THE KNOWLEDGE EXPLOSION AND THE KNOWLEDGE DIVIDE

INTRODUCTION

The present study attempts to provide a frame of reference to examine the prospects for the development of science and technology in developing countries during the first two decades of the 21st century.

This essay begins by presenting the main components of the conceptual framework and the outline of an explanatory scheme that would link the various components of the alternative model in an organic fashion. It then offers a brief historical perspective describing the evolution of speculative knowledge, the changes in technology base and the transformation of productive and service activities. The third part examines the emergence of the knowledge society in the second half of the 20th century, describing its main characteristics and implications, before turning to a simultaneous and paradoxical phenomenon: the knowledge divide. Several strategies and policies at the national and international level are proposed for bridging the knowledge divide. This is followed by an analysis of progress and development. The paper concludes by drawing out main directions for developing countries and implications in the post-Baconian age.

{Main lines of Argument}

KNOWLEDGE, TECHNOLOGY AND DEVELOPMENT: A CONCEPTUAL FRAMEWORK

In order to offer a different 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 way. For this purpose, it is possible to distinguish a set of components which, together with their interrelations and a directionality, conform an alternative conceptual framework for classifying knowledge.

The first component is the *evolution of speculative thought* which seeks to generate knowledge to understand natural and social phenomena, and to provide 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 (techniques) to confront the challenges posed by the physical and social environment, and also with the criteria to select among these responses. The third component is the *modification and expansion of productive 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 structured and linked to each other through a set of institutional arrangements, and are immersed within the broader social, cultural, and political context of human societies.

Even while it is necessary to reject the Western view as a unique frame of reference for comparing the achievements of different societies, it is impossible to deny that, considering its success in the material and intellectual schemes of human action and its diffusion at the planetary scale, the Western vision of "progress" (which took several centuries to conform) dominates the present world and has become an implicit standard.

For this reason, and in order to rescue the universal in all its diversity from the dominance of Western concepts and things, it is necessary to examine and understand the impact that the West has had on the rest of the world. This requires a study of the evolution of the knowledge generation process, of the transformation of the technological base, and of the expansion at the world level of the productive system that characterized Europe and North America. However, in this study it is necessary to be en garde in order to avoid adopting an implicit Europocentric perspective.

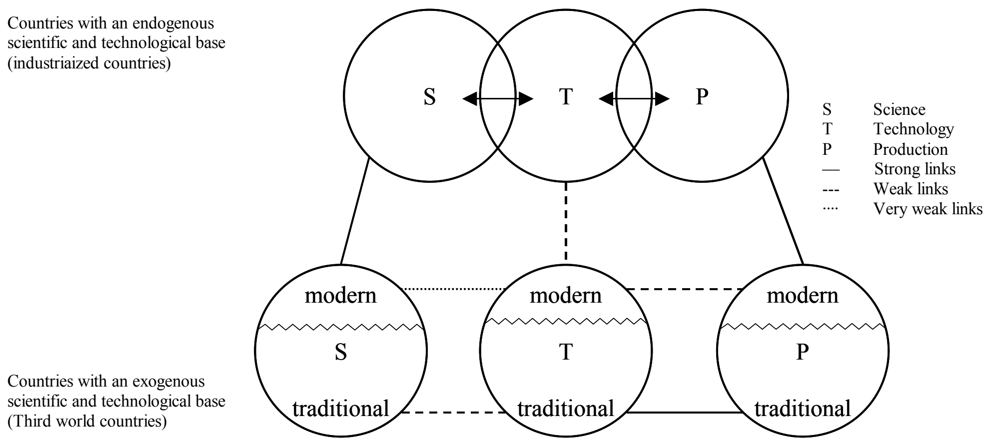
The development of the different civilizations and societies in the last few centuries should be seen as a complex whole, whose components are in continuous action and transformation, and in which a perspective ─the Western one─ came to influence all others but, at the same time, these other cultures preserved their individuality, affected Western culture, 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 Western civilization, implicit in the metaphor of different cultures as tributary rivers that converge on the sea of Western culture, must be rejected.

When discarding the perspective of Western civilization as the frame of reference to appreciate the march of other cultures, there still remains the problem of posing a directionality for the process of social evolution, that would act as a backdrop for any comparison. For this purpose, it appears adequate to accept Wertheim's arguments for whom "the general tendency of human evolution ... consists in a growing emancipation from the forces of nature", which is accompanied by "the emancipation from the domination of privileged individuals or groups". Emancipation, considered man's capacity to forge his own destiny and to realize fully his own potential, can be considered an end in itself, and the process of development as a gradual advancement towards this end.

