulating markets for exchanging symbolic representations of the actual goods. A variety of complementary institutions evolved over time to structure the organization of production and service activities. Property rights and contracts allowed economic agents to receive the benefits and pay the cost of their production and service activities. As the geographical scope of exchanges of goods and services expanded, market transactions superseded the small community of personalized trade and kinship-based connections that embodied trust relations. Impersonal exchange with strangers required other mechanisms to curtail opportunistic behavior and make market transactions reliable.

Many different institutions, some related to incipient state organizations and others to private associations, emerged to provide the public goods —means to validate and enforce contracts, information on the past behavior economic agents, agreements on trading rules, standards regarding weights and measures, information on the terms of previous transactions— required for the proper functioning of self-regulating markets and for reducing transaction costs. Similarly, going well beyond the creation of money as a means to facilitate market exchanges, financial and insurance institutions were created to allow transactions that spanned long distances or occurred over a long period of time.

As a consequence, production activities expanded and diversified at an unprecedented pace during the Renaissance and the centuries that followed. Improved means of transport increased trade and led to greater specialization and division of labor between economies in Europe and in other parts of the world.

Surpluses obtained from trade, agriculture and the colonies began to be channeled into new productive ventures, often through incipient financial institutions. As early as the 13th century, Italian merchants had begun to open accounts with one another to reduce the costs and risks of paying with coin. Bills of exchange were issued authorizing the seller to draw down on the buyer's account at a particular time. As this practice spread, deposit-taking merchants engaged in transactions with various sellers and buyers realized that they did not need to maintain in full the amount of financial resources associated with specific transactions. Idle balances could be used to purchase bills of exchange at discount from sellers who wanted their money before the specified time, thus allowing the deposit-taking merchant to reap the difference between the full and discounted amounts. From these beginnings, a full range of banks and other financial institutions emerged gradually to finance trade and investments in production facilities

As requests for funding from potential producers and traders grew, those individuals and firms engaged in the provision of financial resources faced the problem of selecting among competing requests for resources. In this way, banks gradually transformed themselves into project selection entities that decided on the allocation of financial resources, primarily on the basis of information about the expected returns from each venture. The worldwide expansion of colonial empires increased significantly the availability of financing obtained from trade surpluses, and this increased the importance of banks as financial intermediaries to the extent that they were able to finance, not only productive and commercial enterprises, but also wars and expeditions undertaken by states.

Production and service activities experienced profound transformations during the 18th century, particularly with the Industrial Revolution that started in England and then spread through Europe. The factory system, which was first established in the textile industry, began to expand into other areas of manufacture. The institutional transformations that accompanied the Industrial Revolution required that large-scale, self-regulating markets for labor, land and money be established. These nation-wide markets emerged first in England, and required the forceful intervention of the central government to become a reality.

The swift expansion of European empires in Africa, Asia and Latin America made it impossible to consider the evolution of knowledge production, acquisition, distribution and use, as well as the institutions associated with these activities, without reference to the West.

The repertoire of European technical and technological responses, particularly in the military field, would prove overwhelming to African, Indian, Mexican, Andean, Chinese and Southeast Asian civilizations. At the same time, the exchange of plants and animals expanded considerably agricultural activities in Europe and the conquered lands. Production and trade in the colonies and in far-flung trading posts was organized as a function of the requirements of the European powers, as indicated by the spice trade, the mining of gold and silver, the establishment of plantations and large farms, the trade in textiles (cotton, silk and wool) and the infamous slave trade. In each of these regions, traditional knowledge and institutions did not disappear completely and in many cases, such as the Andean region, China and India, they coexisted uneasily with their transplanted counterparts from the West during several centuries. In contrast with the colonized lands, Japan adopted policies that allowed it to remain relatively isolated from European influence through the mid-19th century, where deliberate efforts to acquire Western knowledge and technology, and to adapt Western institutions to the Japanese setting, were made by the Meiji dynasty.

The emergence of two major industrial activities in the second half of the 19th century —electricity and organic chemistry— signaled the transition towards science-based production in the industrialized nations. This would become a prominent feature of the evolution of knowledge and information during the 20th century, as production and service activities derived from scientific discoveries and technological advances increased in number and pervasiveness.

Beginning in the mid-19th century, agricultural technologies also began to experiment major transformations, particularly in the United States with the establishment of the Land Grant Colleges and a network of experimental agricultural stations and of extension services. Medical sciences, technologies and practices, which had experienced major advances through improved anatomical descriptions and the use of the microscope in the 17th-18th centuries, would experience a further jump in the 19th century with the development of vaccines, the germ theory of disease and the use of anesthetics.

In manufacturing, following the seminal description and explanation of the impact of the division of labor provided by Adam Smith in the 18th century, the advent of time and motion studies pioneered by Lillian Gilbreth, and rigorous scheduling procedures, initially put forward by Henry Gantt, led in the late 19th century to the development of industrial engineering and of scientific management (as Frederick Taylor would call it two decades later). Thus the methods of science began to be applied, not only to the development of technological knowledge for production, but also to a wide variety of production management, administration and coordination activities.

Towards the end of the 19th century, a broad process of integration into world markets was well under way in most regions, even though trade patterns were highly asymmetric. The more industrialized nations of Europe and North America exported manufactures and other knowledge-intensive goods and services, while colonies in Asia, Africa and the Middle East, as well as the independent nations of Latin America, exported mainly primary commodities. World War I, the Great Depression and World War II interrupted this integration process, and at the same time created the conditions for the development of production activities outside Europe and North America. Developing countries enjoyed a certain "natural protection" for their industrial activities, as their productive systems in the more advanced industrialized countries turned to the war effort in 1914-1917 and, once again, in 1939-1945, and as their production activities experienced a major crisis during the 1930s. For example, Latin American countries took advantage of this and expanded their industries to supply domestic demand, and a similar situation prevailed in India.

This brief review of changes in the social organization of production, which are a consequence of the way in which surpluses are used and of the direction taken by the accumulation process, interact with the transformations of the technological base and the evolution of speculative thought. The expanded repertoire of technological responses presents the productive system with a range of possibilities for increasing the generation of surplus, while the greater availability of financial resources constitute a challenge to human inventiveness and stimulates the development of new technologies and the evolution of new forms of speculative thought. The emergence of the secular concept of reason, the desacralization of nature, and the rational conception of the world that found its expression in thinkers like Rene Descartes and Francis Bacon, provided the ideological foundations for the organization of production in accordance with the demands of the process of accumulation, and also with the private appropriation of the surplus associated with the emergence of market economies. At the same time, the diffusion of capitalist production, characteristic of the industrial civilization of the West, contributed to the predominance of the secularized and instrumental vision of "rationality", which expanded its scope relentlessly.

A constant in the process of evolution of production activities, particularly during the last four centuries with the diffusion of capitalism and the industrial civilization of the West, has been the enlargement of their geographical scope. From their organization at the local level, production and service activities extended at the regional and continental levels, and at present encompass the whole planet. This internationalization process has been accompanied by the emergence of a global consumer elite with rather similar consumption patterns, superimposed over a variety of local forms of consumption—corresponding to much lower levels of income and resource use— in the developing societies.

2.5 Interactions among the currents: the "triple crisis"

According to the proposed conceptual model, the interactions between the different stages in the evolution of these three currents, visualized against the background of social, political and cultural institutions, characterize the degree of development of a particular society. For example, in the West the evolution of speculative thought led to science as the key method for generating knowledge, which accelerated the transformation of the technological base and helped in the transition from "technique" to "technology", while receiving at the same time the assistance of many technological advances that contributed to the expansion of scientific research. Production and service activities found increasing support in the new science-related technologies, to the extent that at present production activities that employ technologies with scientific origin are clearly superior and dominate the economic scene. All of this took place together with the acceleration and reorientation of the process of accumulation and with the emergence and expansion of capitalism as the dominant mode of production, a process that fed on technological and scientific advances and which, in turn, gave the stimulus and the material resources to support the research activities that generated such advances. This is what led to the emergence of an *endogenous scientific and technological base* in the highly industrialized countries.

In parallel, other cultures and societies developed their own ways of linking these three currents and of relating them to their social, political and cultural contexts. For example, Chinese scholars made great advances in speculative thought and in knowledge about celestial and physical phenomena, Chinese artisans and skilled workmen created techniques based on the systematic application of general rules (as shown by their clock making proficiency), and Chinese philosophers and administrators evolved social organization forms —such as the imperial bureaucracy— to rule a vast and diverse empire. However, a variety of social, economic, and political factors —which emerged as a response to the specific environment of Chinese culture and civilization— were not conducive to modern science and to the creation of an endogenous scientific and technological base. Similar considerations can be applied to India, the Islamic world, and to the indigenous civilizations and cultures of other regions such as Latin America and Africa.

Examining in detail the transformations experienced by these three currents, their interactions and their contexts in different societies (a task well beyond this essay), it would be possible to identify a variety of paths towards emancipation or towards the creation and realization of values. Such an examination would make it possible to assess progress towards "development", but without using the achievements of Western civilization as a yardstick. In turn, this may help to place the achievements of the West in their proper perspective, and to understand its limitations and the nature of the crisis Western civilization is experiencing as we enter into the 21st century. Moreover, an exercise of this sort would provide insights for exploring new roads towards the progressive acquisition of endogenous scientific and technological capabilities in the developing countries.

The interactions between the three currents are highly complex and difficult to trace, among other reasons because they move at different speeds and their mutual conditioning takes place within different time horizons. Considering a historical period of several centuries, the major qualitative changes in the nature of speculative thought and in the process of knowledge generation will determine the overall direction for social evolution. As a result of these changes, the conception of human beings about themselves and about their relation with the biophysical world is transformed, and the emerging conception gradually permeates and encompasses all human activities, and particularly the technological base and the structure of production activities.

At the other extreme, considering the relatively short span of several decades, the structure of production and service activities plays the key role in shaping social behavior. It defines the specific products and services available to the community, the orientation of the process of accumulation and the distribution of the social product. In this regard, the dominant form of speculative thought, which emerges as the result of an evolutionary process taking several centuries, would constitute a "fixed" background against which the relatively short-term modifications in the structure of production activities take place.

The time span in which the technological base experiences major transformations occupies an intermediate place, somewhere in between the several decades necessary for the emergence of significant changes in the structure of production activities, and the several centuries required for the evolution of the dominant forms of speculative thought. A period between one and two centuries appears appropriate for conceptualizing the major transformations in the technological base, which define the repertoire of responses available to confront the challenges posed by the physical and social environment. Furthermore, although these transformations take place within the framework of a particular dominant form of speculative thought, they also exert a reciprocal influence on its evolution. At the same time, the prevailing technological base sets the scene for the changes that production and services activities undergo.

Thus the three currents evolve at different speeds, with the changes in production activities crystallizing in a span of decades, with the transformations of the technological base taking place in a period between one and two centuries, and with the evolution of speculative thought experiencing major changes in a span of several centuries. The modifications in the structure of production and service activities generate tensions that accumulate and pressure for changes in the technological base; in a similar way, the transformations of the technological base generate and accumulate tensions that induce fundamental changes in the nature of speculative thought. Therefore, any account of the evolution of these three currents must take into consideration both their internal dynamics and the set of reciprocal influences among them. In addition, the time span chosen to frame a particular inquiry will define which of the three currents plays the dominant role.

Societies experience a period of instability and adjustments when making the transition from one to another structure of production activities, a process that takes place every several decades and can take up to twenty years. Greater upheavals and instability can be expected when there are major changes in the technological base, which occur every century and a half or so and take place over a few decades. Finally, profound upheavals, turmoil and turbulence accompany the transition from one to another dominant form of speculative thought every several hundred years, a process that can take a century or more.

The transition from the 20th to the 21st centuries is a particularly complex and difficult period, in which humanity as a whole is experiencing fundamental changes in the dominant mode of speculative thought, the technological base and the structure of production activities. In the first of these, we are in the early stages of the transition to a “post-Baconian” age, which is opening the doors to new forms of knowledge generation that will eventually complement and possibly supersede science. The technological base has experienced major alterations with the emergence of a new set of responses, based on the manipulation of digital information, to respond to the challenges of the biophysical and social context. Production and service activities are in the middle of the transition from a techno-economic paradigm based on cheap oil and energy as the key input, into one where the microchip holds center stage. Because of the simultaneity of these transitions we are witnessing a veritable "knowledge explosion", whose manifestations will be discussed in the following section.

These simultaneous processes of transformation in the three currents have acquired the character of a "triple crisis" that is affecting all of humanity to an unprecedented degree. Their impact has been heightened by the accelerated process of globalization, and by the emergence of a fractured global order during the last quarter of the 20th century.

3. The knowledge explosion and its manifestations

The triple crisis at the beginning of the 21st century is closely associated with the simultaneous transformations that speculative thought, the technological base and the structure of production activities are undergoing an explosive growth in the generation and utilization of knowledge of all types, particularly of the results of scientific research. This has led to: (i) the emergence of the "knowledge society"; (ii) the transformation of scientific research; (iii) highly complex and systemic innovation processes; (iv) a change in the structure of production activities and a transition towards a new techno-economic paradigm, and (v) to the acknowledgement of the importance of traditional knowledge, techniques and production. Each of these will be discussed in turn.

3.1 The emergence of the knowledge society

Scientific advances and technological innovations are at the root of the complex processes of social change that have taken place during the second half of the 20th century. An inflexion point in the growth of human capabilities to understand the biophysical and social context, and to devise effective responses to the challenges posed by them, can be identified around the time of the World War II.

Throughout history the capacity to generate and utilize knowledge has been associated, to a significant extent, with the conduct of war. Yet, the scale and impact of the mobilization of science for military purposes during World War II was extraordinary and unprecedented. Major advances in physics and engineering led to the construction of the Atomic bomb, the development of radar and other electronic devices, and of the jet engine and new airplane designs. Scientific research also led to the production of new drugs, to advances in medical treatment and to improved synthetic materials. In addition, there were advances in the management sciences, including operational research and mathematical statistics, and in psychology and the study of group behavior.[7]

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[7] The nature of this inflexion point has been described by J. D. Bernal in a paper on "The Lessons of War for Scientists", when referring to the emergence of "operational research" as an integrative and practical way of linking the conduct of scientific and technological research to war operations:

The impulse given to scientific research by World War II continued in the years that followed, spurred not only by the Cold War, but also by the expanded opportunities for the commercial exploitation of research results. As a consequence, during the last fifty years there have been profound modifications in the way knowledge is generated and utilized, and the products of scientific research and technological innovation have become more tightly bound with and more deeply enmeshed in all aspects of human activity. The growth of scientific research, supported by advances in information and computer sciences, has been primarily responsible for this knowledge explosion.[8]

A “knowledge society”, which is radically and qualitatively different from the agricultural or industrial societies of older times, has emerged during the last few decades. In countries with an endogenous science and technology base, advances in productivity and the “dematerialization” of economies have reduced the relative importance of agriculture, industry and mining, and the proportion of workers engaged in manual labor to produce goods has steadily diminished. In contrast, the share of “knowledge workers” involved in education, government and private services, information processing and exchange, media and the arts has increased steadily. Even in the manufacturing industries, the knowledge content of products has steadily increased; for example, about half of the value of a new car lies in design, engineering, styling and related intangible components.

This has introduced profound modifications in the relations between workers involved in the production and distribution of knowledge and those engaged in various forms of manual labor. It has altered their relative status and pay, increased

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> “The original implications of operational research are already making themselves felt in peacetime economy. In principle it amounts to the statement that any human activity and any branch of that activity is a legitimate subject for scientific study, and subsequently for modification in the light of that study. Once this is accepted in practice, which implies the provision of research workers to carry out these studies, the way is open to a new level of man’s control of his environment, one in which economic and social processes become scientific through and through.” (quoted in Bernal, 1967, p. xxi).

[8] The explosive growth of knowledge has been described by David Linowes (1990, quoted in Dahlman, 1994, p. 2) in the following terms:

the educational content of jobs, introduced the need for life-long learning, and led to more flexible and unstable employment patterns.

The rise of the knowledge society, the emergence of a wide range of "knowledge industries" and the growing importance of "knowledge management", has made it necessary to focus on the great variety of types of knowledge that exist. There is an increasing recognition that knowledge acquired as a result of scientific research is but one of many forms of knowledge and —partly as a reaction to the thoroughly Western character of the modern science— there has emerged a renewed interest in non-Western traditional or indigenous forms of knowledge. Scientists from both developed and developing countries have began to explore in a systematic manner the ways in which these other types of knowledge can complement and enrich the products of science (see section 3.5).

3.2 The twilight of Bacon's program and the transformation of scientific research

The knowledge explosion that led to momentous changes in all areas of human activity is one of the main expressions of the success and maturation of the "Baconian Program". This program has dominated the speculative knowledge scene during the last four centuries and has been associated with the rise of the West. Its architect, Sir Francis Bacon, philosopher and Lord Chancellor of the British Crown, was and still remains a controversial figure, but he was the first to articulate a coherent view on how to use the power of modern science for the benefit of humanity. Nearly four centuries after he put forward his program, our lives and thoughts are deeply influenced by the visions of this extraordinary man. Two of the manifestations of the success and maturation of this program have been the heated controversy that emerged on the nature of science at the closing of the 20th century (what has been referred to as the "science wars"), and the major changes that have taken place in the way scientific research is conducted, especially in the most advanced fields.

"It took from the time of Christ to the mid-eighteenth century for knowledge to double. It doubled again 150 years later, and then again in only 50 years. Today it doubles every 4 or 5 years. More new information has been produced in the last 30 years than in the previous 5,000."

The twilight of Bacon's age. The Baconian program has been defined by philosopher Hans Jonas in the following terms: "...to aim knowledge at power over nature, and to utilize power over nature for the improvement of the human lot..." Jonas (1984, p. 140). Several features distinguished this program from other views on the production and use of knowledge that were current in Bacon's time:

- A keen awareness of the importance of appropriate procedures to generate knowledge: scientific method and of scientific research;
- A clear vision of the purpose of the knowledge-generating scientific enterprise: improving the human condition; and
- A practical understanding of the arrangements necessary to put the program in practice: scientific institutions and state support.

In later times, and particularly during the Enlightenment, the idea of indefinite, linear and cumulative human progress would become the driving force of the Baconian program. The combination of these three features with the belief in progress, all of them anchored in the firm conviction that humanity occupied the central place in the universe, gave the Baconian program a powerful and unique character, which allowed it to withstand the test of time and endure till the end of the 20th century.

A fundamental assumption of Baconian program was that human beings occupy the central place in a God-created universe; in Bacon's view divine intervention awarded humans a privileged position in the cosmos. This belief in our centrality would later be carried over into the secular realm and maintained in practically all narratives of human evolution, even though God would be dispensed with in most scientific accounts of the origin of the universe and of our species.

The assumption of humanity's uniqueness and superiority, and the centrality we awarded ourselves in the cosmic order, have both come under attack from many fronts. New challenges to our inherited conceptions of reality and of what is to be human have emerged during the 20th century, and especially during the last five decades. As a consequence, we are now being compelled to regard ourselves in a new light and from new perspectives: we are being forced to reposition humanity in an ex-centric manner in relation to other living organisms and to the world that surround human beings.

Among the findings that require a reframing of our concepts of human nature and a revision of the postulates of Bacon's program, it is possible to find:

- Advances in particle physics, which have changed our ideas of physical reality and the notion that there exists an independent world "out there", separate from us as observers.
- Discoveries in quantum cosmology, which are forcing us to modify our views regarding the origin and fate of the universe, and our conception of the place we occupy in it.
- Findings about the nature of time, which require that we abandon the idea of an absolute and immutable flow of time as a backdrop to the progress of humanity.
- Acknowledgment of the tight coupling that exists between human activities and physical ecosystems, which is forcing us to abandon the idea that nature is exists for us to conquer and dominate.
- Advances in biotechnology and genetic engineering, which are giving us the capacity to consciously alter the direction of our own biological evolution.
- Developments in artificial intelligence, which have emerged to complement and challenge conventional ideas about the uniqueness of human reason; and
- Advances in information sciences and technologies, which are in the process of creating new levels of reality and of fundamentally altering the nature of human interactions.

These challenges are a product of the scientific and technological advances of Western civilization; their combined impact, coming with thunderous force at the beginning of the 21st century, is forcing us to reassess the legacy of the Baconian age. Moreover, the unfolding of Bacon's program, the emergence and spread of capitalism, and the worldwide expansion of Western civilization proceeded hand in hand during the last four centuries. As a result, the Baconian Program ended up affecting all other cultures and civilizations in a most significant manner.

In each and every area of human inquiry our knowledge is advancing with such speed that it is nearly impossible to provide an accurate picture of the breadth and intensity of the changes under way. As a consequence of these advances, we have been compelled to accept strange notions regarding the probabilistic nature of the physical world, which is no longer seen as something objective "out there"; and to entertain even stranger conceptions postulating that there is a multiplicity of universes, whose existence cannot be proved or disproved with the tools of modern science. We have had to revise our views of linear and absolute time, which can no longer be seen as providing an immutable backdrop for the idea of indefinite human progress. We have also been forced to abandon our human-centered view of the environment, and to renew our ancestors' acceptance of reciprocity linkages between human beings and the biophysical world that surrounds us.

At the same time, we are in the process of becoming responsible for guiding the biological evolution of our species, regardless of our readiness to accept such awesome responsibility. We have had to face the challenge of artificial intelligence, which has shown us that the capacity to reason is not an exclusive prerogative of human beings; and we have also been forced to cope with the swift emergence of cyberspace, a new level of reality, which has challenged the dualism that underpinned the modern scientific outlook. Last, but not least, we have realized that technological advances in information technologies are intensifying and transforming human interactions, fragmenting our selves, and profoundly altering our sense of personal identity.

These challenges make it necessary to reconsider the foundations and main premises of the Baconian program. The methods of modern science have evolved gradually since the time of Bacon, Descartes, Galileo and Newton, but are poised to experience even more significant transformations during the 21st century. Our efforts to improve the human condition have had a host of unintended negative consequences, which have made it impossible to unambiguously abide by Bacon's injunction to employ knowledge for the benefit of humanity. The institutional settings for the generation and utilization of knowledge, together with the idea of public support for research, are experiencing wrenching transformations, as private firms and market interests penetrate the hallowed halls of basic science. In addition, confidence in the steady and indefinite character of human progress has been badly shaken by the human catastrophes of the 20th century (World War I, the Great Depression, Nazism, the Holocaust, World War II, post-Cold War genocides). The progressive loss of the ethical and moral dimensions that Bacon had built into his program, may be seen as one of the main reasons for the paradox that the program's success ended up undermining its own foundations.

All of this suggests that, as we enter into the 21st century, we are witnessing the maturation and incipient twilight of the Baconian age. The challenges to the Baconian program and the assaults on the centrality of humanity, as well as our attempts to cope with them, are creating confusion, anxiety and a widely shared feeling that humanity has lost its bearings.

One manifestation of this confusion are the "science wars" debates of the 1990s, which have pitted practicing scientists against students of the conduct of science. These debates have been seen by some academics as following from the earlier controversies spurred by the publication, four decades ago, of C. P. Snow's book *The Two Cultures and the Scientific Revolution* (Snow, 1963) which focused on the different perspectives, methods and social impact of science and the humanities. The radical critics of the scientific enterprise on one side of the science wars debate (postmodernists, feminists, radical sociologists) argue that science is socially constructed, that it the knowledge it generates is not inherently objective and thus not superior to other forms of knowledge. In consequence, the results of scientific research should be viewed and treated no differently from other forms of knowledge generated by history, literature, the humanities or the social sciences.

These views are not representative of researchers in the wider field of science, technology and society studies, in which historians, sociologists and anthropologists, study the conduct of science in a rigorous and systematic way. However, they may be seen to emerge naturally out of this field of inquiry, which aims to apply the methods of science to the study of the conduct of science itself. In this way, as the Baconian

Program reaches its full deployment and maturation, the conduct of science has acquired a self-reflective character and the scientific method is being used to scrutinize the practice of science itself.

The response of many physical and biological scientists has been to reject the relativist claims of the radical critics and, in some cases, to argue that scientific truth has an intrinsically objective character and that scientific research is not affected by extraneous factors. More moderate voices acknowledge social and institutional influences on the conduct of science, particularly in the choice of research topics, the formulation of hypothesis and adoption of a the research approach, but assert that scientific findings have a privileged place in relation to other forms of knowledge — primarily because of their verifiable character and their widespread practical applications.

Modern science is also being challenged by religious fundamentalists, who argue the supremacy of knowledge as revealed by the particular divinities associated with their creeds. Perhaps the most serious threat to a secular and reason-based view of the world and of humanity at the beginning of the 21st century comes from the Christian "creationist" movement in the United States, where some states have mandated their educational systems to treat both evolution and creationism as hypothesis on the same level. In other parts of the world the scientific outlook is under siege by religious fundamentalists who reject its association with everything they find odious or objectionable in the West. Still other, more moderate, critics of Western science, argue that alternative ways of conceiving biophysical phenomena and human interactions —associated with traditional and indigenous forms of knowledge and cosmologies—, should be recognized as having validity and usefulness, rather than being considered as backward and rejected out of hand by the scientific community.

The transformation of scientific research. The last decades of the 20th century have also witnessed major transformations in the conduct of scientific research. The first of these refers to the multiple and complex interactions between scientific research, technological innovation and the commercial exploitation of research results, which are now characteristic of the most dynamic sectors of the world's economy. These interactions have shown the inadequacy of a linear conception of scientific and technical progress, in which scientific findings lead directly to new technologies that can be subsequently incorporated into production and service activities. Instead, the accumulation of technological innovations provides a base of observations for science to delve into, and technological progress plays an important role in defining the agenda for scientific research. Innovations in industry, agriculture, mining, energy, transportation, education and health care, among many other fields of human activity, continuously identify new problems to be addressed by science. At the same time, new instruments for observing, measuring and testing biological and physical phenomena have become a major determinant of scientific progress.

All these interrelations have dramatically reduced the time between scientific discovery and economic exploitation of research results. During the 19th century it took fifty years between Faraday's discovery that a moving magnetic field can produce electricity and the first practical system for the generation and distribution of electric energy. Forty years elapsed between Einstein's early 20th century discovery of the fundamental relations between matter and energy and the detonation of the first Atomic bomb. Twenty years were necessary for Watson and Crick's discovery of the structure of DNA in the mid-20th century to be applied in first transplant of genes. Yet, it took only six years between the discovery of the electron tunneling effect by Esaki in 1957 and the first commercial application of semiconductor diodes. The time between the creation of new knowledge and its incorporation into new products and processes has been shortening very rapidly, particularly in the fields of information technologies, biotechnology and new materials.

A second transformation refers to the institutional settings for the conduct of basic research, applied research and for the development of science-based products and processes. Shifts in funding sources and the more prominent role the private sector in the conduct and financing of scientific research are behind these institutional changes. In most of the high-income countries the private sector is now responsible for conducting at least half of research and development activities (in Japan, Sweden, Finland and Ireland the proportion is even higher). Universities account for 15 to 20 percent and public research institutes are responsible for the rest. Moreover, in addition to their own research and development activities, private firms also finance research in universities and work jointly with government institutions.

As a result, links between universities and private firms are strengthening, collaborative industrial research and technological alliances have become an imperative in the more advanced technological fields, and venture capital firms and some specialized government agencies are playing an increasingly important role in providing capital for new-technology businesses. These changes have been taking place during the last three decades and primarily in the high-income countries, although several newly industrializing nations —particularly in South East Asia— are also moving in this direction. This new situation stands in marked contrast to the estimates provided by J. D. Bernal for the United Kingdom in the 1930s, which indicated that private industry accounted for 25 to 30 percent of research expenditures.

Institutional settings for the conduct of scientific and technological activities have also changed largely in response to major increases in the cost of basic and applied research, which are also bringing about greater concentration in fields where large facilities are needed and results may take a long time. Certain fields of inquiry (particle physics, genetics, molecular biology, astrophysics, among many others) have become increasingly dependent on high cost instruments, which —as in the case of chemical synthesis and advanced microelectronics research— combine advances in electronics, materials sciences, optics, analytical techniques and information processing.

The consequences for developing countries of the maturation of the Baconian program and of the changes in the conduct of scientific research are quite significant. While the twilight of the Baconian age will last for a rather long time, spanning at least the first half of the 21st century, it is not too early to begin the search for a new program to replace the one articulated by Bacon nearly four centuries ago, but one in which all civilizations and cultures may see their heritages and contributions reflected. Without falling into the excesses of religious fundamentalism and radical postmodernism, it is necessary to frame the achievements of the Baconian Program, of Western civilization and of modern science in a broader framework that should leave room for other perspectives to complement and enhance the scientific outlook of the West.

The implications of the transformations of scientific research are more immediate and direct. The high cost of advanced instruments and financial constraints have effectively put many fields of research out of the reach of the vast majority of scientific institutions in developing countries. At the same time, advances in information technologies may be ameliorating some of these trends. First, relatively inexpensive "virtual" advanced instruments can be replicated by using software that runs on standard personal computers, and it has been pointed out that the virtual version of an instrument —which is often more versatile— can cost 20 times less than a conventional scientific instrument.

Second, advances in microelectronics, information processing and telecommunications now allow researchers from all parts of the world, including the poorer regions, to actively participate in joint research projects. There is greater access to libraries and other sources of written information, it is also possible to interact in real time with peers in distant places through electronic conferences, and there is also the possibility of sending data and test results to centers with advanced facilities to analyze them. While these opportunities are still being explored, it is clear that there is a great potential for developing country scientists to become actively involved in many aspects of scientific research, even in areas such as theoretical physics that would appear at first sight closed to them.

Finally, the accelerated pace of scientific progress requires a continuous effort to keep up with advances in the state of the art, for the stock of knowledge and the capabilities acquired through training and research become obsolete rather quickly. These needs and trends have important implications for human resources development and for training researchers in advanced scientific fields, particularly in the developing countries where highly qualified professionals are in short supply.

3.3 The systemic nature of technological innovation.

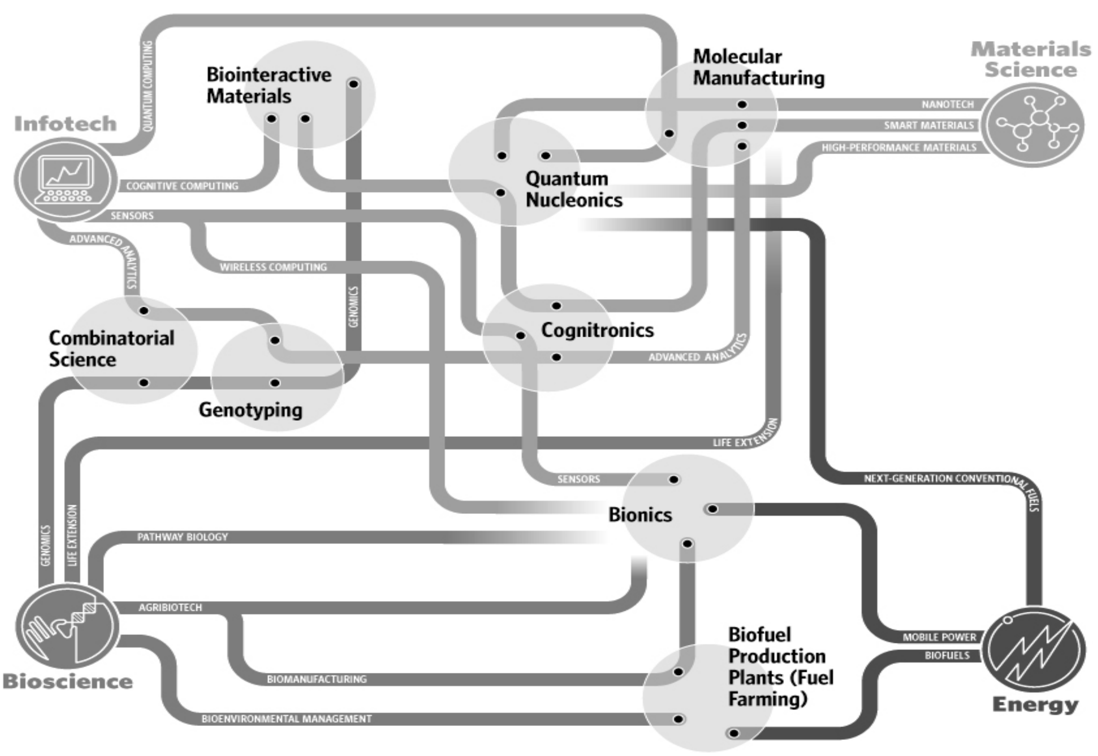
In parallel with the transformations of scientific research, and closely associated with the changes in the technological base, the nature of the innovation process has changed significantly: it has acquired a more complex and systemic character, particularly in science-intensive industries. Innovation has now become more expensive, requires greater sophistication in management techniques, gives rise to new forms of appropriation of technological knowledge, intensifies both international collaboration and competition, and has also transformed the role that governments play in support of innovation.

The systemic nature of the innovation process is manifested in at least three ways: the emergence of new technologies as a result of the convergence of advances in rather different fields, the complementary character of specific technical advances required to materialize a particular innovation, and the larger network of institutions and support services necessary for innovation to take place.

First, while innovation was seen until recently as a process of pushing the frontiers of a particular technological field or trajectory, during the last three decades a host of innovations have emerged largely as a result of combining and integrating very different technologies. It is anticipated that this process of technological intermingling and fusion will continue and accelerate in the first decades of the 21st century, and that a host of new technologies will emerge out of it. Box 2 presents a speculative account of how the future interactions of four broad technology fields.

Second, new technologies complement each other and it is seldom the case that individual advances in information technology, new materials, chemical synthesis and biotechnology, among many others, can be applied on their own without complementary inputs from other technological fields. This has become clearly noticeable in automation and computer aided manufacturing, where microelectronics, computers, telecommunications, opto-electronics and artificial intelligence are fusing together into an integrated technology system, as well as in fields like aircraft production, biosynthetic materials and the development of new drugs and treatments.

BOX 2: **A Speculative technology road map for the next two decades**



In mid-2002 *Business Week* published a special report with a popular account of eight emerging technological fields based on four basic categories of technologies: bioscience, information technologies, material science and energy technologies. While highly speculative, this report indicates the way in which advanced technologies are combining with each other to open new opportunities for innovation. They underscore the notion that in the coming years breakthroughs are most likely to come as a result of the integration of technological advances in a diversity of fields. The eight fields of technological convergence are:

Biointeractive materials. Biologic sensing devices will become small enough to reside on or inside people, animals, and crops. There they can monitor the host's health and even act on problems as they arise, transmitting information or releasing agents to deal with them. They include fabrics that change color when exposed to unsafe chemical or biological compounds. These biosensors could eventually be implanted inside the human body and help repair damaged tissue, such as nanoscale crystals that bind to form synthetic bone.

Biofuel plants. The objective is to replace oil with fuels —ethanol, methanol, biodiesel, among others— from genetically engineered crops. This will become possible in the near future, but could have negative effects by displacing food production and using scarce water, as well as the dangers associated with the possible uncontrolled dissemination of genetically altered plants.

Bionics. The technologies that converge in this field aim at replacing lost or disabled body parts, which represents an extension of existing technologies (pacemakers, hearing aids). This requires developing small, long-lasting power supplies, microchips and new materials that can be safely integrated into the body. For example, electroconductive plastics that take orders directly from the brain may be used to replace muscles and create prosthetic arms and hands.

Cognitronics. The aim is to develop reliable and removable interfaces between the brain and electronic devices such as computers. While efforts in this field are still primitive, a combination of advances in sensor technologies, new materials, advanced analytical methods and brain research, may yield significant progress and lead to the development of such interfaces in the not too distant future.

Genotyping. Mapping the human genome will allow to link diseases to specific genes, a feat that has been accomplished in a partial manner by merging advances in the biosciences with information technologies. While much more work remains to be done for this field to lead to safe and reliable disease prevention and health preserving technologies, it is likely that practical results will be achieved within one or two decades, and that they will spawn complex ethical, legal and institutional challenges.

Combinatorial science. This refers more to a research method than to a technology field, and involves the combination of advances in statistical methods with massive computing power to process and extract information from huge amounts of data. Already in use to a limited extent in data mining and simulation activities, this method may lead to new ways of examining complex interactive phenomena, such as climate change and the behavior of economic systems, and of developing scenarios and other planning tools.

Molecular manufacturing. This field aims to build complex structures atom by atom, and involves the convergence of new materials, nanotechnology, advanced analytical methods and possibly quantum computing. While still a long way off and would require the development of molecule-size assemblers to initiate molecular manufacturing and building microscopic motors, scientists have succeeded in positioning individual atoms on a surface and in building carbon nanotubes whose walls are 10 atoms thick and are from 50 to 100 times stronger than steel.

Quantum nucleonics. Even more speculative than the preceding technology convergence fields, this involves tapping the energy of the atomic nuclei without resorting to fission or fusion, and aims at developing a portable, safe and non-polluting source of nuclear power. If perfected, it could provide a powerful source of energy that leaves behind no residual radiation. It could also be used in photolithography to etch circuits onto denser, faster microchips.

Source: Paul Saffo (2002), "Untangling the Future", *Business 2.0*, *Business Week*, June, 2002. For additional information and linkages to websites with detailed information on the technological advances mentioned here see: http://www.business2.com/articles/mag/0,1640,40434,FF.html

The technological convergence implied by the more systemic character of innovation has made it necessary for leading firms to develop expertise in a broader array of technologies and scientific disciplines, as evidenced, for example, by the need for the food processing and pharmaceutical industries to develop competence in biotechnology, molecular biology and advanced electronic instrumentation. It also has implications for the concept of critical mass in research and innovation, for in addition to quantitative critical mass (amount of resources, number of people) and qualitative critical mass (type of resources, personnel qualifications, nature of facilities), it becomes necessary to acquire an "interface critical mass", which refers to competences and capabilities in fields that are adjacent or indirectly related to the one in which the particular innovation is focused.

Third, the increasingly systemic character of innovation is also reflected in the larger number of actors that take part in the process of bringing major innovations to the market and the users. In addition to the firms and government agencies directly involved in this process, there may also be subcontractors, suppliers of inputs and equipment, laboratories and other organizations that provide technological services, legal and technical advisors in intellectual property rightss, management consultants, educational and research institutions, marketing research units, distributors and trading companies, financial institutions and venture capital firms. All of these complemented by various government agencies and departments engaged in the formulation and implementation of policies that affect the innovation process, either directly or indirectly. The concept of "national systems of innovation" was advanced in the 1980s to account for the growing complexity of the institutional arrangements, legal frameworks, incentive systems, strategies, policies, practices and attitudes required to bring about the innovation process.

The systemic character of innovation has several consequences that affect the way in which policies are designed and implemented, the cost of innovation, the pace and geographical spread of changes in production systems, and the demands it imposes on management capabilities and infrastructure facilities.

The growing complexity of the innovation process requires that a distinction be made between "explicit" science and technology policy instruments, which directly influence decisions regarding innovation, and "implicit" policy instruments that affect them indirectly through the creation of a conducive environment, or through second order effects mediated by other policies and by decisions made by private firms, government agencies or academic institutions. These implicit policies influence the conduct of scientific research and of technological innovation, but lie outside the conventional boundaries of science and technology policy. They include financial, credit, educational, labor, tax, trade and regulatory policies, among others. In consequence, to promote innovation it is not enough to focus on explicit policies, it becomes essential to harmonize these with a wide range of implicit policies to ensure they reinforce and not cancel each other.

Another consequence of the more complex and systemic character of innovation has been a steady increase in the cost of incorporating research results into production and service activities, and of bringing new products to the market. The higher costs of innovation and the larger risks faced by firms in a more competitive environment have increased barriers to entry in many fields of industry, particularly in those where government regulation plays a major role. For example, in the pharmaceutical sector the cost of discovering, testing and bringing to market a new medicine may exceed US $500 million and take12-15 years, while a factory to produce microchip wafers in the late 1990s cost over $1 billion and had an expected lifetime of five years (which means a depreciation rate of about $4 million per week). Paradoxically, the increase in competitive pressures has generated a host of cooperative arrangements between industrial firms, primarily in pre-competitive research and marketing. However, only firms with substantive financial or technological assets (including small firms focusing on specific technology niches) can be expected to become players in the game of international technological alliances.

In addition, new technologies have made it cost-effective to produce more differentiated products and to accelerate innovation by adopting shorter product cycles. Flexible automation is lowering the minimum efficient plant size in several industries, and advances in communications and information technology permit adopting a "just-in-time" approach to production management, reducing inventory costs and requiring close interactions with suppliers and markets. Low labor costs are no longer the dominant criterion to locate production sites, especially for high end manufactured products, and corporations are finding it more advantageous to establish industrial production facilities close to their markets, suppliers and research and development centers. The result has been that facilities for the production of many manufactured goods and the provision of certain services (data processing, for example) have spread out throughout the globe.

The more systemic character of innovation requires a greater emphasis on management skills and capabilities. To realize the full potential of new technologies it has become necessary to introduce innovations in organization and management, a task for which advances in information technology have provided many tools. A well developed physical infrastructure is also required to support innovation, including a good network of roads and transport facilities, telecommunications and data transmission networks, reliable electricity supply, access to waste disposal facilities, and clear water supply. In addition, it may be necessary to count on advanced repair and maintenance services for a variety of laboratory and industrial equipment. However, the greater complexity of large-scale technological infrastructure facilities also increases their vulnerability and the risk of systemic failure. Risk assessment and management has become essential in large systems such as financial information networks, air traffic control, and energy generation and distribution.

The changes in the nature of the innovation process have mixed effects on the prospects for developing countries. On the one hand, there is the possibility of incorporating advanced technology components into traditional and conventional technologies, in what is known as "technology blending," which can lead to more appropriate and higher productivity innovations geared to developing country needs. On the other hand, the comparative advantage of developing countries is shifting away from low labor costs and natural resources, forcing major changes in education, industrialization and environment policies. In addition, the physical and institutional infrastructure required to support increasingly complex innovation processes may well be beyond the existing capabilities of most developing countries.

However, it must be kept in mind that a significant proportion of products and services in these countries are produced, distributed and consumed locally using traditional methods, which eases to a certain extent the pressures exercised by the taxing demands of innovation processes in the more advanced and competitive fields. There are about 2 billion people, a third of the world's population, the vast majority of them living in poor countries, without access to electricity, and for them advanced technology innovation has little meaning. Alternative approaches and policy frameworks are necessary to examine the nature of innovation systems in poor countries facing severe resource constraints.

For example, it becomes necessary to adopt an explicit strategy for the management of technological pluralism to take advantage of the broad range of available technological options in the context of specific developing country situations. This implies combining advanced technologies that are based on the results of scientific research, with conventional technologies resulting from the accumulation of research and technical improvements over several decades, and with traditional techniques that are the result of empirical trial and error that took a very long time. For this to happen, it is necessary to create conditions for the coexistence of a diversity of traditional, conventional, modern and blended technologies with different productivity levels, labor requirements, energy intensities, environmental impacts and opportunities for learning. Such eclectic combinations of technology are likely to be better suited to local conditions in developing countries.

3.4 The restructuring of the world production and a new techno-economic paradigm

The maturation of the Baconian program, the transformation of scientific research and the growth in complexity of the innovation process, have all coincided with major changes in the worldwide production of goods and services. These are manifested in a set of changes in the content and distribution of production activities, and in a transition of the dominant techno-economic paradigm that underlies the dynamic sectors of the world economy.

The distribution and content of production activities. The world production of goods and services has grown at a rapid rate during the last fifty years. The total global output of goods and services at the end of the 20th century was six times larger than that of 1950, and this high rate of expansion is likely to continue during the next two decades. World trade has grown even faster, particularly in goods and services with high technological content.

This growth of production and trade has been accompanied by major shifts in the geographical distribution of production (Table 1). The United States of America accounted for about thirty percent of world production in 1950, but its share had diminished to around twenty percent at the end of the 1990s. Europe, Japan and a few emerging economies increased their share significantly, while countries of the Former Soviet Union saw their participation in world production drop precipitously in the 1990s. It is expected that the high growth rates experienced by China during the last two decades will continue well into the 21st century, to the extent that the most populous country in the world is likely to overtake the United States of America as the world's leading producer of goods and services during the next three to five decades.

The redistribution of productive capacity at the world level during the last half of the 20th century has proceeded in parallel with major increases in direct foreign investment, although most of it has been taking place primarily between developed countries. In 2000 these countries accounted for about 70 percent of total outflows and 80 percent of foreign direct investment inflows. Moreover, foreign direct investment in developing countries concentrates in about a dozen emerging economies, primarily China, India, Mexico, Brazil and, until recently, Argentina, even though when calculated in *per capita* terms, this apparently high degree of concentration diminishes significantly.

The reasons for international corporations to invest in developing countries have evolved during the last several decades. In the 1950s and 1960s investments were primarily oriented towards the exploitation of natural resources, while in the 1960s and 1970s a significant proportion was oriented towards import substitution schemes, particularly in the relatively large developing countries where transnational corporations invested to take advantage of domestic markets. From the 1980s on foreign direct investment in developing countries focused on establishing export-oriented productive facilities in the emerging economies, aiming to achieve greater efficiency and reduce costs in globally integrated production and distribution systems.

TABLE 1: **Distribution of World Production of Goods and Services**
(in percentages)

Country/Region	***Year***							
	1870	1913	1950	1960	1970	1980	1990	1998
U.S.A.	8.73	19.00	27.13	23.94	22.05	20.80	19.97	21.93
Japan	2.26	2.53	2.91	4.32	7.14	7.66	8.38	7.53
Western Europe[(a)]	30.97	30.05	25.38	26.05	25.77	24.03	22.39	20.64
Western Offshoots[(b)]	1.16	2.40	3.20	3.10	3.10	3.17	3.10	3.15
Eastern Europe	13.54	15.50	14.01	14.51	13.87	12.52	10.02	5.32
Latin America	2.55	4.23	7.52	7.78	7.87	9.26	7.70	8.72
Asia[(c)] & Oceania	37.26	23.98	16.40	16.99	16.92	19.29	25.42	29.63
Africa	3.52	2.31	3.44	3.31	3.28	3.27	3.02	3.08
World	100	100	100	100	100	100	100	100
World Total[(d)]	**1,127.9**	**2,726.1**	**5,372.3**	**8,448.6**	**13,810.6**	**20,005.8**	**27,359**	**33,725.9**

Sources: Maddison, Angus (1995) *Monitoring The World Economy 1820-1992*, OECD Development Centre, Paris; and Maddison, Angus (2001) *The World Economy: A Millennial Perspective*, OECD Development Centre, Paris.
Notes: [(a)] Southern Europe included; [(b)] U.S.A not included; [(c)] Japan not included; [(d)] World GDP Level in billions 1990 constant Dollars. Maddison used a sample of 199 countries up to 1990 and a sample of 217 countries for 1998.

The sectoral distribution of world exports has also shifted in a major way towards technology-intensive goods, particularly during the last two decades. Table 2 shows the shares of different types of products in world exports for 1985 and 1998, and also the proportion of these exports accounted for by developing countries. During this period, the share of primary products was cut nearly in half and the share of high technology manufactures increased significantly. The proportion of exports of low, medium and high technology manufactures accounted by developing countries (mostly emerging economies) also grew at a rapid pace, partly as a consequence of the creation of "global value chains" that involve the establishment of production and distribution facilities in many different countries.

TABLE 2: **Market Shares of Exports, 1985 and 1998**
(in percentages)

	All products	Primary	All Manufactures	Resource Based	Low Technology Manufactures	Medium Technology Manufactures	High Technology Manufactures
	Shares of products in world exports						
1985	100	21.7	73.8	21.1	13.7	30.2	12.4
1998	100	11.5	84.2	14.5	15.8	32.8	21.1
	Shares of developing countries in world exports						
1985	24.3	52.1	16.4	26.3	26.7	8.3	10.7
1998	25.0	39.7	23.3	23.7	34.5	15.3	27.0

Source: Adapted from Sanjaya Lall (2000), "Skills, Competitiveness and Policy in Developing Countries", QEH Working Paper Series No. 46, who calculated the figures using United Nations Comtrade data provided by UNCTAD.
Note: 'Other' transactions are not shown here, and account for the difference between total exports and primary plus manufactured products.