In order to activate a process of development, which would approach emancipation progressively, it is necessary to consider that modern science has demonstrated to be the most efficient method to generate knowledge for understanding the phenomena that surround man and, as Bronowsky said paraphrasing Bacon, to dominate not through force but rather through understanding. Moreover, the technologies that emerge through the systematic reflection (logos) about the repertoire of responses and practices that are available to act upon the physical and social world (*techne*), gives an enormous power of manipulation to confront the challenges posed by the environment. Finally, productive and service activities associated to modern technology have acquired a huge potential to satisfy human needs. In this way, for a particular social group, and for those individuals that conform it, it is impossible to conceive an advance towards emancipation without a minimum level of autonomous capabilities to generate or adapt scientific knowledge, for transforming it into technology, and for incorporating these technologies linked to scientific discoveries into productive and service activities. This capacity has been called an endogenous scientific and technological base, and to count with it becomes an indispensable requisite for the process of development.

Hence, it is possible to distinguish between two types of countries: those where the evolution of scientific activities led directly to, or was clearly linked with advances in production techniques; and those in which the knowledge-generating activities was not related in any significant way to productive activities. We shall refer to the first as countries with an endogenous scientific and technological base, and to the second as countries with an exogenous scientific and technology base. This division corresponds to that established between industrialized and developing countries respectively (see Figure 1).

FIGURE 1
Relations between science, technology and production in industrialized and Third World countries



Source: Francisco Sagasti, *Towards endogenous science and technology for another development*, Development dialogue 1979:1, pp. 13.

Therefore, 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 productive and service activities); the social, cultural, and political context and the institutional arrangements in which these three currents unfold; the interactions among these three currents, between them and their context, and between these currents and their counterparts in other societies; a global directionality for the evolution of these currents, contexts and interactions (the concepts of emancipation and development); and an instrumental condition (to count with an endogenous scientific and technological base).

The unfolding and deployment of these components and the concrete forms they assume over time characterize the historical development of each society, and also condition their future possibilities and options. An appreciation of the paths that have been covered in the past, conceptualized in terms of the proposed framework, would allow to explain the present situation of backwardness of developing countries and make it possible to design strategies for overcoming it. The following section summarized briefly the joint evolution of the processes associated with the generation of knowledge and the institutional arrangements that supports it, highlighting the way in which they have been closely intertwined. The main lesson derived from this historical overview is that, in order to take advantage of the extraordinary opportunities offered by the explosion of knowledge and information, countries need to devise their own ways of linking the development of their capacities to produce and acquire knowledge, with the creation and consolidation of the appropriate institutional arrangements to disseminate and utilize knowledge.

A BRIEF HISTORICAL PERSPECTIVE

The proposed conceptual framework allows the development of an explanatory scheme that can throw light on the nature and present manifestations of the phenomena of development and underdevelopment. It is necessary to begin by recognizing that in every society each of the three currents mentioned above, their contexts, and their interactions undergo a series of transformations in time. Nevertheless, considering a long historical period, the main transformation experienced by societies take place when there are major qualitative changes in the nature of speculative thought and in the process of knowledge generation. As a result of these changes the conceptions of man, about his relation to the physical world, will also evolve and expand progressively to encompass the technological base and the structure of productive activities. Awarding the character of *primus inter pares* to the changes in the nature of speculative thought implies giving cognitive activities the role of primary ordering element in the explanatory scheme.

The challenge of the West

The evolution of the different societies can be examined in a relatively independent way until the period between the fifteenth and seventeenth centuries, in which the knowledge generation process underwent a radical transformation. Before this period, it is possible to analyse each society considered individual unit. Thus, it is possible to examine, within reasonable limits, the European, Andean, Maya, Aztec, Islamic, and Chinese civilizations employing the conceptual framework proposed here to follow the historical evolution of speculative thought and the generation of knowledge, of the technological base, and of productive and service activities, relating them to each other and to the wider social, cultural and political context.

However, the world suffered an irreversible transformation beginning with the scientific, bourgeois and industrial revolutions, which were accompanied by qualitative changes in the technological base and by the expansion of the productive capitalist system of Western Europe at the planetary level. After those events it is not possible to consider the evolution of societies in an independent way, and their study should take into account the challenges placed by the West to the non European societies, as well as the responses that the latter generate. The point of inflection can be identified with the transformation of speculative thought and with 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, through which it is possible to link systematically the abstractions and experiments about natural phenomena, to discover laws that rule the physical world, and to derive postulates, norms for action, and prescriptions that increase the control of man over nature, constitute an irreversible change in the evolution of humanity.

In parallel with these conceptual changes, there were changes in the technological base, but these transformations were slower and would only accelerate two centuries later, when the number of production techniques based on scientific discoveries increased significantly. Not withstanding their diffusion throughout all the regions of the world beginning in the sixteenth century, the transformations in the nature of productive and service activities were even slower, although their pace has accelerated during the last century and a half, as a consequence of their increasingly close relation with technologies based on scientific discoveries.

The evolution of speculative thought

Throughout history, magic, myths, religion and science have provided different ways of generating knowledge about the physical and social environments in which human societies evolve (Frazer, 1964; Malinowski, 1974). 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 priests acting as intermediaries between God 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 generating knowledge to uncover 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), 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 atomic theory that incorporated 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 (Bernal, 1971).

Abstract thinking also led to the development of symbolic logic, geometry and various branches of mathematics in ancient Greece, India, Islam and other civilizations. 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.