Considering just manufactured exports (Table 3), between 1980 and 1996 the share of resource based and low technology manufactures declined as a percentage, while the share of medium technology manufactures remained stable, and the percentage of high technology manufactures nearly doubled. This indicates the extent of the shift in the structure of world production and trade in favor of products with a higher science and technology content. Underlying these structural shifts there is a persistent long-term deterioration of the terms of trade between primary products and manufactured goods —with the short term exception of the 1970s, when the price of oil tripled as a result of concerted action by the Organization of Petroleum Exporting Countries—, and also of a deterioration of the terms of trade between industrial commodities (resource based and low technology manufactures) and high technology products.

TABLE 3: **Evolution of World Manufactured Exports by Technological Categories** (percentage shares)

Technology categories	*Year*				
	1980	***1985***	***1990***	***1995***	***1996***
Resource based	19.5	19.3	15.5	14.0	13.7

Low technology	25.3	23.4	23.7	22.0	21.3
Medium technology	38.6	37.3	38.5	36.9	37.2
High technology	16.5	20.1	22.2	27.1	27.7

Source: Adapted from Sanjaya Lall (2000), "Skills, Competitiveness and Policy in Developing Countries", QEH Working Paper Series No. 46, who calculated the figures using United Nations Comtrade data provided by UNCTAD.

These shifts in export shares proceeded in parallel with changes in the rules for international trade and finance. Liberalization and deregulation in both developed and developing countries gave a greater role to market forces in determining the volume, content and direction of the international flow of products, capital, technology, information, knowledge and skilled labor. Barriers to trade and investment were dismantled, regulations harmonized and there is greater convergence in national trade and investment policies. However, while tariffs and quantitative restrictions on trade were lowered or eliminated, progress in reducing qualitative barriers to trade, primarily in the form of standards and various types of certification, was much slower. In particular, environmental regulations and social concerns are becoming barriers to developing country exports. At the same time, stricter environmental regulations could encourage the use of environmentally friendly technologies, as well as the recovery and upgrading of ecologically sound traditional techniques.

The "Trade-Related Aspects of Intellectual Property Rights" (TRIPS), which are the subject an agreement administered by the World Trade Organization, are another important feature of the international trade scene at the beginning of the 21st century. The provisions of this agreement will affect developing countries in widely different ways depending on their level of science, technology and innovation capabilities. In general, they are likely to increase the costs of importing technology and increase the bargaining power of technology owners, mostly firms in the developed countries. They also restrict opportunities for reverse engineering, and for copying and adapting technologies, which were key components of the technological development strategies of European countries, the United States of America and Japan, as well as the newly industrialized countries of East Asia. While more stringent intellectual property rights regulations could conceivably encourage research and promote foreign direct investment, the range of developing countries that can benefit from these is restricted to the emerging economies that have already substantial technological and innovation capacities.

The rapid growth and diversification of financial transactions has been a distinctive feature of the international economic scene, primarily during the last three decades. International financial markets now comprise a tight web of transactions involving global securities trading, arbitrage in multiple markets and currencies, futures trading with exotic financial instruments, portfolio investment through a bewildering array of international funds, and massive trans-border capital movements. Financial transactions have acquired a life of their own and have largely become uncoupled from the production of goods and services. For example, currency transactions, which in the early 1970s represented about ten times the value of international trade, shot up and reached about seventy times that value in the mid-1990s The number of transactions in financial derivatives linked to interest rates increased from about one million in the early 1980s to more than twenty million in the early 2000s. Deregulation, liberalization and the incessant search for higher returns and risk diversification, together with advances in information and telecommunications technologies, have been behind the enormous growth in world financial activities.

The growth and diversification of financial markets and instruments has had an important influence on the creation and acquisition of science, technology and innovation capabilities in firms and countries. Venture capital firms and specialized government agencies now play a key role in financing scientific research and technological innovation in developed countries, particularly in the high technology sectors, and they are also becoming important in the emergent economies. From a less positive perspective, the constant search for high returns and risk diversification in a highly complex and volatile international financial context can work against investments to develop innovation capabilities, particularly in countries where equities markets are an important source of enterprise financing. The pressures to exhibit short-term returns in order to maintain high equity valuations may shift resources away from the complex and long term tasks of building technological capacities within the firm, and may not encourage experimentation that spurs innovation.

The structure and content of world production activities have changed radically during the last half-century, primarily as a result of the combined impact of technological advances, institutional changes and of modifications in the international policy environment. But these, in turn, have been influenced by the interests of powerful countries and large corporations, which have sought to reap and keep most of the benefits of scientific and technological progress. The dominant position of the United States of America during this period has allowed it to shape the rules of the international trade and finance game, to chart paths for the evolution of technologies in most fields, and to push forward the interests of American firms throughout the globe —as exemplified by the adoption of Intellectual Property Rights that reinforce the position of American corporations.

Transition of techno-economic paradigm. The changes in the structure and content of world production, as well as the transformation of the production system at the national level, can be interpreted as the latest manifestation of a series of cyclical phenomena that have characterized the history of economic activity during the last few hundred years, with the alternation of phases of rapid growth and stagnation giving rise to five "long waves" with a periodicity of about five to six decades.

The most widely accepted long waves account of economy cycles has been suggested by Christopher Freeman and Carlota Perez, who postulate that the transition from one long wave to another involves changes in the dominant "techno-economic paradigm".[9] A techno-economic paradigm is a combination of interrelated product and process, technical, organizational and managerial innovations, which generate significant and sustained increases in potential productivity for all or most of the economy, and which open up an unusual range of investment and profit opportunities. A major characteristic of the diffusion pattern of a new techno-economic paradigm is its spread from a set of initial industries and services that serve as carriers to the economy as a whole. In the transition from one techno-economic paradigm to another, the production activities related to the old one do not disappear but lose their dynamic character in comparison with those associated with the new techno-economic paradigm.

The organizing principle of each paradigm is to be found most of all in the dynamics of the relative cost structure of all possible inputs to production. In each paradigm, a particular input or set of inputs —the "key factor"— fulfills the following conditions: (i) low and rapidly falling relative cost; (ii) apparently almost unlimited ability of supply over long periods, which is an essential condition for the confidence to take major investment decisions; and (iii) clear potential for use or incorporation of the new key factor or factors in many products and processes throughout the economic system, either directly or through a set of related innovations, which both reduce the cost and change the quality of capital equipment, labor inputs and other inputs to the system.

The key factor in the techno-economic paradigm that is being superseded is oil, whose falling cost, apparent unlimited supply and widespread utilization reorganized the production of goods and services at the world level from the 1920s onwards. Transport related industries (automobiles, trucks, tractors, aircraft, motorized armaments), consumer durables, and oil-based products (petrochemicals, synthetic materials, textiles, packaging), accompanied by the expansion of the physical and institutional infrastructure to make full use of these products (highways, airports, gasoline distribution systems, consumer credit), set the pace for economic growth during what has also been called the "Fordist mass production wave." This wave extended through the 1970s, and included the 1950-1973 "golden age" of unprecedented world economic and trade expansion.

A new techno-economic paradigm emerged in the 1980s as the microelectronic chip began replace oil as the key factor. Information and telecommunications industries and services (computers, electronic consumer goods, robots and flexible manufacturing systems, computer aided design and manufacturing, telecommunications equipment, optical fibers, ceramics, software, multimedia, information services) took the lead in the process of economic growth. Digital telecommunications networks, routers and other special purpose computers, cable

[9] See: Freeman (1983), Freeman and Perez (1988), Perez (1989) and Perez (2000).

services and satellites, whose cost has reduced dramatically, provide the infrastructure for the rapid expansion of information and communication services.[10]

This transition has profound implications for the way in which production is organized in enterprises, for competitive strategies and for the institutional arrangements to support production and service activities at the national and international levels. The well proven set of common sense managerial guidelines, derived from decades of successful experience in increasing efficiency within the framework of the techno-economic paradigm based on oil, is giving way to a new set of efficiency principles and practices associated with the new possibilities opened up by the microelectronic chip. The transition from a mass production model of organization for production, characteristic of the age of oil and the automobile, to a flexible networks model, which is associated with information technology, upsets the premises of managerial common sense in enterprises. For example, from mass products and standardized markets it is necessary to move to diversified adaptable products and highly segmented markets; rules of operation that focus on "one best way" of routinely doing things must yield to continuous product improvements and frequent process changes in learning organizations; and centralized structures with hierarchical pyramids, functional compartments and rigid communications channels, must give way to decentralized networks, strategic centers, semi-autonomous functional units and interactive communications. These shifts require fundamental changes in management styles and practices

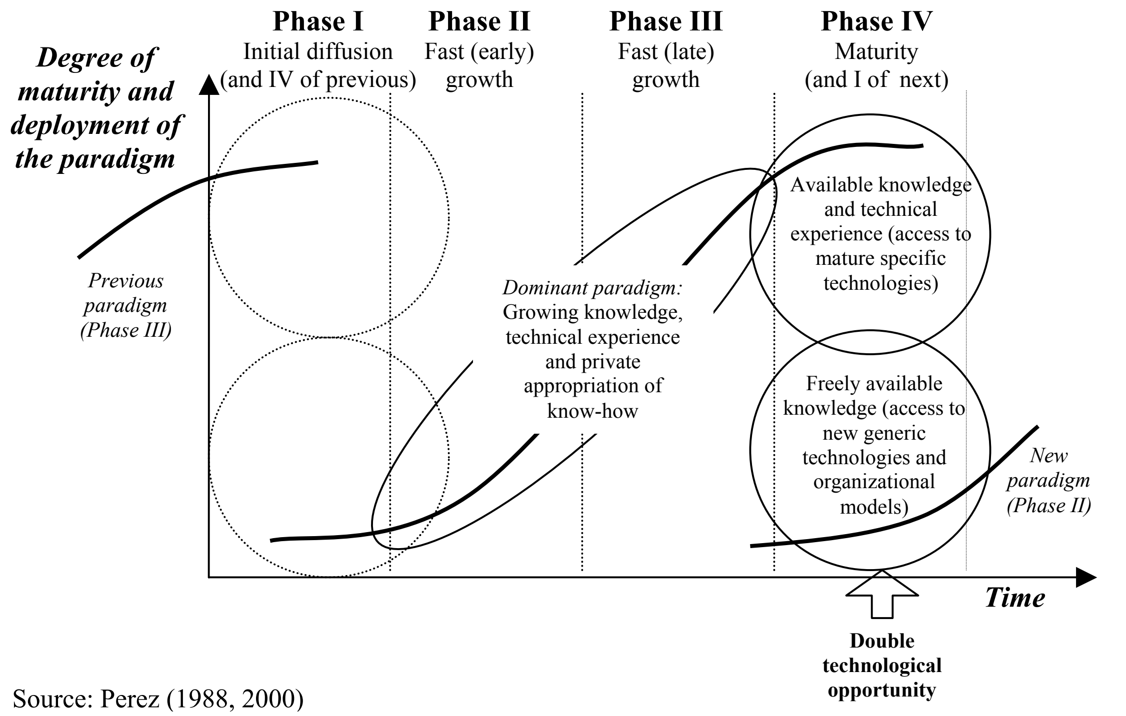
During the transition from one paradigm to another, the overlap between the mature phase of the old paradigm and the initial phase of the new one provides greater opportunities to secure technological advantages and improve competitiveness. Firms

[10] The speed and spread of information technology advances has been characterized UNDPs *Human Development Report 2001* in the in the following terms:

> "In 2001 more information can be sent over a single cable in a second than in 1997 was sent over the entire Internet in a month. The cost of transmitting a trillion bits of information from Boston to Los Angeles has fallen from $150,000 in 1970 to 12 cents in 2001. A three-minute phone call from New York to London that in 1930 cost more than $300 (in 2001 prices) costs less than 20 cents 2001. E-mailing a 40-page document from Chile to Kenya costs less than 10 cents, faxing it about $10, sending it by courier $50. …The Internet has grown exponentially, from 16 million users in 1995 to more than 400 million users in 2000 —and to an expected 1 billion users in 2005. Connectivity is rising at spectacular rates in Europe, Japan, the United States and many developing countries. In Latin America Internet use is growing by more than 30% a year —though that still means that only 12% of individuals will be connected by 2005" (UNDP, 2001, p. 32, 37).

and countries face an unusually favorable situation: a "double window of opportunity" provides access both to what until recently was privately appropriated knowledge in the fully deployed and mature paradigm, and to what will soon become private appropriated knowledge in the new techno-economic paradigm (Figure 2). Usually there are lags in the diffusion of the technological innovations involved in the transition from one paradigm to another, which could extend the time the window of opportunity remains open. This could allow firms in developing countries to enter into well-selected markets for products linked to the new technologies, and also to successfully compete in international markets with rejuvenated products associated with the old techno-economic paradigm.

FIGURE 2: **Phases of the dominant techno-economic paradigm**



Source: Perez (1988, 2000)

However, to take advantage of the double window of opportunity offered by the change in techno-economic paradigm, firms and countries must be well positioned not only with regard to their scientific and technological capabilities, but also in relation to managerial skills, institutional flexibility, capacity to adapt, ingenuity and creativity. In the end, those firms and countries that take advantage of this opportunity may not be the most advanced in their scientific and technological capabilities, but those that arrive at the best match between science and technology potential, institutional framework, good governance and social consensus, and where this match is in tune with the international policy environment.

As the new techno-economic paradigm based on the microchip and on the spread of information technologies becomes dominant and moves into phases II and III, the possibility for developing countries to take advantage of the opportunities it offers diminishes. The accumulation and private appropriation of knowledge, technical experience and know-how creates barriers for new potential entrants into the various production and service activities associated with the dominant techno-economic paradigm. Building up technical and organizational capabilities to take advantage of new opportunities requires time, particularly in developing countries with weak science, technology and innovation systems. For this reason, it may be pertinent to speculate about the characteristics of the next techno-economic paradigm and to prepare for its emergence. Such speculations are fraught with uncertainty and should be viewed with utmost care, but could nevertheless help envisage the broad range of scientific and technological capabilities that would be necessary to follow up developments in scientific research, technological trajectories, institutional arrangements and social pressures that will lead to the emergence of one or another new techno-economic paradigm.

A scenario building exercise could help to anticipate the features of the possible key factors that would underpin alternative techno-economic paradigms, as well as the potential carrier industries that would lead to their deployment in the coming decades. It has been suggested that environmental friendly technologies (e.g. new sources of energy) and some aspects of biotechnology (e.g. genetically manufactured organisms) may provide the impetus for the emergence of a new paradigm. The technology map of Box 1 provides further candidates for these speculations. The main point of such exercises would be to explore what would be necessary to take advantage of the maturation of the dominant techno-economic paradigm as it becomes fully deployed (possibly in the next two or three decades), and also to build capacities to foresees and accompany the emergence of a new techno-economic paradigm, so as to seize opportunities as they emerge.

3.5 Traditional knowledge, techniques and production

The importance of traditional knowledge, techniques and production has been highlighted in the conceptual model of section 1, particularly because in most developing countries they provide the means of subsistence for large segments of the population. Non-scientific modes of speculative thought still play an important role in these countries, the evolution of the stock of techniques has been largely the result of localized trial and error processes, and the transformations of the productive system have usually been the result of relatively slow changes made to adapt to local conditions and demand. It has been estimated that more than three fourths of the world's population relies on indigenous knowledge to meet their medical needs, and at least half relies on traditional knowledge and techniques for crops and food supplies. As about one third of the world's population does not have access to electricity, all modern technologies and production activities that depend on this source of energy are out of their reach.

Indigenous or traditional knowledge is crucial for survival and for improving the quality of life of poor people. However, such knowledge is rarely codified and systematized —or codified in highly idiosyncratic manners— which make it difficult to transmit, at least according to modern scientific and technological standards. It therefore depends on its depositaries or users for its diffusion, which usually takes place by imitation, exchanges of goods and the recounting of oral traditions. In many cases, indigenous knowledge, techniques and products have been lost because there are no reliable mechanisms to record and store them, and because the dominance and presumed superiority of Western ways have led to their being ignored or discarded. Local specificity is a constraint to their wider application, and even when they might be suitable for transfer to other locations, the limited number of people who know about them and the small scales of production limit their diffusion. These features of traditional knowledge, techniques and production are related to the rationale of pre-capitalist societies in which artisan work and custom-made production are the rule.

A selective screening and upgrading of traditional techniques could enhance their contribution to improvements in living standards and poverty reduction. For this to happen, it is necessary to devise strategies, create institutions and adopt policies to foster a sustained interaction between the depositaries of indigenous knowledge and techniques on the one hand, and scientific researchers and engineers on the other. One approach would be to focus on blending traditional techniques and modern technologies, injecting modern components to improve the performance and increase the productivity of traditional systems of production.

Another approach would involve focusing on the complex interactions that take place within indigenous productive systems, attempting to understand their logic and functioning before injecting modern or upgraded indigenous techniques and knowledge components. This leads to the recognition that there exist "indigenous innovation systems", which evolve and change in response to challenges and stimuli that are different from those of market-based innovation systems. Their distinctiveness is a result of a community's conception of the world and the place of human beings in it, its history of successes and failures with techniques and production (for example, discovery of new plant varieties, crop loses due to bad weather), of institutional factors (for example, collective decision making, prevalence of reciprocity relations, rigidly structured power relations), accidental discoveries and findings, and also of the specific characteristics of the ecosystems in which they live. Participatory research methods, which actively involve the members of the community, may provide an effective way of understanding the logic of these indigenous innovation systems and help to improve their performance.

The different levels of productivity of traditional techniques and modern technologies have important implications for employment generation. This is important in developing countries with high population and labor force growth rates, and where a large proportion of jobs are self-generated. The deliberate management of technological pluralism (section 3.3) can help to link indigenous knowledge, technology and production with their modern counterparts. In turn, this may help to create an endogenous science and technology base in developing countries —which need not necessarily follow the same trajectory as that of the developed countries of today.

4. The knowledge divide and disparities in developing country capacities

The impact of the knowledge explosion has been felt throughout the planet, but in a most uneven manner. At the beginning of the 21st century, the capacity to generate and utilize scientific and technological knowledge has become highly concentrated in a few developed countries, while the majority of developing countries still rely on traditional knowledge and techniques, complemented by a rather thin layer of modern knowledge, technologies, products and services, passively received from the technologically advanced countries. This has created a "knowledge divide" between those parts of the world where science, technology and production are tightly intertwined, and those in which the limited scientific, technological and modern production activities remain apart from each other and where traditional knowledge, techniques and products are predominant (Figure 1). This divide has been relentlessly deepening and enlarging, thus creating a sort of "knowledge apartheid" that radically separates those societies that have evolved and acquired an endogenous science and technology base from those that lack it.

The explosive growth of information technologies and of the infrastructure to support them has also become a source of inequality between developed and developing countries. The term "information poverty" has been coined to describe the plight of poor countries with very limited access to the world sources of information, a condition which drastically reduces options, choices and possibilities for development.

There is great variation in the level of science and technology capabilities of developing countries. A few have managed to build their endogenous science and technology bases during the last half-century, others have lost the capabilities they accumulated over decades of effort, many have built some capacities in specific fields and scientific and technological activities, while another group has not even began to create the human resources, institutional, financial and physical infrastructure to support modern science and technology. The interventions that are appropriate for each of these groups of developing countries are quite different, which suggests the need for a classification scheme to guide policy design and implementation.

4.1 The magnitude of the knowledge divide

Disparities between science, technology and innovation capabilities of developed and developing countries are much larger than economic disparities. At the end of the 20th century, the ratio between the Gross Domestic Product (GDP) *per capita* of the high-income countries of the Organization for Economic Cooperation and Development (OECD) to that of the low income countries (as defined by the World Bank) was about 64 to 1, while the ratios of global national investment *per capita* and trade *per capita* were 64 to 1 and 67 to 1, respectively (Table 4). If India —with its nearly one billion inhabitants— is excluded from the group of low income countries, the first and third ratios would improve slightly while the second would worsen a little. These economic disparities between rich and poor countries have been growing continuously during the last decades; for example in 1989 these three ratios were, respectively, 62 to 1, 51 to 1, and 30 to 1.

However striking these disparities may be, they are dwarfed by the differences between developed and developing countries in their capacities to produce scientific knowledge, modern technology and high-technology goods and services. The ratio of scientific publications per 100,000 inhabitants in OECD countries to that of low income countries is 89 to 1 including India in the latter group, but rises to 331 to 1 if this country, which has a large and very active scientific community, is excluded. The ratio between patent applications by residents per 100,000 inhabitants is 197 to 1 including India and 260 to 1 excluding it, while those of high technology exports *per capita* are 646 to 1 and 730 to 1, also including and excluding India, respectively.

In the mid-1990s total annual expenditures in research and development by the high-income OECD countries century exceeded US $500 billion, a figure greater than the combined GDP of about 80 of the world's poorest countries. Western Europe and North America, together with Japan and the emerging Asian countries, accounted for about 85 percent of total world expenditures in science and technology; China, the countries of the Commonwealth of Independent States (former Soviet Union) and India, accounted for a further 10 percent, while the rest of the world accounted for only about 5 percent. Regional differences in research and development expenditures

TABLE 4: **Economic Disparities and the Knowledge Divide** (1999)

Indicator	*Values and ratios*				
	(A) OECD countries	**(B) Low income countries**	**Ratio (A)/(B)**	**(C) Low income countries (excluding India)**	**Ratio (A)/(C)**
Gross domestic product ***per capita*** (constant 1995 US$)	29,578.0	461.0	64.2	465.8	63.5
Gross capital formation ***per capita*** (constant 1995 US$)	6,730.3	101.7	66.2	95.2	70.7
Trade ***per capita*** **(imports + exports of goods and services)** (constant 1995 US$)	13,030.9	190.6	68.4	246.4	52.9
Scientific output: Scientific publications per 100,000 inhabitants (1995)	72.9	0.8	88.8	0.2	331.4
Technological Output: Patent applications by residents per 100,000 inhabitants	75.4	0.4	197.2	0.3	260.0
Production Output: High-technology exports ***per capita***	831.6	1.3	645.5	1.1	729.5

Source: World Bank, *Global development indicators 2001,* CD-ROM
Notes: High income OECD countries (1999 gross national income above US$ 9266): Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States. Low income countries (1999 gross national income below US$ 755): Afghanistan, Angola, Armenia, Azerbaijan, Bangladesh, Benin, Bhutan, Burkina Faso, Burundi, Cambodia, Cameroon, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Eritrea, Ethiopia, Gambia, Georgia, Ghana, Guinea, Guinea-Bissau, Haiti, India, Indonesia, Kenya, Korea (Democratic Republic), Kyrgyz Republic, Lao PDR, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Moldova, Mongolia, Mozambique, Myanmar, Nepal, Nicaragua, Niger, Nigeria, Pakistan, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, Solomon Islands, Somalia, Sudan, Tajikistan, Tanzania, Togo, Turkmenistan, Uganda, Ukraine, Uzbekistan, Vietnam, Yemen Republic, Zambia and Zimbabwe.

are also indicative of the disparities in science and technology capabilities: Latin America and Sub-Saharan Africa spent about 0.3 percent of their GDP in research and development, China 0.5 percent, and India and Central Asia about 0.6 percent while the US and Japan, with much higher GDPs, spent 2.5 and 2.3 percent respectively.

The distribution of human resources devoted to science and technology is slightly more balanced than the distribution of science and technology expenditures, which reflects the lower cost of highly qualified human resources in developing countries. About 50 percent of the world's scientists and engineers is concentrated in the OECD countries, 17 percent in Eastern Europe and in the Commonwealth of

Independent States, 15 percent in India, China and the newly industrializing countries of East Asia, and the rest in the developing regions of Asia, Africa, Latin America and the Middle East. By the end of the 1990s there were approximately 1.1 million scientists and engineers in the United States and 630,000 in Japan, which compares with about 585,000 scientists and engineers in China and 160,000 in India. However, when these figures are expressed in relation to total population, the gap between developed and developing countries becomes once again evident: there were about 4.1 scientists per thousand population in the US, Union and 4.9 in Japan, but only 0.96 in China and 0.16 in India.

Scientific research and technological development organizations in most developing countries are highly vulnerable to changes in the domestic economic and political climate, which can affect negatively the slow and arduous process of institutional consolidation, and also vulnerable to the attraction exerted by better financed and more advanced research and development organizations in developed countries. Building a world-class research institution takes at least a decade and a half of sustained efforts, but these achievements can be destroyed in a couple of years by the emigration of highly-qualified staff. As pointed out in the prologue, economic and political instability in many developing countries has made the building of science and technology capabilities akin to mythological Sisyphus' efforts to push a heave stone uphill. Yet, there is one developing country which has made spectacular gains in human resources capabilities during the last two decades: university enrolment rates in the Republic of Korea rose from 15 percent to 68 percent between 1980 and 1997, and 34 percent of total enrolment was in science, engineering and mathematics —which exceeds the OECD average of 28 percent.

In some poor regions a university education can be considered as a passport out of poverty. About three quarters of African and Indian emigrants to the United States have tertiary education, and this proportion is about one half for China, the Republic of Korea and South America. Yet, in the case of Korea these emigrants represent only about 15 percent of the total number of people with tertiary education, and the corresponding figures are about seven percent for South America and less than three percent for India. The "brain drain" of scientists and engineers creates serious problems for the smaller developing countries, but not as serious for those countries in which there is large reservoir of highly skilled potential emigrants. Some developed countries have focused on attracting such qualified persons, and a senior United States government official once stated that, from their perspective, highly skilled people where a "common heritage of mankind".

The distribution of the world's scientific and technological output, measured with the rather imperfect indicators of scientific publications and registered patents, also shows a rather extreme degree of concentration of capabilities to generate modern knowledge and technology. In the mid-1990s, nine high-income countries and India accounted for nearly 80 percent of world scientific publications, and high-income countries published 25 journal articles for every one of low-income countries. Similar degrees of concentration were found in patent indicators: more than 96 percent of patents were registered by the United States, the countries of Western Europe and Japan, and the United States received 54 percent of total world royalty and license fees payments, with a further 12 percent going to Japan.

Access to the rapidly growing world stock of knowledge and information, together with the capacity to screen, select, process and utilize it, have become essential in the process of building endogenous science and technology capabilities. Disparities in access to sources of information are also very large, even in conventional means of communication such as newspapers, radio and telephones. For example, at the end of the 20th century, there were about 600 newspapers circulating daily per 1000 inhabitants in Japan, while the corresponding numbers were a hundred times lower in Bangladesh and 2000 times lower in Burkina Faso (0.3 newspapers per 1000 inhabitants). Moreover, there were only about 30 radio receivers for every 1000 Tanzanians and 80 for every 1000 Indians, but 1000 for every 1000 Canadians.

In 2001 there were 56 telephones per 1000 inhabitants in Africa and 202 in Asia, in contrast with 840 in Europe, 1100 in the United States and 1180 in Japan. Most of the growth in telephone access at the world level, and particularly in developing countries, has been due to the recent introduction of wireless technology. Mobile phone use grew at an annual average rate of approximately 50 percent between 1995 and 2001, the number of mobile phone subscribers increased from about 90 million in 1995 to 946 million in 2001, and about half of the total phone service subscribers in the world now use mobile phones.

Disparities in the number of homes with personal computers and access to the Internet are also very large, and may be widening the knowledge divide between developed and developing countries. There were about 85 computers per 1000 inhabitants at the world level in 2000, but this average hides very wide differences: in Africa there is about 10 computers per 1000 inhabitants, in Asia about 30, and in Japan and the United States the corresponding numbers are 350 and 620, respectively.

The Internet consists of a massive network of permanently interconnected host computers, which route traffic, exchange e-mails and provide information, and of a huge number of temporary connections created by users when they log on with their personal computers. In early 2001 there were about 100 million host computers, a growing number of which are web servers providing information through the World Wide Web. The growth of web servers has been nothing short of spectacular: from 75,000 in 1995 to more than 25 million in 2000. The number of countries connected to the Internet has grown from eight in 1988 to 214 in 2000, and only a handful remain unconnected, primarily for political reasons. However, the limited availability of telephone services in developing countries is a major constraint to growth in the number of users

Nevertheless, the number of Internet uses in developing countries has grown at about twice the rate of that of developed countries during the last decade, and in 2000 the latter accounted for about a quarter of the 315 million users worldwide. Between 1998 and 2000 the number of users increased from 1.7 million to 9.8 million in Brazil, from 3.8 million to more than 17 million in China, and from 2,500 to 25,000 in Uganda. In spite of these high rates of growth in the number of users, disparities between developed and developing countries remain huge. While almost a third of the people in developed countries are connected, less than two percent of the population in the developing countries has access to Internet. About 80 percent of Internet users live in the high-income OECD countries, which contain only 15 percent of the world's population.

These figures provide a snapshot of the huge disparities in the worldwide distribution of science and technology capabilities and of access to information at the end of the 20th century. However, the asymmetries are much greater than these figures would suggest, primarily because of the cumulative character of the processes of building capabilities in modern science, technology and production. As capacities in these fields are acquired it becomes easier to continue on accumulating them, and those countries that have a long history of doing so are in a much better position to reap the benefit of future advances in science and technology. This "Matthew effect", which gives to those that already have, is a consequence of increasing returns to scale in the economics of scientific research and technological innovation. It poses a major challenge to the building of endogenous science and technology capabilities, and also highlights the importance of international cooperation to assist developing countries in meeting this challenge.

All of this suggests that the science and technology capabilities, as well as the information and communications technological infrastructure, of most developing countries are far too limited to deal adequately with the challenges they face at the beginning of the 21st century. With the exception of a few large countries (India, China, Brazil, Mexico) and some emerging economies (Republic of Korea, Singapore, Taiwan, Malaysia) that have built a significant base of scientific and technological activities, as well as an excellent telecommunications infrastructure, low and middle income countries do not have the capabilities to generate scientific and technological knowledge. In many cases they also lack the capacity to effectively select, absorb, adapt and use imported knowledge and technologies, and also for identifying and selectively upgrading their large stocks of traditional knowledge and techniques.

Severe resource constraints and growing social demands tend to undermine long-term efforts aimed at building scientific and technological capabilities, and the creation of an adequate information and telecommunications infrastructure. Difficult decisions must be made between alleviating poverty in the short-term and building capacities to generate and utilize knowledge in the long-term. The metaphor or a starving farmer eating the seed needed to plant next year's crop comes to mind when confronting such painful choices.

4. 2 Disparities between developing countries: a Science and Technology (S&T) Capacity Index

While the knowledge divide between developed and developing countries is the most noticeable feature of the contemporary knowledge and technology scene, disparities between developing countries are also very large and have important implications, particularly for the design of strategies and policies to build endogenous science and technology capabilities. These strategies and policies have to be tailored to the situation and characteristics of particular developing countries, but it is also possible to identify general categories in order to group countries that are similar with respect to their knowledge, technology and innovation capabilities.

The conceptual framework advanced in section 2 (Figure 1) suggests a way of constructing an index that combines the capacities to conduct scientific research, to generate science-based technologies, and to incorporate the results of research and technological development into production through the process of innovation. Ideally, the construction of an index to measure the degree to which a country has built and endogenous science and technology capacity should reflect the intensity of interactions between knowledge, technology and production. However, identifying and measuring indicators of these interactions is a most difficult task, feasible only through detailed case studies that produce data that are not amenable to statistical aggregation. Moreover, as there are no indicators of the level of traditional knowledge, technology and production capabilities, it is impossible to build this very important aspect into the design of the index. For this reason, rather than attempting to construct a broad “Knowledge and Technology Capacity Index”, a narrower “Science and Technology Capacity Index” has been designed.

Box 3 describes the components and the method of calculation for the S&T Capacity Index, which has been constructed to place countries along the spectrum of science and technology capabilities and to group them in more or less homogeneous categories. The idea has been to select and combine individual indicators that represent the level of domestic capacities in scientific research, technological development and the incorporation of new technologies into production, and also the intensity of the linkages between these and their international counterparts. The three indicators of internal capacity are normalized and averaged in a simple manner, the same is done for the three indicators of external linkages, and the S&T Capacity Index is calculated as the simple average of these two averages. While it would be possible to assign weights to each of the indicators, so as to reflect the relative importance of each component of internal capacity and of external linkages, this has not been done for this exercise.

Figure 3 shows the results of the calculation of the S&T Capacity Index for the 85 countries with available data. The values of the index vary over a wide range, and suggest that there are four distinct groups of countries as follows:

Type I. These countries have well developed endogenous scientific and technological capacities and a consolidated national system of innovation. Government policies encourage innovation and support the generation, acquisition and effective utilization of knowledge, and their science and technology linkages with other countries are very strong.

Type II. These countries have moderate levels of endogenous scientific and technological capacities, usually focused on the dynamic sectors of their economies. Even though most of them have a reasonably well-developed stock of human resources, they have not been able to create a broad base of scientific research and technological innovation activities that are effectively linked to their productive systems. They are actively engaged in scientific, technological and production exchanges with other countries, focusing on how to take advantage of the stock of knowledge available in Type I countries.

Type III. These countries are still in the early stages of establishing modern productive systems. They have a rather limited stock of highly qualified human resources, and incipient scientific research, technological development and innovation capacities. Many have a few enclaves of modern production activities (usually associated with foreign investment) that coexist with large segments of production activities based on traditional and conventional technologies, most of which are not able to compete in world markets. They face information, institutional and financial problems, and their linkages with the external sources of knowledge and technology are weak and sporadic.

Type IV. These countries have practically no significant scientific research, technological development or innovation capacities, and also have a very limited human resources base. Apart from the extraction of natural resources or the provision of some services, which take place in isolated enclaves, they generally use traditional and conventional technologies, which operate at low levels of productivity and efficiency. Linkages with the world scientific and technological community are extremely limited and in some cases non-existent.

Table 5 and Figure 4 show the average values of the indicators comprising the S&T Capacity Index for each of these four categories of countries. There is large difference between the average values of Type I countries, which have acquired an endogenous scientific and technological base, and those of Type II, III and IV countries that still lack it, although to differing degrees. This is also clearly shown in Figure 5. This suggests the presence of some sort of increasing returns to scale phenomenon or "Matthew effect", in which countries that already have endogenous technology capabilities are able to continue on developing such capacities at a greater rate than those that have not been able to do so.[11]

There have been other exercises aimed at developing indexes of science and technology capabilities, including those conducted by Wagner *et al* (2001), by the Human Development Report that created the "Technological Achievement Index" (UNDP, 2001), and by the International Council for Science Policy in a report prepared for UNESCO (1990). Table 6 compares the various components of these other indexes. Even though these exercises are not based on an underlying conceptual framework such as the one proposed in section 2 of this essay, they lead to similar results with regards to groups of countries (see Annex B).

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[11] The usual caveats that apply to the use of indicators in general, such as lack or poor quality of data and inconsistent use of definitions, apply when measuring such a complex set of capabilities included in the S&T Capacity Index. In addition, there are some specific limitations. First, the use of "high technology exports as a percentage of total exports" as a proxy for "gross product of knowledge intensive productive sectors as a percentage of GDP" is problematic. Exports do not necessarily denote internal capacity, especially in countries with high foreign direct investment. Second, the lack and poor quality of data introduce distortions in the indicators for type III and IV countries, and the value of some indicators might be grossly overestimated or underestimated. In order to keep the consistency of the series for each indicator, instead of combining data from different sources to increase the number of countries in some of the series we have used data from a single source, which is the UNESCO World Science Report.

The S&T Capacity Index uses as components indicators of science, technology and of high technology production activities, and thus focuses exclusively on the capacity to generate and utilize knowledge, and not on any indicator of economic development or general welfare of the population. Nevertheless, there is a high correlation between the S&T Capacity Index and the Human Development Index (HDI) calculated by UNDP, which includes income per capita, life expectancy and years of schooling. Figure 7 shows clearly that Type I countries belong to the category of high HDI, Type II and III belong to the medium HDI group, while Type IV coincides with the category of countries with low HDI.

TABLE 5:
Average Values of the Indicators and of the S&T Capacity Index by Group of Countries

Type of country	**Internal Capacity**			**External linkages**			**S&T Capacity Index**
	Number of scientist and engineers	**Expenditures on R&D / GDP**	**Exports of High technology sectors / Total exports**	**Scientific Publications**	**Number of patent applications filed**	**Infrastructure, communications and technology index**	
Type I	0.438	0.610	0.438	0.353	0.225	0.547	0.435
Type II	0.203	0.220	0.229	0.074	0.070	0.164	0.158
Type III	0.063	0.123	0.101	0.010	0.019	0.055	0.062
Type IV	0.026	0.034	0.005	0.002	0.016	0.024	0.017

BOX 2: **The Science and Technology Capacity Index**

Components of the Index. The components of the science and technology capacity index are derived from the conceptual model proposed in section 2 of this essay. The indicators of internal capacity and of external linkages for science, technology and production are:

SCIENCE	TECHNOLOGY	PRODUCTION
Internal Capacity		
Expenditures in Research and Development/GDP	Number of scientist and engineers per million people	Gross product of knowledge intensive productive sectors/GDP [(1)]
External linkages		
Number of scientific publications (in logarithms) [(4)]	Number of patent applications filed by residents and non-residents (in logarithms) [(2) (4)]	Infrastructure, communications and technology index [(3)]

The following observations are in order about some of the indicators:
(1) Due to lack of data, the indicator actually used as a proxy was "high technology exports as a percentage of total exports".
(2) Although other authors use the number of US Patents by country or origin as a proxy measure external linkages in the case of technology capacity, this indicator may be strongly biased in favor of industrialized countries (88% of all patents registered in the US originate from the United States, Japan and three countries of the European Union). For this reason we prefer to use the total number of patent applications. In addition, the considerable administrative costs of obtaining a US patent may discourage some inventors from developing countries from applying for US patents.
(3) The index of infrastructure, communications and technology is a composite indicator that includes numbers of televisions sets, fax machines, personal computers, internet hosts and mobile phones available in a given country. This indicator was elaborated by Francisco Rodríguez and Ernest J. Wilson, *Are poor countries loosing the information revolution?,* Infodev Working Paper, available in http://www.worldbank.org/infodev
(4) These two indicators are specified in logarithms to prevent the very large number of publications and patents of the United States from distorting the results during the normalization process.

Calculation of the Index. The S&T Capacity Index is the simple average of the internal and external indexes, as follows:

$$\text{S\&T Capacity Index} = (\text{Internal Capacity}_i + \text{External Linkages}_i)/2$$

Where i = country 1, 2, 3, …, n

To normalize the value of each country indicator, the six indicators that make up both indices were calculated in the following way:

$$I_{ij} = \frac{X_{ij} - minX_j}{maxX_j - minX_j} \qquad i = 1,\ldots,85 \quad j = 1,\ldots,6$$

Where

I	=	Value of the indicator
i	=	Country (85 countries in total)
j	=	Indicator (six in total, see Table above)
X_{ij}	=	Value of the country indicator
Min X_j	=	Minimum value of the indicator j
Max X_j	=	Maximum value of the indicator j

FIGURE 3:
Ranking of Countries According to their S&T Capacity Index

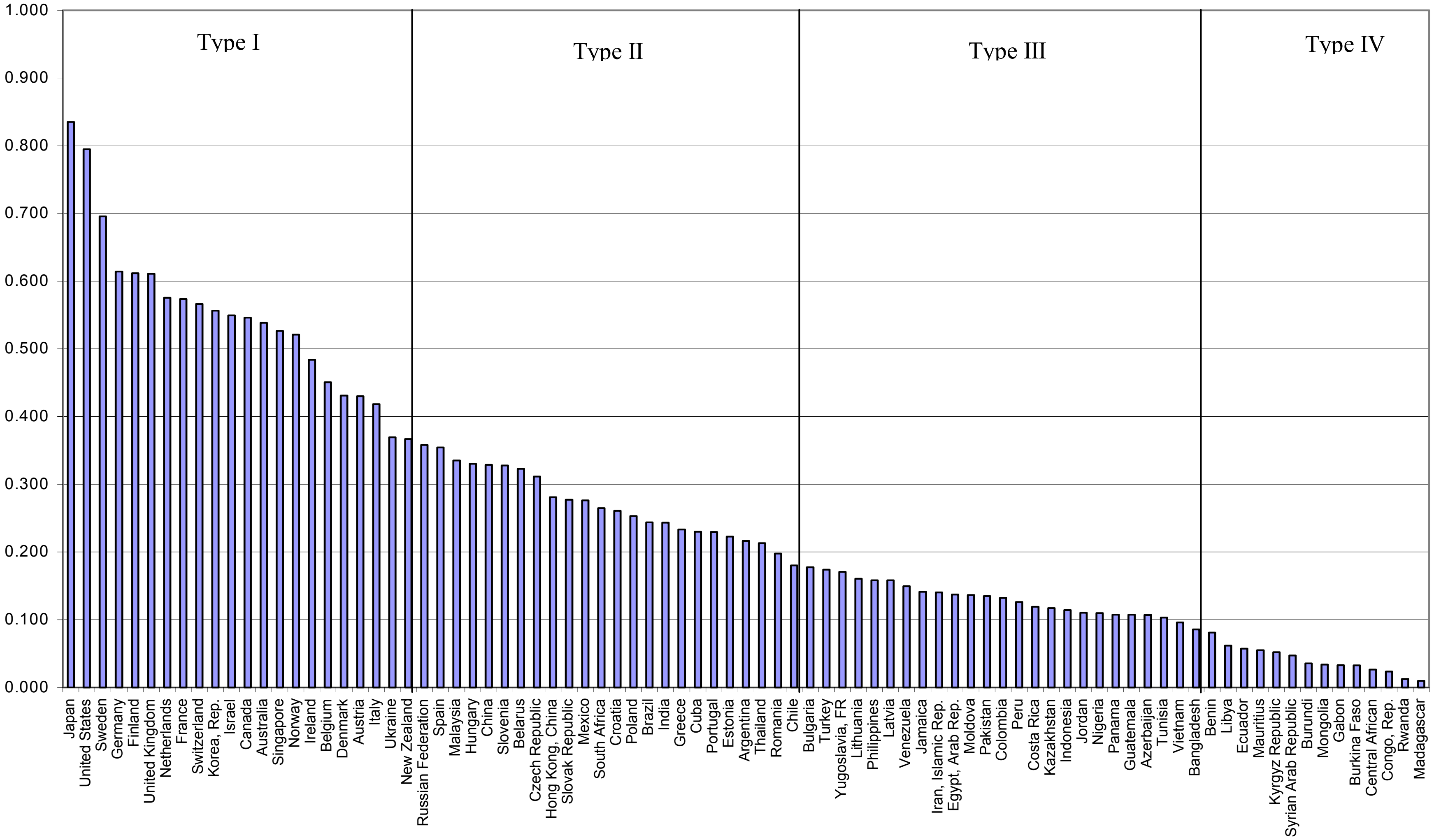
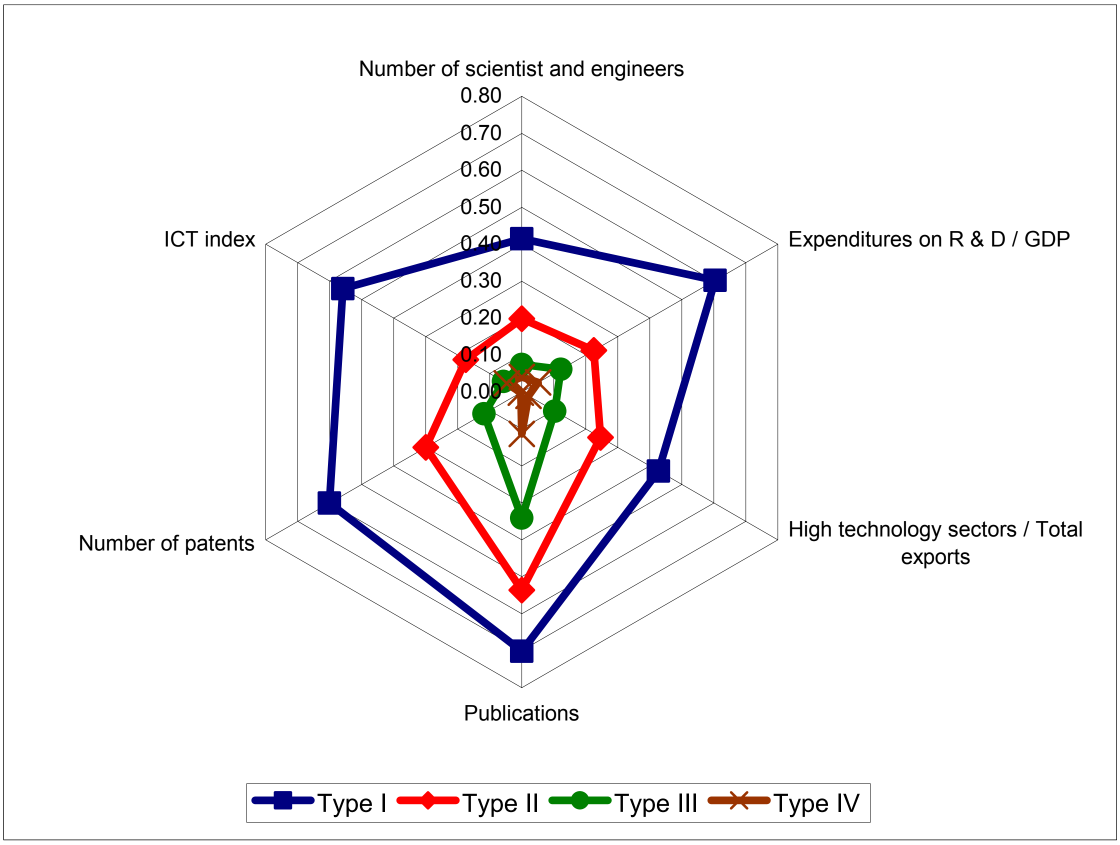


FIGURE 4:
Typology of Countries According to the Value of the Indicators Comprising the S&T Capacity Index



Note: ICT index = Infrastructure and communication index

FIGURE 5
Science and Technology Capacity Index: averages for each category

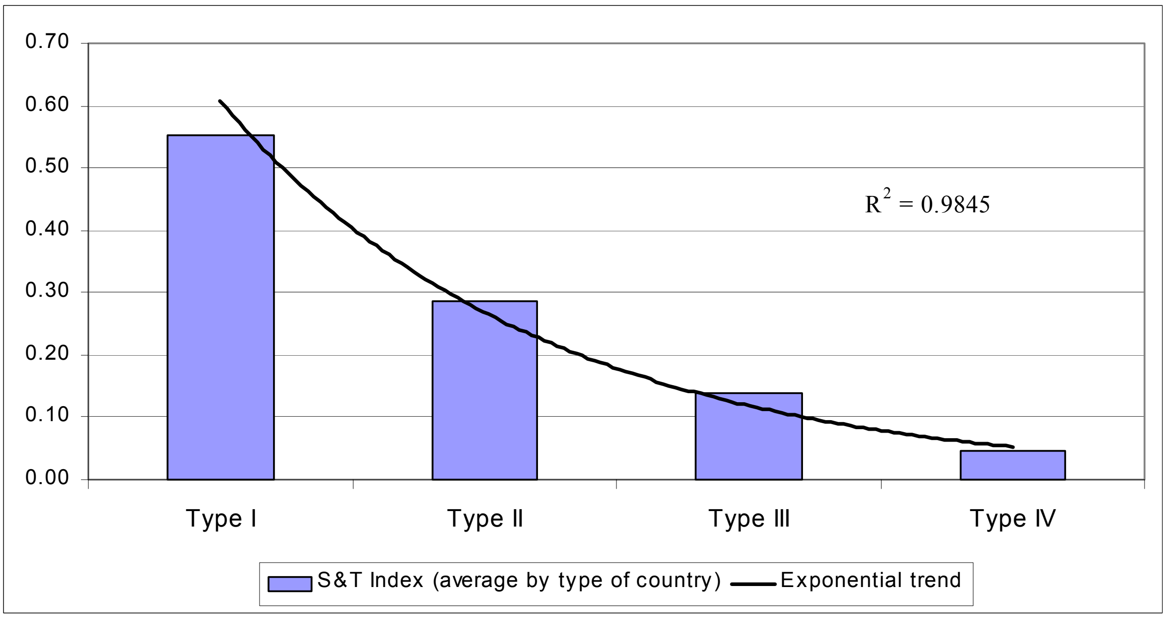
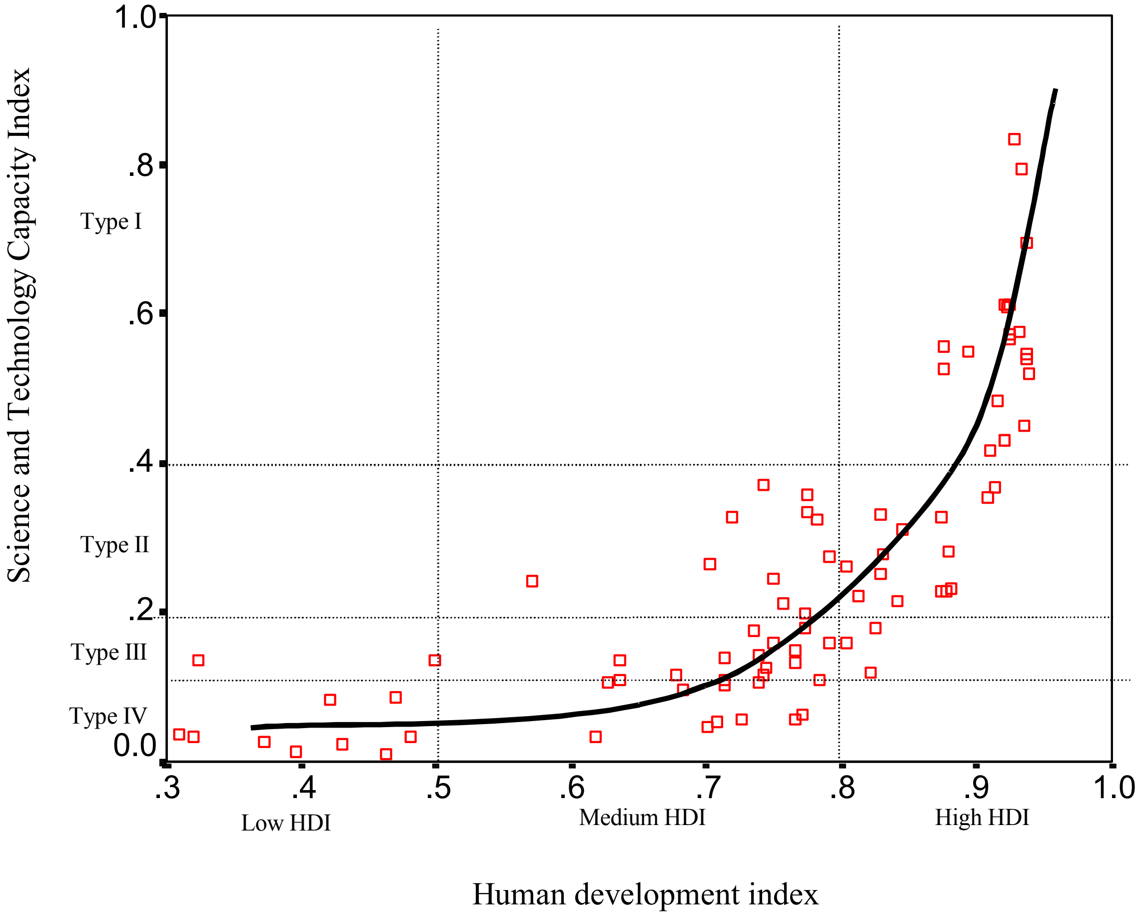


TABLE 6: **Comparison Between the Components of Four Indexes of Science and Technology Development**

Index	Dimension and indicators	Index	Dimension and indicators
S&T Capacity Index	**Science** • Number of scientist and engineers • Publications **Technology** • Expenditures on R & D / GDP • Number of patent applications filed **Production** • Exports of High technology sectors / Total exports • Infrastructure, communications and technology index	**RAND**	**Infrastructure** • The per capita gross national product (GNP) of the country **Human resources available for S&T activities** • Number of scientists and engineers per million people **S&T outputs** • Number of S&T journal articles and patents produced by citizens • The number of patents filed through the U.S. Patent and Trademark Office (USPTO) and the European Patent Office (EPO). **Input into S&T** • The percentage of GNP spent on R&D **External knowledge sources** • Number of the nation's students studying in the United States adjusted for those who chose not to return home at the conclusion of their studies
Technology Achievement Index (TAI)	**Creation of technology** • Patents granted per capita • Receipts of royalty and license fees from abroad per capita **Diffusion of recent innovations** • Internet hosts per capita • High- and medium-technology exports as a share of all exports **Diffusion of old innovations** • Logarithm of telephones per capita (mainline and cellular combined) • Logarithm of electricity consumption per capita **Human skills** • Mean years of schooling • Gross enrolment ratio at tertiary level in science, mathematics and engineering	**UNESCO**	**The distribution of overall human resources** • Distribution of countries according to population **The distribution of income levels** • GDP per capita • % of manufactured products exports from total national exports and total developing countries manufactured exports. **Research and development intensity** • R&D share of the GNP • Scientists and engineers in the population • R&D personnel in higher education per Thousand population **Accomplishments in S&T education** • Number of potential scientists & engineers • Number of R&D scientists per million population • Number of third level students per 100.000 inhabitants. • R&D personnel in industry **An overall typology of S&T capabilities** • "Scoreboard" according groupings achieved by countries in each case

FIGURE 7

The Human Development Index and the Science & Technology Capacity Index



Source: Elaborated by the authors. The HDI data was obtained from the UNDP website, http://www.undp.org/hdro/hdro.html

5. Strategies and policies for building an endogenous science and technology base

The preceding sections have made explicit the Sisyphean challenge faced by developing countries in mobilizing knowledge for development. The obstacles that must be surmounted in responding adequately to it suggest the need for well-thought strategies and for effective policy instruments, so as to make the best possible use of scarce resources and limited opportunities. However, even the best efforts by developing countries are unlikely to succeed in an adverse global context. Without a positive attitude and the active engagement of the global scientific and technological community, of international institutions and government agencies in developed countries, and of private sector firms, universities and research centers that control the access to knowledge and technology, it will be nearly impossible for developing countries to bridge the knowledge divide and to build endogenous science and technology capabilities. For this reason, international cooperation plays a special role in meeting this challenge.

5.1 The context for mobilizing knowledge and innovation for development

Efforts to mobilize knowledge and innovation to improve the human condition will take place in the context of a turbulent, segmented and uneven globalization process. At the beginning of the 21st century, the accelerated expansion of productive and service activities throughout the world, the rapid growth of international trade and the massive exchanges of information that can be accessed anywhere in the planet, coexist with the concentration of such "global" activities in certain countries, regions, cities, even neighborhoods, and even in a few hundred transnational corporations.

The simultaneous integration and exclusion of countries, regions —as well as of peoples within countries— are two intertwining aspects of the many-faceted paradoxical processes of globalization and fragmentation under way in our turbulent period of history, a time that is witnessing the emergence of *a fractured global order*. This is an order that global but not integrated; which puts us in contact with one another, but at the same time preserves and creates deep divisions between countries and between peoples in these countries; and which benefits a small part of humanity and segregates the vast majority of the world's population.

The emergence of this fractured global order has old historical roots. As pointed out in section 2, the fissures that characterized the globalization process now under way began to appear in the 15th and 16thcenturies, with the worldwide expansion of Western Europe. Yet, the swift and profound upheavals of the last half of the 20th century have created a radically new context for human evolution. To a very large extent, this is because advances in science and technology —closely associated with the transformation of knowledge generation activities, the changes in the technological base and the modifications of production activities (see section 3)— have wrought profound changes in the way human beings interact, in our conceptions of human nature and in the way we visualize the future evolution of humanity.

Ambiguities, contradictions and inconsistencies, which generate confusion and uncertainty, accompany this uneven process of globalization and fragmentation. The various forces —political, security, economic, financial, social, environmental, cultural, governance, religious, scientific, technological— that interact to produce the fractured global order do not all pull in the same direction. They may generate positive or negative results depending on the structure of power relations of those affected by them, and also on the capacity to design and put in practice strategies to take advantage of opportunities and to limit undesirable effects. Considered alone, any one of these forces of change has important consequences for the future of developing countries and, indeed, for the whole planet. Taken together, they represent an epochal change, a fundamental shift in the international frame of reference for efforts to achieve prosperity and wellbeing, which demands a fundamental reappraisal of how the emerging international context shapes options for developing countries.

The fractured global order gives rise to a series of demands which require strategic responses from governments, businesses and civil society organizations in developing countries. The emergence of *new international security concerns* —ethnic and religious conflicts, chemical and bacteriological warfare, terrorism, proliferation of nuclear weapons, organized crime, drug trafficking, environmental disputes— demand new arrangements for international and regional security, as well as new national defense doctrines. This became evident after the September 11, 2001 terrorist attacks at World Trade Center in New York and the Pentagon in Washington.

Growing *economic and financial interdependence*, together with changes in international economic relations, demand new strategies for the insertion of economies and businesses in an international scene, which is increasingly competitive and volatile, which is becoming increasingly integrated and in which financial globalization plays a leading role.

Social conditions and persistent inequalities pose an enormous challenge to the maintenance of social cohesion. Demographic imbalances between rich and poor countries; rapid growth in the demand for food, health, education, housing, drinking water and sewerage services in the developing world; widespread poverty associated with economic, political and social exclusion; and unemployment and underemployment, which affect rich countries as well as poor, all require imaginative and practical responses both at the international, national and local levels. Similarly, the significant changes which have occurred in gender relations, primarily as a result of the ability women have acquired to regulate more easily their own fertility, have great importance for the world of work and home: they demand a new perspective on the conventional division of responsibilities between men and women, both in the workplace and in the upbringing of children.

Awareness of the imperative of *environmental protection and the sustainable use of natural resources*, associated with the appearance of environmental problems of a regional and global nature, demands responses to ensure that economic growth, widespread poverty, and unsustainably consumption patterns do not limit the opportunities of future generations. The scale and intensity of human activity means that we cannot now blindly trust in the automatic regenerative capacity of ecosystems, but that must consciously devise environmentally friendly ways of going about our business in an increasingly fragile planet.

The growing importance of *religious, ethical and cultural* factors in the conduct of government and business affairs adds fresh demands to an already overcrowded public agenda: it brings to the fore issues such as religious tolerance, respect for human rights, ethical behavior, and tensions between towards pressures towards cultural homogeneity and the affirmation of cultural identity. In the same way, the *spread of democratic practices* and the collapse of one-party totalitarian systems in Eastern Europe and the former Soviet Union have wrought significant changes in the institutional structures of states and governments, highlighting the importance of social capital and institutions in political and economic performance.

Finally, sections 2 and 3 have highlighted the importance of *advances in science, technology and innovation*, which are both a cause and a consequence of all the other changes in the forces that are shaping the emerging fractured global order.

It should be kept in mind that only certain sectors of the global economy, including financial services, manufactured products with a high technological content, mass media and telecommunications, have expanded their activities worldwide. As highlighted in section 3.5, a large proportion of productive and service activities remain firmly anchored in their local settings. This is the case of many agricultural activities, of small manufacturing, crafts and a whole range of services whose geographical reach is limited, and also of practically all activities linked to subsistence economies. It is difficult to estimate what percentage of the world's population remains outside the global circuits of production, commerce, finance and consumption, but it is likely that a significant majority of those who live in poor countries do not participate and are little affected by them.

Nobody is directing in any conscious or deliberate manner the processes leading to a fractured global order. There is no overall coordinator who takes decisions on the course of the contradictory processes of globalization and fragmentation —no one is "in charge" of the turbulent processes that are creating a few winners and many losers. Their diverse components function in accordance to their own logic and the logics of the interactions between them. However, this does not mean that the processes leading to a fractured global order lack a general direction, which —for the time being— is rooted in the pro-market and anti-state ideological stance prevalent at the end of the 20th century, although it is now shifting to a more balanced perspective of the role of the state, the market and civil society in the process of development.

The fractured global order, with all its paradoxes and ambiguities, constitutes the stage on which developing countries will face the Sisyphean challenge of building endogenous science and technology capabilities.

5.2 The experience with science and technology policies in the developing countries

As the growing importance of science and technology began to be recognized during the second half of the 20th century, several countries designed and put in practice strategies and policies to build scientific and technological capabilities. These policies responded to the specific situations and historical backgrounds, which to a large extent conditioned their content and success. The rather long time required to build and consolidate knowledge, technology and innovation capacities ensures that the inertia of past interventions and outcomes influences the range of options available to policy and decision makers at any given time. In particular, the coverage and quality of education —especially tertiary education in the physical, biological and engineering sciences— exerts a determining influence on what can be achieved in scientific research, technological development and innovation.

The values of the Scientific and Technological Capacity Index and the typology put forward in section 4.2 describe the result of country strategies and policies put in practice during several decades. For example, the Republic of South Korea is the only country in the Type I category which started nearly five decades ago as a very poor country, with practically no domestic knowledge and innovation capabilities. Massive investments in education science and technology allowed this country to catch up with the more advanced countries of the West in just a few decades. Also, starting from relatively low levels, Israel and to a lesser extent Ireland may be said to have moved relatively fast in the acquisition of science and technology capabilities. In contrast, the countries placed in the Type IV category have made little or no effort to systematically build their science and technology capabilities, largely because of a host of political and economic limitations that have put and kept them at a disadvantage for most of the last half century. The Sisyphus syndrome, whereby hard won science and technology capacities are lost because the inability to sustain efforts, can be clearly observed in many developing world during the last five decades, and more recently in the countries of Eastern Europe and the former Soviet Union.

The study, design and execution of science and technology policies, as we understand it now, began in the period immediately after World War II, a few years after this field was defined and delimited in the seminal work of J. D. Bernal *The social function of science*.[12] At that time governments in industrialized nations started to emphasize the application of science to peaceful uses, following the success with which it had been used during the war. Science and technology policy studies and practice evolved through several phases, marking a gradual transition from concerns centered around the growth of scientific research in the

[12] See Bernal (1967, reprinted from the 1937 edition)

1950s, towards preoccupations with technological innovation and competitiveness in the following decades. In parallel, a number of science and technology policy research programs were created in Europe and the United States, and over a period of three decades these programs created a well-established field of study and practice. A similar evolution took place in a few developing countries —for example, India, Brazil, Egypt, South Korea and Mexico— where these studies were often encouraged and supported by international institutions, including the United Nations Education, Science and Culture Organization (UNESCO), the United Nations Trade and Development Conference (UNCTAD), the Organization of American States (OAS) and the Canadian International Development Research Centre (IDRC). Perceptions of the role of science and technology in development evolved from rather optimistic view in the 1950s and 1960s, to a more skeptical perspective in the 1980s and 1990s. Along the way, a valuable experience —both positive and negative— was accumulated regarding how to design an dimplement strategies and policies to acquire knowledge and innovation capacities.

Five partially overlapping phases can be identified in the evolution of science and technology policies for development, based primarily on what happened in those regions and countries that attempted to build capabilities in this field: Latin America, several countries in South and South-East Asia, and a few countries in Africa and the Middle East. First, there was a *science push* phase, which extended from the early 1950s to the mid 1960s. The design of science and technology policies during this phase was shaped by the "linear innovation model" perspective, in which scientific research led directly to technological innovation which, in turn, improved productivity and economic growth. Therefore, the main task was to boost the scientific capacity to produce discoveries and inventions. This approach led to a surge of support for the creation of scientific research facilities in universities and public institutions. Many developing countries created National Research Councils at this stage, which were given the task of promoting and financing scientific research.

Second, there was a *technology transfer and systems analysis* phase that began in the late 1960s and lasted through the 1970s. Technology transfers and the choice of appropriate technologies were the main concerns in this phase. Direct foreign investment, particularly by transnational corporations, played an important role in relocating some technologically mature industries in developing countries. While these investments were viewed in a positive light because their potential impact on industrial transformation, employment generation and productivity improvements, the policies used to attract direct foreign investment backfired in many developing countries. High tariff barriers for consumer and light durable goods, coupled with low tariffs for capital goods and intermediate products and with generous tax incentives, succeeded in attracting transnational corporations to countries with relatively large internal markets. However, they also led to external accounts imbalances due to poor export performance, increases in machinery and materials imports, profit remittances and hefty management and technology fees. The response was to establish government agencies to regulate foreign direct investment, technology license agreements and to provide information about technological options to domestic firms. These were accompanied by efforts to promote the use of "appropriate technologies", defined as those requiring less capital investments and skilled labor, better suited to domestic consumer tastes, and that made use of local natural resources.

In the mid to late 1970s, technology transfer concerns were superseded by attempts to apply a "systems approach" to the design and implementation of science and technology policies. The limited success of what were seen as narrowly focused efforts justified the adoption of comprehensive approaches to science and technology capacity building. The greater availability of empirical studies of technological development, together with evaluations of the impact of science and technology policies, provided a more informed basis for policy design. Yet these policies were still primarily centered on how to improve the performance of government agencies, universities and public research institutions. The consolidation of technological and innovation capacities in the productive sector did not figure prominently as a policy concern, and firms remained largely isolated from domestic scientific research and technological development institutions. At this time, many "National Research Councils" were transformed into "National Science and Technology Councils", which increased their scope considerably in comparison with the focus on research and development that dominated the in previous phase.

Third, a *science and technology policy implementation phase* began in the mid-1970s and extended through the mid-1980s. Priority was given to policies to promote technological change in manufacturing, agriculture, mining and other priority sectors, and also to improve the technological capacity of private and state-owned firms. Special funds to support innovation were established, fiscal incentives for research and development were created, and information, quality control and training programs were put in practice to assist enterprises. One of the core concerns in this phase was assessing the impact of science and technology policies on the behavior of economic agents and of science and technology institutions. This led to a number of comparative studies on the design and implementation of technology policies, on the impact of these policies on the behavior of productive units, and on the difference between implicit and explicit science and technology policies, all of which were supposed to help in the identification of more effective science and technology policy instruments.[13]

The fourth phase, which prevailed during most of the 1980s and stretched into the early 1990s, could be labeled as that of *disregard for science and technology policies and emphasis on the free play of market forces*. The economic crises in Latin America, Sub-Saharan Africa, and in some countries of South Asia and Asia-Pacific, led to drastic reductions in government budgets and in public allocations for science and technology. Macroeconomic disequilibria —high inflation, exchange rate misalignment, trade and fiscal deficits— became common in developing countries, at the same time that growing external debt payments exerted pressures on foreign exchange earnings and fiscal accounts. As a response, international financial institutions designed, advocated and pressed for economic policy reforms —trade and financial liberalization, privatization, deregulation, tax reform, fiscal discipline, among others— which were codified in what was labeled as the "Washington Consensus" in the late 1980s.

In this context, most firms halted long-term investments and relegated technology concerns to a second or third plane. Maintaining financial health in an unstable economic environment became the overriding concern of managers and entrepreneurs, while operational, technical and human resource issues became much less important. The few state-owned firms that had played a leading role in technological curtailed their research and development activities, and many professionals in technology research, development and management left these firms and emigrated. During this phase, many countries experienced the loss of science, technology and innovation capabilities that had taken substantive efforts and a long time to build.

[13] The model proposed in section 2 of this essay, the concepts of endogenous and exogenous science and technology base, and the ideas regarding the selective recovery of the traditional technological base were first introduced during this phase.

There is a substantive overlap between the fourth phase in the design and implementation of science and technology policies, and the current phase of *competitiveness and innovation systems*, which emerged in the mid-1990s. Economic policy reforms led to price, exchange rate and fiscal stability, but did not succeed in promoting sustained and substantial growth or in improving social equity. Firms that survived the tough process of commercial and financial liberalization increased their efficiency and became more competitive, but a large number of enterprises that had previously catered to domestic markets disappeared together with their technological and innovation capacities. In addition, the attainment of fiscal stability and the redirection of public expenditures towards social support programs to ameliorate the impact of adjustment policies led, in an indirect way, to reductions in public budget resources for science and technology.

A reappraisal of the policies contained in the "Washington Consensus" in the late 1990s identified the need for a "second generation" of policy reforms focusing on institutional development, the rule of law, accountability and openness in government, and also on a better balance between state intervention, market forces and civil society advocacy. The need to penetrate foreign markets led to initiatives to improve competitiveness, and to a renewed interest in science and technology policies. The emphasis shifted towards strengthening technology and innovation capacities in firms, with research facilities and technology institutes seen as playing an important but supporting role in the quest for competitiveness. The role of science and technology councils became fuzzier and less important, especially as new technical assistance, quality control, market information, certification and financing programs outside their purview were launched to support innovation. These were complemented with measures to encourage commercial spin-offs from university and research institutes, the creation of technology parks to attract high technology foreign investment, and the consolidation of clusters of small and medium size enterprises around large modern firms to promote technology diffusion. Some of these measures had been tried before with mixed success, but they were now seen as components of a comprehensive approach to innovation and competitiveness.

The concept of "National Innovation Systems" provided a framework to view and articulate science and technology policies in this phase. Similarly to what the systems approach advocated in in the late 1970s, this concept the roles played by a wide variety of capable and strongly interacting agents to materialize innovation. However, it does so in the setting of competitive markets that extend beyond national boundaries, while focusing more sharply on the role of enterprises and stressing the need for monitoring, evaluation and continuous adjustment of government policies. The acquisition and effective utilization of knowledge in production and service activities becomes a source of competitive advantage, and the activities of universities, research institutes, consulting firms and other agents involved in the generation and transmission of knowledge must ultimately be seen as feeding into the innovation and technology learning processes. With a long-term perspective, this amounts to tightly binding science, technology and production, which would gradually lead to the creation of an endogenous science and technology base. However, in the short and medium term, an innovation system will rely more on imported sources of knowledge and technology, while scientific and technological research capabilities are built and consolidated.

Although not all developing countries experienced these fice phases simultaneously and sequentially, on the whole they show the main trends followed by science and technology policy followed during the last fifty years in developing countries. However, in spite of this evolution, it is necessary to acknowledge that the impact of these policies has been —with a very few notable exceptions— rather limited. In most developing countries, scientific research, technology development and innovation capacities remained incipient and isolated from each other. As indicated in section 4.1, the rather low participation of developing countries in the world's scientific and technological effort did not improve in any significant way. In short, it has proven most difficult to build endogenous science and technology capacities in the vast majority of developing countries.

Yet, the experience with science and technology policies in developing countries contains many lessons that can be taken advantage of in the Sisyphean task of mobilizing knowledge and innovation to improve the human condition.

5.3 An approach to strategy and policy design

The preoccupation with the design and implementation of national development strategies reemerged in the mid-1990s, after more than a decade of dominance of ideas and policies based on the free play of market forces as the preferred path to the improvement of living standards in developing countries. During that period, which coincided with the fourth phase in the evolution of science and technology policies described in the preceding section, influential academic researchers, opinion leaders and senior officials in international organizations sought to reduce the role played by the State in the economies of developing countries. To this end they promoted liberalization, deregulation and privatization policies, often without the necessary institutional prerequisites in place (regulating agencies, accountability procedures, government transparency and openness). The undesirable consequences of this approach —growing inequalities between and within countries, increases in the number of poor people, widespread exclusion, corruption of senior government officials, among others— became evident during the 1990s, and a more balanced perspective on the role of market forces, State intervention and civil society participation has began to emerge. This happened together with the transition from the fourth to the current phase of science and technology policies, which emphasizes competitiveness and the role of national innovation systems.

The return of strategy to center stage in development thinking and practice coincided with a growing interest in the role played by knowledge in development, and also with advances in strategic planning in complex organizations, which provided conceptual and methodological tools to organize comprehensive and participative planning processes. The emergence of the knowledge society, the knowledge explosion and its manifestations, and the visibility of the knowledge divide made it necessary to explicitly incorporate science, technology and innovation —as well as the recovery of traditional knowledge and techniques— into the design of development strategies.

However, in most developing countries there is not as yet a widespread awareness and understanding of the importance of science and technology in development, nor an acceptance that short term sacrifices must be made to build the capacities to generate and utilize knowledge. A first task is to raise social consciousness about the critical role that knowledge plays in development, and to persuade political, grass roots, community, business and civil society leaders that science, technology and innovation are essential to improve living standards. It is also necessary to call their attention to the huge and growing disparities in the capacity to generate and utilize knowledge, which are at the root of the asymmetries in power relations between governments and firms in developed and in developing countries, and which considerably limit the room for maneuver in the design and implementation of development strategies.

There are several principles to guide the design and implementation of strategies to create and acquire endogenous science and technology capabilities. These have emerged out of the experience, both positive and negative, of many developing countries in the last three decades.

The first principle is that *strategies and policies for establishing an endogenous science and technology base must be fully incorporated into the design of a comprehensive development strategy for the country*. Isolated attempts at creating pockets of science, technology and innovation capabilities without strong linkages to broader development objectives and the means to achieve them are unsustainable in the long run. Conversely, development strategies that do not envisage a major role for science, technology and innovation are likely to fail in the knowledge society of the 21st century. The often heroic efforts of science and technology researchers and policy makers in developing countries are futile in the face of indifference, neglect and even hostility by political, government and business leaders. The few developing countries that have made spectacular economic and social gains during the last few decades are precisely those that adopted development strategies that envisaged a key role for science and technology. This requires a strong public sector presence, at least in the initial stages of building an endogenous science and technology base. The social and private rates of return to investments in scientific research, technological development and innovation differ widely, for these activities are characterized by strong externalities that prevent private agents from reaping the full benefit of their efforts. In many of its forms, knowledge is clearly a "public good ", which many people can take advantage of without diminishing its usefulness to others. As Thomas Jefferson put it "he who receives an idea from me receives [it] without lessening [me], as he who lights his [candle] at mine receives light without darkening me."[14]

The second principle acknowledges that *the cumulative process of building endogenous science and technology capabilities requires continuous and sustained efforts* *over a long time*. There are many prerequisites for success in this enterprise — macroeconomic stability, an educated human resource base, well-functioning institutions, an active research community, open-minded and innovative entrepreneurs, among others— and these are not acquired overnight. History counts and the results of previous efforts condition the options available to policy and decision makers. Institutions take a long time to build and there is no substitute for the steady evolution of practices and habits of interaction that create a favorable environment for science and technology. Nevertheless, while maintaining a steady course in the long-term process of building science and technology capabilities, there must also be a readiness to take advantage of unexpected short-term opportunities (discovery of natural resources, economic windfalls, availability of new technologies, geopolitical shifts). Occasionally, there may emergence possibilities for "leapfrogging" into more advanced technological stages, but leapfrogging requires "technological legs" that take time to grow. Persistence must be balanced with flexibility in the process of building an endogenous science and technology base.[15] A corollary of this principle is the readiness to accept failure, for it is most improbable that each and every policy intervention will be successful during the decade or two that would be required, in the best possible circumstances, to create an adequate level of scientific research, technological development and innovation capabilities.

The third principle is derived from the difficult economic situation and the scarcity of resources that beset most developing countries. *The process of building endogenous science and technology capabilities must be highly selective, but without losing sight of unusual opportunities that may emerge*. This argues for focusing efforts on a few clearly identified areas of science, technology and production, while leaving space and a modest amount of resources to support non-priority but potentially useful initiatives. Adhering to this principle requires a willingness to make choices in the face of uncertainty (about technological advances, the international context, institutional performance, the behavior of researchers and entrepreneurs), fully acknowledging the long-term consequences of such difficult decisions. The selection process locks-in resources for a decade or more in the chosen areas and their

[14] Knowledge satisfies the economic conditions for defining a public good: it is non-excludable in the sense that it is difficult and costly to exclude those who do not pay for it from consuming it, and non-rivalrous in the sense that any one person's consumption of the good has no effect on the amount of it available to others. See Sagasti and Bezanson (2001).

[15] The "double window of opportunity" created by the transition from one techno-economic paradigm to another (section 3.4, Figure 2) provides an illustration of the need for both persistence and flexibility.

upstream and downstream linkages, which puts a premium on using the best available information and decision making procedures.

The fourth principle emphasizes the integrative nature of the process of building an endogenous science and technology base, where *science, technology and production, together with traditional knowledge and techniques, must all be fully integrated*. Within the chosen priority areas, measures to develop scientific research, technological development and innovation capacities, as well as to promote their interactions, must be viewed as a coherent whole and adopted in a logical sequence to increase the likelihood of success. It is not enough to build excellent scientific research capacities, expecting they will automatically lead to technological development; nor it is sufficient to import advanced technologies to improve production, assuming that they will trickle down and enrich technological capabilities. This underscores the importance of thinking about "knowledge and technology delivery systems" that can foster and sustain innovation. As the innovation process has acquired a more systemic character, and as the age of analysis yields to the age synthesis in technology design, engineering skills and capabilities have become the glue that holds together the various knowledge, technology and production components. Therefore, building engineering schools and creating technology management programs are among the high priority tasks in the acquisition of endogenous science and technology capabilities.

The fifth principle is related to the global character of modern science and technology: *the international dimension must be explicitly considered in the design of strategies to build an endogenous science and technology base*. This implies encouraging cooperation in scientific research, securing access to the sources of technology, promoting trade in knowledge-intensive goods and services, creating conditions to attract foreign investment that brings technology to the country, fostering the exchange of highly trained personnel, making use of graduate fellowship programs, and harmonizing policies and international agreements that regulate the global flow of knowledge and technology. Putting in practice this principle requires close coordination between policy makers in charge of science and technology on the one side, and those responsible for international trade, foreign investment, higher education, selected economic sectors and diplomacy on the other. The international negotiations agenda of developing countries should include the expansion and better coordination of cooperation initiatives to support their science and technology efforts, particularly in view of the limited number and dispersion of existing international organizations, programs, mechanisms and facilities supporting science and technology in developing countries.

The sixth principle emphasizes the importance of *adopting a learning stance in the process of building an endogenous science and technology base*. The effectiveness and efficiency of policy instruments should be continuously monitored and evaluated, but allowing time for them to influence the behavior of the variety of agents engaged in the generation, acquisition, dissemination and utilization of knowledge. As domestic and international conditions change rapidly, policies, policy instruments and the procedures to put them in practice are likely to require adjustments and changes. Learning from past experience, and from the experience of others, becomes essential to avoid wasting resources, time and political capital in the arduous long-term process of building endogenous science and technology capabilities. This puts a high premium on counting with a highly qualified group of science, technology and innovation policy makers, and also of ensuring that those in charge of policy making in related fields are aware of the importance of building science, technology and innovation capabilities.

5.4 The repertoire of policies and policy instruments

There is a vast repertoire of possible government interventions to foster the generation, acquisition, dissemination and utilization of scientific and technological knowledge, most of which have been devised and tried out in developed countries. The last three decades have also seen a growing interest in many developing countries in the range of policy instruments that can be used to build endogenous science and technology capabilities, and in the overall strategies that articulate their deployment.[16] The emergence of the concept of national systems of innovation and its application to developing country situations, particularly during the 1990s, has recently helped to focus attention on the institutional arrangements and policy interventions to promote innovation.

The conceptual model advanced in this essay can be used to identify the main categories of policy instruments to create an endogenous science and technology base, which

[16] The first large-scale comparative exercise to examine the range of possible developing country government interventions in developing countries was the "Science and Technology Policy Instruments" (STPI) project, which was carried out in the early 1970s (Sagasti, 1976). A similar, but much broader exercise on strategies for science and technology was conducted in the late 1970s (Halty, 1986).

are now available to policy and decision makers in developing countries (Table 8). The first category comprises government interventions aimed at building science, technology and innovation capacities; the second includes measures that focus on the creation of linkages between domestic science and technology and those at the global level, and particularly in developed countries; and the third category comprises actions that establish a favorable contexts and an appropriate institutional framework for the creation of scientific research, technological development and innovation capacities. Each of these will be briefly discussed for illustrative purposes.

Building science, technology and innovation capacities. This category of policy instruments has four main components: supply side measures that aim at building institutions and capacities to produce scientific and technological knowledge, and also to recover and upgrade traditional knowledge and techniques; demand side interventions to promote the utilization of the knowledge generated in the country in production and service activities; measures to strengthen the linkages between the supply and demand of domestically produced or adapted knowledge; and actions to strengthen science and technology policy making capabilities.

The *supply side component* of a strategy to build endogenous science and technology comprises institution building (creation, reorganization and consolidation of science and technology research centers; strengthening of university, government and independent laboratories; establishment of science support institutions including libraries, information centers, laboratory maintenance and repair facilities, metrology institutions, and calibration and standardization services); financing of science and technology activities (direct public budget support, special funds for research, endowments for foundations, competitive grants, block grants, research and services contracts, foreign bilateral assistance grants, loans from international financial institutions, tax incentives for private firms, venture capital); human resources development (fellowship programs, internships in the country and abroad, small grants for individual research and dissertation projects, science education programs in schools, expansion of higher education programs and facilities for science and technology, specialized graduate programs for technology management, sabbatical leave programs for researchers, short-term courses given by high-level foreign specialists); science and technology foresight and planning (analysis of trends and potential developments in science and technology, definition of strategies for research and innovation in selected areas, identification of activities that should be given priority in resource allocation, dissemination of information on trends, strategies and policies); and fostering networking among science and technology institutions (establish multidisciplinary scientific research and technological development programs, create linkages between public and private research centers, foster interactions between institutions through periodic events and seminars).

The *demand side component* of the strategy to build an endogenous science and technology base comprises the measures that foster the demand from locally produced science and technology knowledge. It includes encouraging technology planning activities in firms (dissemination of information on measures to improve competitiveness and increase productivity, technical assistance on how to make use of existing domestic knowledge and select the most appropriate external sources of knowledge, technical assistance to improve technology choices in firms); financing of innovation in firms (venture capital, subsidized loans and matching grants to purchase technology-intensive goods and services, tax exemptions and accelerated depreciation of capital goods and high-technology equipment, financing of special training programs for workers and professionals, working capital for experimentation and trial production runs); financing for technology institutions to participate in innovation (lines of credit for domestic engineering and consulting firms, funds for technology development and fine-tuning of processes and products, matching grants for the provision of technical assistance to firms); use of the purchasing power of the State to encourage demand for domestic technology (preference for local suppliers of technology and engineering services in bidding contests, direct contracts with local firms and research centers, purchase guarantees for manufacturers of technology intensive goods); technical norms and standards services (metrology laboratories, quality control programs, public-private partnerships to promote and enforce compliance with standards); and promoting exports of technology intensive goods and services (provision of information on potential export markets, credit lines for exports of machinery and equipment, financing arrangements for suppliers of engineering and consulting services, publicity campaigns to create demand for exports of technology intensive goods, tax credits and rebates for exporters, technical assistance for exports to meet quality control and environmental standards).

The component of the strategy that aims at *establishing linkages between the domestic supply and the demand for scientific and technological knowledge associated with innovation* comprises "push" measures that reach out from research institutions towards the productive

TABLE 8: **Categories of Government Interventions to Establish an Endogenous Science and Technology Base**

Category	Type of policy instruments	Specific measures
Building science, technology and innovation capacities in developing countries	Supply side: creating S&T institutions and building research and technology development capacities	Creation and consolidation of all types of S&T institutions, financing of S&T activities, human resource development, S&T foresight and planning, creation of networks of institutions
	Demand side: promoting the utilization of domestic S&T knowledge in production and service activities	Strategic planning of production and service activities, financing of innovation at the firm level, use of the State's purchasing power, technical norms and standards, fiscal incentives to stimulate innovation, promoting export of technology intensive goods
	Linking the domestic supply with the demand for S&T knowledge associated with innovation in the productive system	S&T parks and incubators, technology extension services, engineering design and consulting services, selective recovering and upgrading of traditional techniques, policies to promote technology diffusion between firms, cluster policies to link technology leaders with other firms
	Strengthening S&T policy making	Creation of specialized S&T policy agencies, coordination of national and local initiatives in S&T, organize policy research and foresight centers, provide information to policy makers
Creating linkages between knowledge, technology and production in developing countries and their global counterparts	Establishing linkages with the world scientific research community	Joint research projects, access to international S&T information, remote access to research facilities and equipment, gathering data about natural resources and biodiversity, monitoring climate change and natural disasters
	Obtaining and securing access to external sources of technology	Purchase of technology intensive goods and services, technology licensing agreements, utilize intellectual property regulations, technology scanning and search
	Establishing linkages with the global production system	Direct foreign investment, import and export of equipment and machinery, trade in goods and services, subcontracting in global value chains
Establishing a favorable context and institutional framework for creating an endogenous S&T base	Providing the physical infrastructure for the performance of scientific research, technology development and innovation	Communications facilities, transport infrastructure (roads, railroads, ports, airports), reliable energy supply (electricity, oil, gas), clean water and sanitation, waste disposal, clean air, appropriate land use regulations
	Establishing institutional arrangements favorable to innovation	Elimination of bureaucratic impediments, transparency, fair and effective regulatory agencies, prevalence of the rule of law, democratic governance
	Creating a stable economic policy framework conducive to long-term thinking in firms and other organizations	Price, interest rate and exchange rate stability, sensible financial and credit policies, prudent fiscal policies, tax arrangements that encourage investment, openness to trade and investment
	Evolving a cultural and social environment that encourages creativity, risk-taking and innovative behavior	General and scientific education, fair and flexible labor policies, environmental protection, access to information and freedom of the press, poverty and inequality reduction, punish corruption, encourage trust and build social capital, promote values congruent with modern S&T and entrepreneurship

sector, "pull" measures for enterprises to draw on domestic sources of knowledge, and measures that encourage the flow of knowledge throughout the productive sector. These include *establishing technology parks and incubators* (associated with public research institutions, technical universities, private research centers); *providing technology extension services* (subsidized and free technical assistance programs for small and medium enterprises, specialized technical information centers, programs to improve productivity); *encouraging engineering design and consulting firms* (matching funds and preferential credit for firms to work with domestic engineers and consultants, support for professional associations and engineering events, preference for local consultants in public procurement); *identifying, selecting and upgrading traditional techniques* (inventories of indigenous techniques and products, research on traditional practices and production methods, technology blending programs); and *promoting technology diffusion between enterprises* (subcontracting and close relations with suppliers, fostering the creation of clusters of enterprises around a technological leader).

The science and technology policy component includes the *establishment of science and technology policy-making bodies* (national councils for science and technology, ministries of science and technology, coordinating commissions, advisory boards, office of the chief government scientist, parliamentary committees, technology assessment agencies); *coordination of national and sub-national policies* (joint boards, national-local advisory bodies, special joint funds and programs); *establishing research and teaching programs in science and technology policy* (technology foresight centers, policy research units, graduate programs, periodic conferences and events, funds for policy research); and *providing information services to policy makers* (policy briefs, evaluation units, national science and technology budgets, inventories of science and technology capabilities).

Creating linkages between knowledge, technology and production in developing countries and their global counterparts. This category of policy instruments has three components: establishing linkages between scientific research in the country and the international research community, securing access to the world sources of technology and establishing linkages between the domestic productive system and its global counterpart.

The component of the strategy that aims at linking the domestic and global scientific research communities includes *organizing and carrying out joint research projects* (twinning programs between universities, collaboration between research centers, networks of developing and developing country institutions); *ensuring access to international scientific and technological information* (subscriptions to scientific research data bases, agreements between libraries in developed and developing countries, exchange of publications); *remote access to research facilities and equipment* (time sharing agreements for using sophisticated laboratory equipment, on-line connections with data processing facilities, creating virtual research communities); *data gathering initiatives for the international research community* (mapping natural resource availability, biodiversity prospecting, monitoring climate change and natural disasters, harmonizing data gathering protocols); and *organizing exchanges of views between researchers* (visiting fellowships, regular international conferences and symposia, sabbatical programs).

The component of the strategy that focuses on securing access to the international sources of technology includes measures to *promote the importation of technology intensive goods and services* (purchase of high-technology products, monitoring of and linking with new technology developments, reverse engineering, contracts with foreign engineering and consulting firms); *technology licensing agreements* (monitoring and evaluating international licensing trends, providing technical assistance to firms negotiating technology agreements, adopt national legislation to encourage licensing); *organizing technology scanning and search services* (technology missions to foreign countries, technical assistance to help small and medium enterprise find technology sources, training programs for technology purchasers).

The component that deals with establishing linkages with the global production systems aims at improving the competitiveness of the developing country and its firms, and also sat seeking a more active participation in the world trade, finance and technology flows. It includes the *promotion of direct foreign investment* (information on investment opportunities, incentives to foreign investors); *promotion of trade in technology intensive goods* (removal of tariffs, tax rebates for the re-export of manufactured goods, credit lines and guarantees for technology imports and exports); *promoting the participation of domestic firms in global value chains* (identification of potential opportunities, technical and financial assistance for domestic firms, cluster policies and subcontracting, incentives to establish strategic alliances with foreign firms).

Establishing a favorable context for scientific research, technological development and innovation. This category includes four main groups of policy instruments: providing the physical infrastructure required for science, technology and innovation; creating institutional arrangements favorable to innovation; maintaining a stable economic framework that promotes investment and long-term thinking in science, technology and production; and evolving a cultural and social environment that encourages creativity, risk-taking, and innovative behavior.

The component dealing with the provision of physical infrastructure includes measures to *install telecommunication networks* (widespread access to low-cost fixed and mobile telephone services, reliable digital data transmission networks, massive access to the Internet, incentives for the acquisition of communication equipment and computers); *construct and maintain transport facilities* (highways and secondary roads, ports, airports, railroads); *ensure a reliable supply of energy* (electricity generation plants and transmission networks, steady supply of hydrocarbon fuels, renewable energy generation sources in remote areas); *provide access to clean water and sanitation* (water treatment plants, water distribution networks, regulations on the use of groundwater, water recycling facilities); *make available waste disposal facilities* (solid waste treatment plants, landfills, special facilities and regulations for toxic waste); and to *reduce air pollution* (measures to reduce the discharge of pollutants into the air, programs to reduce greenhouse gas emissions).

The component that refers to the institutional arrangements favorable to innovation includes the elimination of bureaucratic impediments that affect firms and other institutions (administrative simplification, single-window procedures to approve programs and plans, reducing administrative requirements for operation); ensuring transparency in central and local government operations (full disclosure of information, access to the budgets of public agencies, well-defined bidding procedures for public sector procurement); fair and effective regulatory agencies (autonomy of regulatory agencies, well defined regulation procedures, contracts for the provision of public services, special training programs for regulators); full prevalence of the rule of law (independence of the Judiciary, Congress and the Executive, stability of legal frameworks, well-functioning legal system); and democratic governance (fair and free elections, democratic habits of thought and practice, similar treatment for all economic agents and individuals, measures to build investor confidence).

The component that deals with establishing a stable economic policy framework that encourages long-term thinking and innovation includes appropriate macroeconomic policies (maintain price stability and low inflation rates, ensure currency convertibility and a stable exchange rate, keep adequate levels of foreign exchange reserves, Central Bank autonomy); financial and credit policies (well-functioning financial system, interest rates not too far from the international cost of money, fair collateral requirements for loans, expedient bankruptcy procedures); fiscal policies that encourage investment (tax incentives for reinvesting profits, tax credits for equipment upgrading, accelerated depreciation, tariff reductions for the import of technology-intensive machinery); openness to trade and investment (low tariffs, simple and stable rules for foreign investors, harmonization of developing country policies to avoid a "race to the bottom" when attracting foreign investment, regional agreements to establish free trade zones and common markets).

Finally, the component of a strategy for building endogenous science and technology capabilities that deal with *evolving a cultural and social environment that encourages creativity, risk taking, responsibility and innovation* includes a broad range of policies and policy interventions. These include general and scientific education (reform of primary and secondary education, priority for technical education, scientific literacy programs, distance and remedial education programs for workers, reorientation of the higher education system towards scientific and technical careers, programs to create an public informed about science and technology matters); fair and flexible labor policies (balancing labor mobility with protection of workers, technical training programs for workers in transition from one job to another, measures to encourage the mobility of highly qualified workers and technicians); environmental protection measures (resource and energy conservation policies, incentives to adopt environment friendly technologies, special funds and credit lines to support pollution abating initiatives); access to information and freedom of the press (provision of adequate information to citizens, promotion of probing and responsible behavior of the press, encourage tolerance and the free exchange of ideas); measures to reduce inequalities (access to basic social services, poverty reduction programs, employment generation initiatives, measures to ensure gender equity); exposing and punishing corruption (penalties for taking and giving bribes, banishment of corrupt firms from deals with public entities, barring corrupt politicians from taking part in elections, incentives for "whistle blowers" and others who denounce corrupt acts); and measures to encourage trust, build social capital and promote democratic values that are congruent with modern science and technology (educational campaigns, prizes for innovators, public recognition of contributions by citizens and organizations).

This broad repertoire of policies and policy instruments comprises a large number of possible direct and indirect government interventions to build endogenous science and technology capabilities. Not all of them are equally important to all developing countries, and the choice of interventions has to be adapted to their historical evolution, present situation and development strategy.

Policies and policy instruments have different information, organizational and administrative capacity requirements. Some of them work in clusters and reinforce each other while others work individually and may lead to inconsistencies and contradictions. There are interventions that aim at influencing the behavior of agents in the science, technology and innovation system in a general way, and others that focus on a specific aspect of their behavior. Some policy instruments have an immediate impact, while other take a longer time to filter through the administrative apparatus of the government and their influence is felt with considerable delay. However, policies and policy instruments are just of the many factors that influence the behavior of researchers, professionals, managers, entrepreneurs and government officials who are involved in the science, technology and innovation system. Their background, preferences and objectives, together with market structures, institutional incentives, technological trajectories, capabilities of firms, and the specific characteristics of the technology and of production activities, are among the many other factors that influence scientific, technological and innovative behavior. These are all rather independent of the purposeful interventions of government entities.

Therefore, the choice of policy and policy instruments is a complex task that has to keep in mind their appropriateness, impact, effectiveness, congruence and efficiency, as well as their flexibility and capacity to adapt to changing circumstances. The concept of "capacity building" acquires a different meaning in each of the three categories of developing countries identified by using the Science and Technology Capacity Index (section 4.2), and even within a particular category it will be necessary to tailor the strategies, policies and instruments to the conditions prevailing in a specific country.

The classification of developing countries into three categories using the Science and Technology Capacity Index (section 4.3) can be used to illustrate the relevance of the various policy instruments to countries with different levels of science and technology capabilities. Table 9 presents a list of policy instruments with observations about their relative importance to Type II, Type III and Type IV developing countries. The lower the level of science and technology capabilities, the greater the importance of policy instruments oriented towards

TABLE 9: **Policies and Policy Instruments by Categories of Developing Countries**
(illustrative relevance according to their S&T Capacity Index)

Policies	Policy instruments	TYPE II	TYPE III	TYPE IV
Building science, technology and innovation capacities in developing countries				
Supply side measures: Building S&T infrastructure	Institution building:	++	++	+++
	Financing of S&T activities	+++	++	++
	Human resources development:	++	+++	+++
	Defining S&T priorities and plans	+	+++	++
	Creating networks of S&T institutions	++	+++	++
Demand side measures: Promoting the application of knowledge	Strategic planning of production activities	++	+++	+
	Financing of innovation and the purchase of technology intensive good and services	+++	++	+
	Use of the purchasing power of the State	+	+++	++
	Fiscal measures to stimulate innovation at the firm level	+++	++	+
	Measures to promote the export of technology intensive goods and services	+++	++	+
Measures to strengthen the linkage between supply and demand of S&T knowledge	Policies to promote diffusion of technologies	++	+++	+++
	Cluster-related policies to link technology and production	+	+++	++
	Engineering design and consulting services	+++	++	+
	Norms, standards, and quality control	+++	+++	++
	Selective recovery upgrading of traditional technologies	+	++	+++
	S&T parks and technology incubators	+++	++	+
	Technology extension services	+	+++	++
Measures to strengthen the S&T policy making capacities	Creation of specialized agency in charge of science and technology	+++	++	+
	Coordination of local and regional initiatives to promote S&T	+++	++	+
	Promoting international agreements and cooperation	+++	+++	+++
	Establishing S&T forecasting centers	++	++	+
	Providing information to S&T policy and decision makers	++	++	+++
Creating Linkages between knowledge, technology and production in developing countries and their counterparts at the global level				
Linkages between the global and the domestic science systems	Joint research activities	++	+++	++
	Access to international S&T information	++	+++	++
	Remote access to research facilities and equipment	+	++	+
	Mapping natural resources, climate change, epidemics, disaster, biodiversity, etc.	+	++	++
Linkages with the external sources of technology	Purchasing of technology and technological services	+++	++	+
	Technical and engineering design assistance	+++	++	+
	International intellectual property agreements	+++	+++	++
	Technology scanning and search	+++	+++	++
Linkages with the global production system	Import and export of equipment, machinery and goods	++	+++	++
	Promotion of foreign direct investment	+++	+++	++
	Improving competitiveness and productivity	++	+++	+
Establishing a favorable context and institutional framework				
Providing physical infrastructure for S&T and innovation	Communication	+	++	+++
	Develop transport infrastructure	+	++	+++
	Reliable provision of energy	+	++	+++
	Provision of clean water, sanitation and waste disposal facilities	+	++	+++
Creating institutional arrangements favorable to innovation	Democratic governance	++	+++	++
	Legal framework	+++	++	+
	Competition policies	+++	++	+
	Reduce bureaucratic impediments	+++	+++	++
	Protect intellectual property rights	+++	++	++
Creating a conducive and stable economic policy framework	Stable macroeconomic environment	+++	+++	+++
	Financial and credit policies	++	+++	++
	Fiscal policies	+++	++	+
	Trade openness	+++	++	+
Evolving a cultural and social environment that encourages creativity, risk-taking, responsibility and innovation	Labor policies	+++	++	++
	General education	++	++	+++
	Environmental protection	+++	++	++
	Access to information	++	++	++
	Poverty reduction initiatives and reducing inequality	+	++	+++
	Insurance Freedom of initiative and encourage creativity	+++	+++	+++
	Measures to encourage trust and build social capital	++	++	+++

Notes: (+) Not relevant; (+ +) Moderately relevant; (+ + +) Highly relevant.

creating the basic institutional infrastructure for scientific research, technological development and innovation. Conversely, for the relatively more advanced developing countries, those policies that improve competitiveness and build linkages with global science, technology and innovation become more important.

5.5 A role for international cooperation

The international community plays a critical role in the creation of endogenous science and technology capabilities in developing countries. The preceding sections have indicated that it is not possible to develop domestic scientific research, technological development and innovation capacities in isolation, without continuous and intensive interactions with the world's science, technology and innovation systems.

However, not all types of external linkages contribute to the creation of an endogenous science and technology base, and some of them can undermine efforts to do so. For example, an active involvement with the international scientific community may lead developing country scientists to lose sight of the problems faced in their own regions, primarily because prestige and financial incentives are biased towards research on topics of interest to the developed countries, because the emigration of qualified scientists reduces the possibility of accumulating a critical mass of highly qualified personnel, and because the choice of research themes with little impact on development creates an "internal brain drain". Restrictions on the use of imported technologies imposed by their owners curtail options for productive firms and can also block interactions between those technologies and domestic scientific and technological research. Close relations between international and domestic enterprises can exclude or limit the participation of developing country engineering, consulting and technology services firms in the process of innovation.

These examples indicate that some types of external linkages keep domestic knowledge, technology and production apart from each other, and may hamper the creation of an endogenous science and technology base. Discoveries and knowledge generated in developing countries could be appropriated by developed country researchers and firms, and even find their way back to their place of origin as costly technology packages. Controversies regarding intellectual property rights and the patenting of indigenous medicinal plants by transnational pharmaceutical corporations suggest that this is not a farfetched idea.

Therefore, the task is to forge appropriate and mutually beneficial linkages between knowledge, technology and production in the developing countries and their counterparts at the global level. In addition to solidarity, respect and a positive disposition from members of the scientific and technological communities, this requires favorable attitude in the part of government authorities and private sector managers in developed countries. A broader conception of "enlightened self-interest", which incorporates support for the creation of endogenous science and technology capabilities, should inform foreign investment and development assistance programs.

However, in spite of the key role that the international community can play in the development of endogenous scientific and technological capabilities, public and private agencies in developed countries, as well as international institutions, have shown little interest in raising international cooperation in science and technology to a level commensurate with their importance in development. The exceptions are a few private foundations (Rockefeller, MacArthur, Packard, Ford, Carnegie Corporation, Wellcome Trust, Gates Foundation and, more recently, Moore and Lemelson) and special agencies, such as the Canadian International Development Research Centre (IDRC) and the Netherlands Development Research Assistance Council (RAWOO), which were created specifically for this purpose. A recent inventory of international science and technology cooperation programs[17] identified more than 250 initiatives under way in the early 2000s, but the vast majority of them are rather small and have very limited funds, or they have other purposes and science and technology play a minor role in their activities. They range over a wide variety of fields and regions, focus on different aspects of the process of building endogenous science and technology capabilities, and appear to operate without significant attempts to coordinate their initiatives.

In spite of the relatively limited magnitude and impact of international science and technology cooperation programs, many valuable lessons of experience can be drawn from the activities of private foundations and development assistance agencies (Box 4). These lessons suggest ways of designing new international cooperation programs, mechanisms and institutions that could measure up to the Sisyphean challenge of mobilizing knowledge and innovation to improve the human condition.

BOX 4: **International support for science and technology in developing countries: A summary of best practices**

A feasibility study for the establishment of a "European Science and Technology for Development" foundation has identified a list of best practices for foundations, development assistance agencies and international organizations to follow:

- Support for science and technology in developing countries requires *a clearly enunciated goal* with attendant thoughts on how to measure progress toward that goal. Most foundations and development agencies describe their focus in sweeping and vague terms such as 'to empower the citizens of the world', 'to eliminate global poverty, inequality and injustice, to promote public involvement in civic affairs', which make it impossible to measure either success or failure.
- Significant change is rarely easy or quick and *long-term commitment* is required. Institutions, cultural patterns, laws, and values al change slowly. The experience of the past thirty years demonstrates amply the very few programmes are successful if they do not have staying power. The most successful of the foundation programmes have taken decades to realise their potential.
- *Scale and critical mass* must be taken into account. Successful support programs have taken seriously the requirement to match resources with problems. Real progress on any significant issue requires large amounts of money; it is impossible to build or test any significant theory or to bring about major capabilities without a funding scale that relates to the problem.
- *Patience and tolerance of errors* are essential. Capacity building does not occur without mistakes and disappointments.. To be effective it is necessary to learn how embrace error. Foundations have a particular comparative advantage in this connection. Compared with governmental and intergovernmental organisations, the flexibility of foundations affords them a major advantage in capacity building.
- *Follow-through and systemic approaches* are required. Long-term support is one thing, but follow-through is quite another. A mayor lesson from previous experience has been that support for science without support to technology and innovation has limited significantly the benefits that have resulted. Foundations, bilateral agencies and international organizations can forever seed new programmes and then jump on to newer subjects. Seeding new programmes is indeed exciting, but unless someone is around to water the seedlings, weed them, harvest the grain, and bake the bread, seeding itself is useless.
- *Risk taking* is increasing among the newer and better foundations. Funders interested in supporting new approaches and ventures have identified a need for this sector to take greater risk in its work. This involves financing start-up ventures, new entrepreneurs and projects that take bold approaches to achieving social and environmental objectives.
- *Leadership development* is key, as good people are at the heart of most successful programs and projects. There is a growing trend for new funders recognise and finance outstanding talent.

Source: Extracted and adapted from Bezanson and Oldham (2000)

The limited impact of the large number of disperse and undersized international science and technology cooperation initiatives contrasts with the periodic calls made in a variety of regional and global forums, and particularly in the United Nations, to expand development assistance in this field. The first United Nations Conference on Science and Technology for the Benefit of the Less-developed Nations was held in Geneva in 1963, and its final declaration argued that science and technology provided short cuts to development and can help to reduce the gap between rich and poor countries. A leading participant in that event (Nobel Prize winner Lord P. M. S. Blackett), used the analogy of a "supermarket" of scientific and technological achievements generated by the developed nations, where

[17] See reference in note 2.

developing countries could easily find solutions "off the shelf". This analogy would be shown to be inappropriate in subsequent decades, among other reasons because intellectual property rights biased in favor of technology owners makes it costly and difficult to gain access to the "shelves" of the science and technology "supermarket".

The imbalances in science and technology capabilities between developed and developing countries were already visible at that time, and prompted calls to use the scientific and technological capacities of the former to address the problems of the latter. The 1970 "World Plan of Action on Science and Technology for Development," prepared by the United Nations Advisory Committee on Science and Technology (ACAST) created at the Geneva Conference, proposed that five percent of research and development expenditures in rich countries should be focused on the problems of poor nations. However, with the minor exception of a few fields such as medical research and health care, the mobilization of developed country scientists to focus on the problems of the developing world has not been very successful.

This proposal highlighted one of the key problems in international science and technology cooperation. Scientific research and technological development in the developed nations can be used to solve specific developing country problems in the short term, but this would not necessarily help to build domestic capabilities in the medium and long term. It is not possible to assume that the twin objectives of capacity building and problem solving can be achieved simultaneously and without conflict. There are urgent demands that require science and technology solutions, and which cannot wait for the relatively lengthy process of building domestic capabilities to satisfy those urgencies later —for example, developing vaccines to prevent malaria and other tropical diseases. Other situations require capacity building efforts first, so as to enable the local scientific and technological community to address problems in a continuous and sustainable manner —for example, developing low cost technologies to satisfy basic needs such as sanitation, housing, primary health care, nutrition and elementary education, all of which must be tailored to local conditions. Box 5 highlights some of the tensions and dilemmas in problem solving and capacity building.

A second United Nations Conference on Science and Technology for Development (UNCSTD) took place in 1979 in Vienna. The years since the 1963 event saw a change in the optimistic view that science and technology are a positive force for development, and

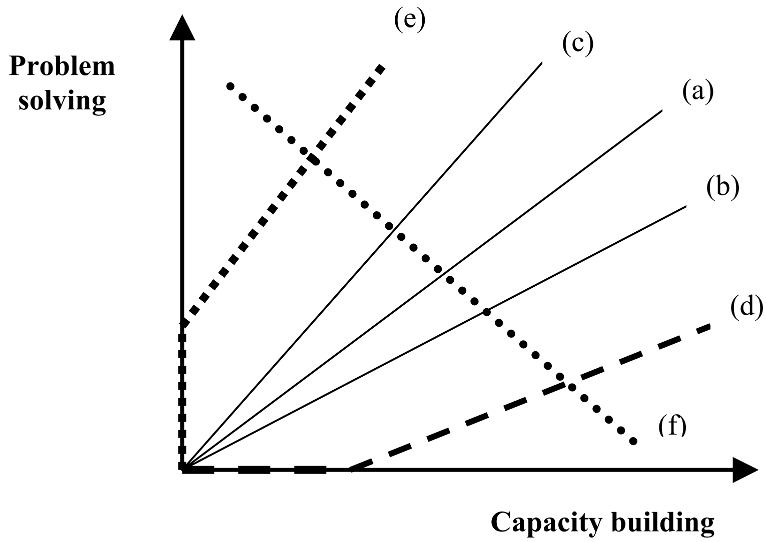
BOX 5: **Interactions between capacity building and problem solving in international science and technology cooperation programs.**

Motivations for international cooperation programs to focus on science and technology issues usually have two sets of objectives: (i) to solve a specific problem (develop vaccines, improve crop yields, provide educational materials); and (ii) to build capacity for developing countries to be able to solve problems on their own (create research institutions, provide fellowships, support local technology development efforts, give access to information). These two objectives are associated to different degrees in specific programs and interventions.

At one extreme, it is possible to use the scientific research and technology development capabilities of developed countries, for example in leading North American and European laboratories or universities, to generate knowledge, technologies and products that address the problem under consideration. This may take a relatively short time and have a higher probability of success than alternative approaches, but would not assist the developing country in building the capacity to address similar problems in the future. The effectiveness of this approach will depend on the problem area, the state of scientific and technological knowledge, and the familiarity of researchers in developed countries with the problem being addressed.

At the other extreme, it is possible to support the creation of domestic science, technology and innovation capabilities in a developing country, which may involve institutional support programs, long-term scientific and technical assistance, information sharing, and graduate fellowships to train science and technology researchers, as well as policy makers and technology managers. This approach takes a relatively long time and has lower probability of success in addressing specific immediate problems than the alternative, but would put in place the capabilities for developing countries to confront their own problems in the future. The effectiveness of this approach will depend on the commitment of the political leaders, on the existence of a supporting policy environment, and on the availability of resources to support science, technology and innovation initiatives.

Between these two extremes there is a range of intermediate approaches that involve, to varying degrees, combinations of problem solving and capacity building programs. The interactions between the two objectives and the programs that support them are rather complex and can be depicted in the following graph. Lines (a), (b) and (c) depict programs that build capacity as they solve problems, although to different degrees. Line (d) suggests that it is necessary to have a minimum level of local capacity before problem solving can be attempted, while line (e) suggests that it is necessary first to solve the problem before capacity can be built. These are cases of positive association between problem solving and capacity building, and a whole set of curves could be drawn to indicate, for example, diminishing marginal returns to capacity building in relation to problem solving, or the opposite. There may be cases in which these two objectives involve tradeoffs and choices must be made between capacity building and problem solving. Line (f) depicts such an unfortunate situation.



Source: prepared by the author.

rather than focusing primarily on using "off the shelf" technologies from developed countries the Vienna Program of Action emphasized the importance of building endogenous science and technology capabilities. This program of action created a United Nations Financing System for Science and Technology for Development (UNFSSTD) made up of voluntary contributions, which was supposed and reach an annual level of US $250 million. The financing system did not materialize in the confrontational international climate of the early 1980s, and was replaced by an Interim Fund for Science and Technology for Development within the United Nations Development Programme. This Interim Fund never succeeded in generating more than a fraction of the resources envisioned in Vienna and languished for a long time before being dismantled in the early 1990s.

Another appeal to revitalize international cooperation in science and technology for development was made in the late 1980s, on the occasion of the tenth anniversary of the Vienna Conference. The members of the United Nations Advisory Committee on Science and Technology for Development issued a declaration pointing out that humanity approached the new century and new millennium confronting a fundamental paradox: "we have never had so much power to influence the course of civilization, to shape the way our species will evolve, and to create an ever-expanding range of opportunities for human betterment —but we remain unwilling or unable to use this new-found power to achieve our full potential as human beings" (see annex C). The declaration ended with a call to develop during the 1990s "a multiplicity of innovative approaches to bilateral, regional and global cooperation in science and technology for development", which went unheeded.

The beginning of the 21st century appears to be an appropriate time for another attempt at launching a major international effort to mobilize science and technology for development. This is partly because of the growing awareness of the emergence of the knowledge society, and because imbalances in science and technology capabilities have reached alarming levels —and still keep on growing. A three-pronged effort will be required to achieve this.

First, it will be necessary to launch a major global communications and information campaign to highlight the importance of science and technology for development. The aim should be to persuade political, business and civil society leaders, as well as citizens in general, that building endogenous science and technology capabilities in developing countries is a high priority task for the international community. Without broad citizen support and pressure from a variety of stakeholders interested in mobilizing knowledge for development, it will be most difficult for leaders to take major initiatives in this field. The success of the environmental movement during the last three decades provides an illustration of what could and should be done with science and technology.

Second, considering the large number and dispersion of current international science and technology cooperation programs, better coordination and the harmonization of practices have become an imperative. The more than 250 programs identified in the inventory prepared by the Center for Global Studies at the University of Victoria suggest there is ample scope for improving the effectiveness of cooperation initiatives in this field, and possibly for the consolidation of several of these programs.

Third, there is ample scope for promoting joint efforts between developing countries that often face the same problems, have similar resource endowments, experience comparable resource limitations and find it very difficult to acquire, on their own, the critical mass of capabilities needed to mobilize knowledge and innovation for improving living standards. In spite of the potential benefits of what is usually referred as "Technical Cooperation between Developing Countries" (TCDC), there have been only sporadic initiatives to establish and sustain such programs. This largely because of the lack of interest of public sector policy makers, of the preference for researchers to work with their counterparts in developed nations, of the bias of the engineering community towards state of the art technologies, and of the predilection of productive sector managers to establish ties with firms from developed countries. Direct foreign investment, technical assistance programs and collaborative research projects that originate in countries with an endogenous science and technology base reinforce these North-South ties, to the expense of collaboration between developing countries. Yet there have been some efforts to organize "triangular cooperation" arrangements, in which developed countries support relatively more advanced developing countries (Type II or III according to the scheme of section 4.2), assist other developing countries with lower science and technology capabilities (those in Type III and IV).

Fourth, there is an urgent need to expand the level of resources allocated to help developing countries to build endogenous science and technology capabilities and to solve their specific problems. The magnitude of the knowledge divide (Table 4) indicates that this is an urgent task, and that the initiatives launched during the last three decades fall woefully short of meeting the Sisyphus challenge. This will require innovative financial mechanisms and new institutional structures to raise, administer and channel a significant amount of resources.

The characteristics of such arrangements can be exemplified through a proposal for the creation of a metaphoric “Global Knowledge and Development Facility”, which could become the first of a new generation of international financial institutions to promote international cooperation and development. The previous generation of such institutions — comprising the United Nations and its agencies, the multilateral development banks, the International Monetary Fund and the European Community, among others— emerged in the years following World War II. They should now be complemented by institutions attuned to the demands of the 21st century, and particularly with the need to bridge the knowledge divide between rich and poor nations. Based on what we have learned about financing international science and technology cooperation initiatives, Box 6 suggests some criteria for designing such a Global Knowledge and Development Facility.

The financial aspects of the facility should take into consideration that there is a new landscape for international development financing. Government sources of development assistance have stagnated during the last decade and have began to edge up only in 2002-2003 for some countries such as the United Kingdom, France and, to a much lesser extent, the United States. It is unlikely that official sources will play anytime soon the leading role in transfers to developing countries, as they did in the mid-1980s, except for the least developed countries. Moreover, the growing list of demands for official development assistance —humanitarian relief, debt reduction, support of economies in transition, halving world poverty by 2015— may make it a rather uphill task to persuade bilateral agencies to support something like the metaphorical Global Knowledge and Development Facility outlined here.

The highly successful 50 year-old model of the multilateral development banks, which have mobilized a large amount of resources from private capital markets for development purposes, provides an indication of what could be done to establish new financial mechanisms to support science and technology in developing countries. The broad range of highly sophisticated financial instruments now available to individual and

BOX 6: **Design Criteria for a Global Knowledge and Development Facility**

The creation of a Global Knowledge and Development Facility, which should be viewed as a set of interrelated financial and institutional mechanisms, should be guided by several design criteria that would ensure its relevance and impact. Among these criteria it is possible to identify:

Quantitative increase. The proposed facility should lead to a major increase in the amount of resources allocated to bridge the knowledge divide and to create endogenous science and technology capabilities in developing countries.

Diversity and differentiation. The proposed facility should be able to tailor its interventions to the characteristics of the developing countries, the economic and social sectors, and the type of science and technology activities involved.

Coordination and spread of best practice. The proposed facility should coordinate the large number of disperse initiatives currently under way. This implies promoting exchanges of views and experiences, organizing networks of researchers and practitioners, and disseminating best practices regarding science, technology and innovation policies, policy instruments, programs and organizations. To this end, the facility should sponsor regular seminars and training courses, briefings for policy makers, and publications in printed and electronic media.

Flexibility and continuity. The proposed facility should balance the need for continuous evaluation and renewal on the one hand, with the need to maintain support for long periods on the other. One option is to organize the facility's activities on the basis of temporary programs of variable duration, subject to sunset clauses. The idea is to avoid the pitfall of creating permanent organizations that eventually outlive their usefulness, and that as time passed they begin answer to the concerns of their staff rather than those of its clients.

Effective governance. The multiplicity of stakeholders involved in mobilizing knowledge for development requires innovative approaches to governance in the proposed facility. Procedures to ensure, transparency, accountability, participation and representation need to be carefully examined, so as to ensure the legitimacy of the facility and to ensure the necessary level of support from all stakeholders.

Existing and new elements. There are many initiatives under way which could eventually become closely associated with the proposed facility. It is important to allow room for accommodating the specific features of current initiatives, so as to incorporate them to the proposed facility. The facility should also specify clearly the characteristics of the new programs to be launched under its auspices.

Learning from similar initiatives. There are some precedents that provide useful points of reference for the proposed facility. he Global Environment Facility, launched by the World Bank, the United Nations Development Program and the United Nations Environment program more than a decade ago; and the Global Alliance for Vaccines and Immunization, which puts together private foundations, government agencies and international institutions, offer valuable lessons for the design of the proposed facility.

Source: elaborated by the author

institutional investors —swaps, guarantees, derivatives, mutual finds, synthetic indexes, among many others—, suggests that it should be possible to devise a set of instruments with the appropriate levels of risk and return for the proposed facility to tap into the vast amounts of private capital searching for investment opportunities. The idea would be to leverage grants from bilateral assistance agencies, foundations, developing country governments, private corporations, wealthy individuals and international institutions by using a portion of these resources to provide an appropriate and attractive level of comfort to private investors. This would allow a relatively modest initial amount of resources to increase significantly by accessing international capital markets.

The proposed facility should be able to take in contributions from different types of partners, some of which are likely to be in kind rather than in cash. Contributions should also be commensurate with the relative financial strengths of the partners. In addition, those responsible for the management of the proposed facility should be free from interference by political or commercial interests and be given autonomy to operate without excessive and cumbersome controls, but with clearly defined lines of accountability to all stakeholder participating in the scheme.

Moreover, there is also the possibility to link the proposed Global Knowledge and Development Facility to the growing international interest in the provision of global public goods. Knowledge is clearly a public good, at least in principle. As pointed out in section 5.3, it is non-rivalrous (the use by one person or firm does not diminish the amount available to another) and it is also non-excludable (once it has been generated it is available to all). Yet the institutional arrangements associated with intellectual property rights have been designed specifically to allow the private appropriation of knowledge, an intrinsically a public good, and to create artificial scarcities of knowledge that generate temporary monopoly rents for its owners. The reasonable argument is that without such incentives private agents would not engage in the production of knowledge, which would then be undersupplied. This has been the main justification for establishing the international system of intellectual property rights and patents that has evolved over centuries, but which now requires urgent revision. [18]

[18] The Commission on Intellectual Property Rights (IPRs), established by the United Kingdom Department for International Development, has stressed the importance of redesigning IPRs to benefit developing countries. Its report states clearly the positive and negative aspects of IPRs from a development perspective:

> "Some argue strongly that Intellectual Property Rights (IPRs) are necessary to stimulate economic growth which, in turn, contributes to poverty reduction. By stimulating invention and new technologies, they will increase agricultural or industrial production, promote domestic and foreign investment, facilitate technology transfer and improve the availability of medicines necessary to combat disease....
>
> Others argue equally vehemently the opposite. Intellectual Property rights do little to stimulate invention in developing countries, because the necessary human and technical capacity may be absent. They are ineffective at stimulating research to benefit poor people because they will not be able to afford the products, even if developed. They limit the option of technological learning through imitation. They allow foreign firms to drive out domestic competition by obtaining patent protection and to service the market through imports, rather than domestic manufacture. Moreover, they increase the costs of essential medicines and agricultural inputs, affecting poor people and farmers particularly badly.
>
> [However] it is essential to consider the diversity of developing countries in respect of their social and economic circumstances and technological capabilities....

Financial arrangements for the provision of global public goods encompass a variety of mechanisms, which range from the creation of markets to direct government financing (Figure 8). Intellectual property rights create markets in which the users of knowledge pay its owners for licenses, patents and technical assistance. When markets are difficult to create, there are other mechanisms to finance the production of scientific and technological knowledge for development purposes (government budgets, grants from bilateral assistance agencies and private foundations, donations from individuals and private corporations, and loans from multilateral development banks, among others).

There is also a need for adopting new approaches to the identification, design and management of initiatives to support the mobilization of knowledge and innovation to improve the human condition. There should be an emphasis on problem oriented programs that involve many scientific disciplines and engineering fields; each program should be backed up by a coalition of relevant and concerned stakeholders, who should contribute according to their abilities and resources; programs should be temporary in nature, with specific organizational arrangements and sunset clauses; programs should be monitored and evaluated by independent external bodies; and there should be a small central unit in charge of identifying, designing and launching the programs, several of which would run simultaneously, but which would not be involved in their management.

During the last decade there has been a proliferation of partnership arrangements between bilateral agencies, foundations, international institutions, private corporations, civil society organizations and academic centers to address specific development issues, such as the production of HIV/AIDS vaccines, biodiversity conservation and the elimination of some endemic tropical diseases, among many others. In addition, there have been some initiatives to change the way in which bilateral development assistance is provided to developing countries (sector programs, block grants, direct budget support, rewards for past performance). This suggests there may be a willingness to explore new arrangements to assist developing countries.

The determinants of poverty, and therefore the appropriate policies to address it, will vary accordingly between countries. The same applies to policies on IPRs. Policies required in countries with a relatively advanced technological capability where most poor people happen to live, for instance India or China, may well differ from those in other countries with a weak capability, such as many countries in sub-Saharan

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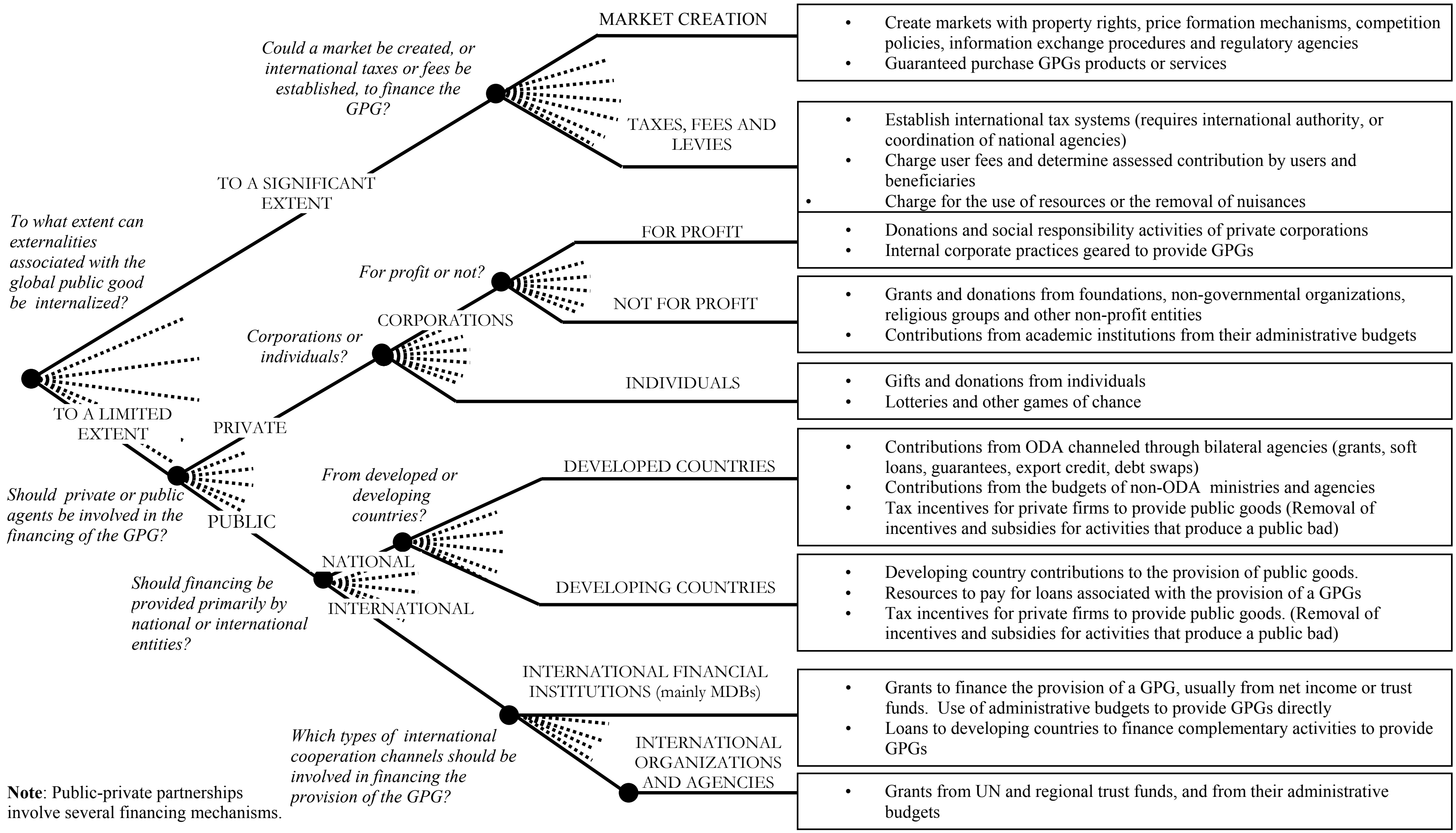
FIGURE 8: **A framework for exploring financing options for the provision of global public goods (GPGs)**



Note: Public-private partnerships involve several financing mechanisms.

Source: Sagasti and Bezanson (2001)

International cooperation can become a powerful force for the creation of endogenous science and technology capabilities in developing countries. Yet, it is still far from fulfilling its potential. New and bold initiatives are required to avoid the knowledge divide becoming an impassable abyss. A design along the lines of the metaphorical Global Knowledge and Development Facility outlined here could help to that potential into an effective force for development, and in particular for supporting the Sisyphean challenge of creating endogenous science and technology capabilities in developing countries.

Concluding remarks

The conceptual framework advanced in the first section of this essay, the historical overview and the characterization of the "triple crisis" of the second section, the examination of knowledge explosion and its manifestations in the third section, the characterization of the knowledge divide and its meaning for developing countries in section four, and the overview of the international context, the experience with science and technology policies, together with the overview of strategies, policy instruments and international cooperation in science and technology in section five, all point out to the critical role that endogenous science and technology capabilities play in the process of development, whatever meaning may be given to this word at the beginning of the 21st century.

Sir Francis Bacon's 1597 dictum "Nam et ipsa scientia potestas est" —knowledge itself is power— has become ever more accurate during the last few decades with the emergence of the knowledge society. It has also acquired ominous overtones as the huge disparities in science and technology capacities between rich and poor nations continue to deepen. Yet, determined action, backed by well-designed strategies, policies and international cooperation, can overcome this situation and make scientific and technological knowledge work for development.

Attempts to build endogenous science and technology capabilities at the beginning of the 21st century will take place in the context of a fractured global order. This is a turbulent and uncertain order in which a variety of contradictory processes open up a wide range of opportunities and threats that defy established habits of thought. Among the fractures of this paradoxical world order, the knowledge divide is clearly the most important because of its pervasive and long-term consequences.

The key challenge faced by the international community is to prevent the multiplicity of fractures of the emerging global order from creating self-contained and partially isolated pockets of mutually distrustful peoples, ignorant and suspicious of the viewpoints, aspirations, potentials and capabilities of each other. It is essential to prevent these fractures from creating inward looking societies —a few of them with an endogenous science and technology base and most with extremely limited and disarticulated science, technology and innovation capabilities— that relate to one another only through tenuous symbolic links forged by mass media, or through narrowly circumscribed economic transactions.

The progressive establishment of an endogenous scientific and technological base in the developing countries need not follow necessarily the same path as that of the developed countries of today. In particular, there is a need to avoid the almost complete subordination of creativity and of knowledge generation to the logic of capital accumulation, which is primarily geared to and driven by the expansion of the production system and the search for profits. There must be room left for exploring alternative forces to drive the process of knowledge generation, and for integrating the achievements of modern science and technology with the cultural and knowledge heritage of non-Western societies.

These observations and the discussions in the preceding sections of this essay suggest four areas for additional research and study. These would shed light into the options available for developing countries to create endogenous science and technology capabilities, for bridging the knowledge divide, and for exploring alternative avenues and meanings for the process of development. These four areas can be briefly summarized as follows:

- First, a broad and long-term program of comparative research and studies to explore the roles of knowledge and of values in different cultural settings, and at how to evolve widely shared reinterpretations of the concepts of progress and development. The program should foster the exchange of views between civilizations and cultures, and include both developed and developing countries with different levels of science and technology capabilities.
- Second, a thorough examination of the evolution of the Baconian program, the reasons for its success and maturation, and of the challenges that it is facing in the early 21st century. This study should explore the outlines of possible alternative programs as humanity enters into the post-Baconian age, taking into consideration the potential contributions of non-Western cultures.
- Third, a comparative review and evaluation of strategies, policies and policy instruments to develop science, technology and innovation capabilities in

different types of developing countries. The idea is to identify best practices and to gather information to assist policy and decision makers in the design of effective interventions to create an endogenous science and technology base.

- Fourth, the establishment of a task force to design the proposed Global Knowledge and Development Facility. This task force should involve representatives from governments, international institutions, private corporations, universities and research centers, scientific and professional societies and civil society organizations. In addition to designing the facility, this task force should conduct initial consultations with policy and decision makers to assess the feasibility of the proposals.

Private foundations and independent development cooperation agencies could play an especially important role in supporting these four areas of further study and research. In contrast with international financial institutions, which must be rather conservative to preserve their financial standing, and with bilateral cooperation agencies, which are instruments of foreign policy, private foundations and independent development cooperation agencies can take greater risks, choose more freely their areas of interest, engage more readily in joint programs, support initiatives for relatively long periods without having to show immediate results, and operate in a flexible way without excessive administrative or political constraints. They are uniquely place to undertake initiatives to face the Sisyphus challenge of building science and technology capabilities in developing countries, and to mobilize knowledge and innovation to improve the human condition.

ANNEX A:

Source Material for the Essay

The bibliography that follows contains a selection of about 50 of the books and papers prepared by the author, which provide the basis for this essay.

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ANNEX B:

Comparison between the Science and Technology Capacity Index, the Technological Achievement Index of the Human Development Report, the RAND Index and the UNESCO Classification

TABLE B-1
Comparison between the categories of countries defined in the S&T Capacity Index and other indexes

Science and Technology Index	Technological Achievement Index	RAND Index	UNESCO
Type I	**Leaders**	**Scientifically Advanced Countries**	**Industrialized countries with effective S&T bases**
These countries have well developed endogenous scientific and technological capacities and consolidated national system of innovation. Government policies encourage innovation and support the generation, acquisition and effective utilization of knowledge.	This group is at the cutting edge of technological innovation. Technological innovation is self-sustaining, and these countries have high achievements in technology creation, diffusion and skills.	These countries have greater S&T capacity than the international mean and higher capacity in all major areas of S&T. For example, they are responsible for 86% of all scientific articles published, and they fund between almost 90% of all the world's R&D.	These countries have greater S&T capacity than the international mean and higher capacity in all major areas of S&T. These countries are considered as industrialized countries with effective S&T bases.
Type II	**Potential leaders**	**Scientifically Proficient Countries**	**Countries with diversified S&T bases**
These countries have relatively modest levels of endogenous scientific and technological capacities, usually focused on a few dynamic sectors of their economies. Even most of them have well developed human resources, they have not been able to create a broad base of scientific research and technological innovation activities that are linked to their production and service systems. Government policies are mostly focused on the creation of science and technology capacities, but not necessarily geared to promote their integration with the productive system.	Most of these countries have invested in high levels of human skills and have diffused old technologies widely but innovate little. Each tends to rank low in one or two dimensions, such as diffusion of recent innovations or of old inventions. Most countries in this group have skill levels comparable to those in the top group.	They possess an overall S&T capacity index value at or over the international average, but they are not as uniformly capable as the advanced nations. Values for some capacity components may exceed the international average while others may fall below the mean. Some of these countries display world-class strength in particular areas or subfields of science. These countries have made investments in the infrastructure and R&D required to build a science base, and these investments are showing results.	The countries and regions in this group have established an industrial basis, with a higher percentage of potential S&T manpower, and relatively high GDP per capita.

Type III	Dynamic adopters	Scientifically Developing Countries	Countries with growing S&T bases
These countries are still in the early stages of establishing modern productive systems and have very limited human resources, research and innovation capacities. Many have a few enclaves of modern production activities (often associated with foreign investment) coexisting with large areas of outmoded and obsolete productive sectors. They face serious information, institutional and financial problems and government policies are not focused on the creation of capacities to generate, adapt, absorb and utilize knowledge.	These countries are dynamic in the use of new technology. Most are developing countries with significantly higher human skills than the fourth group. Many of these countries have important high-technology industries and technology hubs, but the diffusion of old inventions is slow and incomplete.	Although these nations have made some positive investments, their overall scientific capacity is below the world average. The investments that have been made, however, do allow these countries to participate in international S&T. These countries are seeking to invest further in science and, in some cases, they have good capabilities which attract international partners. Several factors such as overall GNP or other infrastructural factors are keeping these countries from being considered among the above category.	These countries and regions are sill in the process of industrialization. They have established a certain industrial basis, with moderate GDP per capita (upper - middle income and lower - middle income countries). Some have a relatively high percentage of potential S&T manpower, but the potential is low in absolute terms.
Type IV	**Marginalized**	**SLC-Scientifically Lagging Countries**	**Countries lacking an S&T base**
These countries have practically no significant scientific research, technological development or innovation capacities, and also have a very limited S&T manpower base. Apart from the extraction of natural resources or the provision of some services (for example, offshore banking), which takes place in isolated enclaves, they generally use traditional technologies and some obsolete modern technologies, which operate at low levels of productivity and efficiency. Government policies pay little attention to science, technology and innovation issues.	Technology diffusion and skill building have a long way to go in these countries. Large parts of the population have not benefited from the diffusion of old technology.	These countries fall below the international mean for all the components of the S&T capacity index. In many cases, these countries have little or no capacity to conduct international level science. In other cases, scientific capacity that does exist has resulted from a natural or geographical resource located in these countries. In other cases, problems with infectious disease, natural disasters, or pollution, mean that international partners are interested in helping these countries, but they often find little indigenous capacity to tap for collaborative projects.	These countries and regions are still in the initial of development with low GDP per capita, low S&T manpower, but the potential and low percentage share of industrial and manufacturing sectors in production.

TABLE B-2: **S&T Capacity Index vs. Technological Achievement Index**

		Technological Achievement Index (TAI)			
		Leaders	**Potential leaders**	**Dynamic adopters**	**Marginalized**
Science and Technology Capacity Index	**Type I**	• Korea, Rep. Kingdom	• Italy		
	Type II	• New Zealand		• Brazil • Thailand	
	Type III		• Bulgaria • Costa Rica		• Pakistan
	Type IV			• Ecuador • Syrian Arab Republic	
Countries not considered by the STI			• Cyprus	• Algeria • Bolivia • Dominican Republic • El Salvador • Honduras • Paraguay • Sri Lanka • Trinidad and Tobago • Uruguay • Zimbabwe	• Ghana • Kenya • Mozambique • Nepal • Nicaragua • Senegal • Sudan • Tanzania.

TABLE B-3: **S&T Capacity Index vs. RAND Index**

		RAND			
		Scientifically advanced countries	**Scientifically proficient countries**	**Scientifically developing countries**	**Scientifically lagging countries**
S&T	**Type I**	• Israel Kingdom	• Singapore		
	Type II	• Russian Federation	Republic Republic	• Hong Kong, China • Mexico • Argentina • Chile	• Malaysia
	Type III		• Bulgaria • Lithuania		• Jamaica • Peru • Costa Rica • Nigeria • Panama • Tunisia • Vietnam • Bangladesh
	Type IV			• Benin • Mauritius	Republic Republic African Rep.

	RAND			
	Scientifically advanced countries	**Scientifically proficient countries**	**Scientifically developing countries**	**Scientifically lagging countries**
Countries not considered by the STI		• Luxembourg	• Armenia • Bolivia • Kuwait • Macedonia • Urzbekistan	• Albania • Algeria • Angola • Botswana • Cambodia • Cameroon • Congo • Côte d'lvoire • Chad • Dominican Republic • El Salvador • Eritrea • Ethiopia • Gabon • Gambia • Ghana • Guinea • Haiti • Honduras • Iraq • Kenya • Korea. • Lao PDR • Lesotho • Malawi • Mali • Mauritania • Moroco • Mozanbique • Myanmar • Namibia • Nepal • Nicaragua • Nigeria • Oman • Paraguay • Saudi Arabia • Senegal • Sierra Leon • Sri Lanka • Sudan • Tajikistan • Tanzania • Togo • Trinidad and Tobago • Uganda • United Arab Emirates • Uruguay • Yemen • Zambia • Zimbabwe

TABLE B-4: **S&T Capacity Index vs. UNESCO Index**

		UNESCO			
		Industrialized countries with effective S&T bases	**Countries with diversified S&T bases**	**Countries with growing S&T bases**	**Countries lacking an S&T base**
S&T	**Type I**	Switzerland Kingdom	• Korea, Rep. • Israel • Singapore		• South Africa
	Type II	• Spain • Hungary • Poland	China	• Malaysia • China	
	Type III	• Bulgaria • Yugoslavia	• Turkey • Philippines • Venezuela • Egypt • Pakistan • Colombia • Peru • Costa Rica • Jordan • Panama • Guatemala • Vietnam		• Bangladesh
	Type IV		• Libya • Ecuador • Mauritius • Congo	• Mongolia • Gabon • Rwanda	African Rep.

	UNESCO			
	Industrialized countries with effective S&T bases	**Countries with diversified S&T bases**	**Countries with growing S&T bases**	**Countries lacking an S&T base**
Countries not considered by the STI	• Czechoslovakia • Germany DDR • Germany FRG • USSR	• Congo • El Salvador • Guyana • Iceland • Kuwait • Lebanon • Nicaragua • Qatar • Samoa • Seychelles • Sudan • Trinidad and Tobago • Uruguay	• Afghanistan • Algeria • Bahrain • Barbados • Bolivia • Brunei-Darussalam • Cambodia • Cyprus • Dominican Rep. • Fiji • Gabon • Ghana • Guinea • Iraq • Kenya • Korea (Dem.) • Luxembourg • Malawi • Malta • Paraguay • Saudi Arabia • Senegal • Sri Lanka • Togo • United Arab Emirates • Zambia	• Albania • Angola • Bahamas • Belize • Bhutan • Botswana • Burma • Cameroon • Capo Verde • Chad • Djibouti • Dominica • Equatorial Guinea • Ethiopia • Granada • Guyana • Haiti • Honduras • Ivory Coast • Lao • Lesotho • Liberia • Maldives • Mali • Mauritania • Morocco • Mozambique • Namibia • Nepal • Niger • Oman • Papua-New Guinea • Sierra Leon • Solomon Isl. • Somalia • Surinam • Swaziland • Taiwan • Timor • Uganda • Yemen • Zaire • Zimbabwe

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ANNEX C:

United Nations Advisory Committee on Science and Technology for Development

Science, Technology and Development: The Imperative of Social Innovation

(A declaration issued by the former chairmen and members of the Advisory Committee on Science and Technology for Development on the occasion of the tenth anniversary of the Vienna Programme of Action in October 1989)

1. Humanity approaches a new century confronting a fundamental paradox: we have never had so much power to influence the course of civilization, to shape the way our species will evolve, and to create an ever-expanding range of opportunities for human betterment —but we remain unwilling or unable to use this new-found power to achieve our full potential as human beings.

2. Throughout most of history, nations and societies have been compelled to behave as though same groups could only progress at the expense of others. Today, advances in science and technology have created new possibilities for all humanity to prosper, if we could but summon the collective will and wisdom to employ the new means available to us.

3. Science has been the most important factor in placing this unprecedented opportunity within our grasp. During the past four centuries, the systematic process of subjecting abstract conceptions and propositions about the world to the test of empirical observations —which is the hallmark of modern science–– has superseded other forms of knowledge generation. As a result, science-based technologies are steadily replacing or improving those that developed through trial and error. At the same time, our understanding of the potentials and limitations of modern science and its applications has increased considerably.

4. Paradoxically, progress in material well being for a growing fraction of the world's population coexists with stagnation and even deterioration in standards of living for the majority of poor people. Deprivation of food, health, education and gainful employment besets a sizeable part of humanity, giving rise to new stresses on the environment which, in turn, undermine the basis for future development. The clash between rising aspirations and the realities of omnipresent poverty, largely triggered by growing awareness of the life styles of the affluent, has become a source of social tension, intolerance and violence.

5. The now enormous potential for human advancement coexists with gross inequalities, possible ominous threats to the global commons (such as the greenhouse effect and stratospheric ozone depletion), and with the diversion of significant proportion of the world's highest intellectual talent to develop technologies so awesome as to threaten human survival. This paradox puts in sharp relief the critical problem of our age: our scientific knowledge and technological mastery have outstripped our collective capacity to manage advances in science

and technology so as to enhance the opportunities and reduce the threats they create. A bold and imaginative effort in social and institutional innovation at all levels —from local to international— is now essential for survival and progress.

6. The 1980s have been through many changes and surprises: the reversal of capital flows between North and South as a consequence as a consequence of the debt crisis, the information revolution and proliferation of personal computers, significant advances in biotechnology, the tragic emergence of AIDS pandemic, the explosive growth of megacities in the third world, and a major redistribution of economic world power, among many others. A new and as yet fluid world order has been in the making in the decade since the United Nations Conference on Science and Technology for Development was held at Vienna in 1979.

7. In this rapidly evolving global context, the 1990s may offer historic opportunities for broader international cooperation in science and technology. After four decades of antagonism and mistrust, the bipolar divisions of the world —East/West and North/South— are giving way to a pluralistic international environment. This creates a unique opportunity for more equitable and pragmatic distribution of the costs and benefits of scientific and technological progress, casting aside the ideological blinders that constrained the visions of statesmen for nearly half century. Our enormous and increasing stock of scientific knowledge and technological skills can become a key resource for easing international tensions.

8. We propose three guiding principles for a renewed mobilization of science and technology in the service of development. The international community of statesmen, scientist, policy makers, scholars, professionals, managers, workers and citizens —within which the United Nations system should play a leading role— must in our view:

(a) Evolve a broad new strategy to ensure equality of access for all people to modern scientific and technological knowledge essential to alleviating poverty, reducing population pressures, achieving minimum standards of health and nutrition, improving educational opportunities, and promoting economic growth. Without sacrificing the incentives for individual creativity and practical imagination, we must evolve a common view that scientific and technological progress should directly foster global equity, both within and between generations;

(b) Undertake a concerted effort to build the human and institutional capacities developing countries need to make independent decisions on the critical science and technology issues which will confront them. International cooperation will play a mayor role in this essential task, particularly because of the huge disparities in scientific and technological capabilities between the industrialized and the developing countries —disparities that dwarf other indicators of global inequality;

(c) Forge new international partnerships to achieve environmentally sustainable development. The times when humanity could act on the physical and biological environment with impunity --blindly trusting in the regenerative powers of ecosystems-- are forever gone. New approaches in which humanity and nature jointly enhance each other's capacities are imperative. This will demand a reevaluation of the many ways in which different cultures to the natural world, using science to build constructively on this diversity, rather than seeking to universalize some single over-arching view of the interactions between human activities and the environment.

9. We believe a successful collective search for social innovations during the last decade of the twentieth century will require a climate of openness and participation at all levels. Imposed solutions or visions –-however well conceived-– will lack authority in today's increasingly pluralistic political communities. Tolerance for cultural and religious diversity, respect for human rights, active encouragement of individual freedom and creativity, and sensitivity to the damaging effects of inequalities of knowledge and power are essential for linking science and technology to the preservation and advancement of humanity.

10. We reaffirm our belief in international cooperation as the most effective way to transcend the conditions which deny the power and benefits of science and technology to those most in need. International cooperation and assistance must evolve beyond charity, or narrowly conceived national interest, into expressions of collective responsibility for the well being of all the humanity in present and future generations.

11. We strongly encourage the international community to develop during the next decade a multiplicity of innovative approaches to bilateral, regional and global cooperation in science and technology for development. The United Nations should monitor these initiatives, fostering the exchange of experiences, and when this century comes to an end, 20 years after the 1979 Vienna Conference, should arrange an international gathering to evaluate progress and chart the course for science and technology for development in the new century.

Francisco Sagasti (Peru)
(1988-1989)

Essam El-din Galal (Egypt) Chairman Chairman
Chairman (1986-1987)

Umberto Colombo (Italy)
Chairman (1984-1985)

M. S. Swaminathan (India)
Chairman (1981-1983)

(The signature of other 45 Committee members follows)

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