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 —if 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 16-17th 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 allow 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 Gutemberg'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 Copernicus' heliocentric ellipses superseding Ptolomeus' 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.

The emergence of the modern scientific method during the 16th and 17th centuries, which would culminate with what has been called "the Newtonian synthesis," allowed to systematically relate the creation and manipulation of abstract concepts and ideas on the one hand, with observable events and tangible phenomena in the biophysical world on the other.

The development of the scientific method —characterized by a set of procedures that linked the manipulation of abstract concepts and symbols to 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 growth of scientific research, generated the need to classify the rapidly growing amount of information and led to the first attempt of French Ecyclopedists.

The scientific method was firmly entrenched as the principal means of generating knowledge; advances in physics had left a prominent scientist wondering if there was anything else of fundamental nature to discover Darwinian evolutionary theory reigned in the biological sciences and would be enriched with Mendel's contributions on genetic factors in inheritance.

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 Einstein's reconceptualization of physical reality, space and time were no longer considered as an immutable, all-encompassing universal stage, independent of the forces and bodies that move on it. They were rather conceived as space-time, a four-dimensional construct which 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 postulated, but as a curvature of space-time caused by the presence of bodies and forces in it (Einstein, 1954; Hawking, 1993).

Quantum mechanics would modify conceptions of physical reality in a 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 is 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 (Heisenberg, 1958).

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 biological and medical sciences, which included procedures for blood transfusion, the discovery of novocain as a painkiller, and the discovery of antibiotics. Modern statistical methods were developed starting in the second decade of the 20th century to extract information from 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 researcher 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 of all types.

Examining briefly the evolution of speculative thought, it is clear that every culture presents its own form of generating and acquiring knowledge but, in general a transition can be observed from the contemplation and passive acceptance of nature towards a greater interaction between man and the phenomena that surround him. Whichever the scheme employed to explain this process --for example, Frazer's ideas on the transition from magic to religion and to science, or the alternative vies provided by Malinowski-- it is possible to perceive a progression towards the use of reason as the principal means to structure the human vision of the physical, social, intellectual, and even spiritual world.

In this way, the changes in speculative thought and in the way of generating knowledge in different societies present certain commonalities although there are great variations in approach, rate of advance, and emphasis (e.g. relative weight of abstract theories versus empirical aspects). This leads to a revaluation of the "traditional" ways of generating knowledge that should be seen from a wider perspective, and not simply in comparison with the rigid and Europocentric pattern of Western science.

Changes in the Technological Base

Throughout history each society has developed a distinctive set of responses to relate to its physical environment. Agricultural practices, irrigation schemes, animal husbandry, metal working, pottery, 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 subsequent 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 to conform 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 15-17th 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 associated with the modification and expansion of productive 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 of interaction, selection criteria— that provided guidance in the process of transforming potential into actual responses, thus guiding the evolution of technological knowledge.

Technological 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 diffuse rapidly throughout the world. The European discovery of new lands, peoples, plants, animals and products stimulated the search for and exchange of scientific and technological knowledge.

In the late 16th century, Francis Bacon argued that gunpowder, the compass and the printing press provided technological breakthroughs that changed the course of human history. Advances in military engineering, and in the construction of palaces, churches, irrigation and water supply systems (what would become civil engineering), spread rapidly as blueprints and designs 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 an ever growing number of persons. As the economic value of such advances in technical knowledge became evident, the first attempts at creating what are now know as "industrial property rights" emerged with the establishment of the patent systems and the first patent was awarded.

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, 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 human intellectual labour, were put forward by Pascal in 1642 and the first notions for the construction of a general purpose computing machine were advanced by Charles Babbage in 1832. 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 Leibniz and Newton would provide the mathematical tools for solving complex problems, such as computing the trajectories of moving bodies subject to acceleration, and 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 is underscored by the privileged position they were awarded by Jefferson and others at the time of the United States independence (Jefferson founded the US Patent Office).

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, 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 the shopfloor and chemical plant. Standardization and manufacturing with interchangeable components led to major increases in productivity, and industrial organization methods.

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 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 whole 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 (e.g. machine tools), agriculture (e.g harvesters and tractors), construction (e.g. bulldozers and concrete mixers), mining and oil (e.g. drilling bits and tools) and administrative tasks (e.g. 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 few decades airplanes would have a major impact on long-distance transport of mail, passengers and cargo, and would also transform the ways in which war was fought. 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 many productive and service activities in the industrialized nations and to replace the technical knowledge acquired through trial and error. Yet, in most parts of the world outside Europe and North America, traditional technologies would still provide for many decades the means to ensure the livelihood of most people in Asia, Africa, Latin America and the Middle East.

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The challenges posed by the physical environment to a society, and the forms of organization adopted to confront them, condition the demand for technical responses and the transformation of its technical into a technological base, a process that also requires the development of a certain level of knowledge generation capabilities. As Needham, Bernal and Alvarez indicate in their analysis of the technological achievements of non-Western cultures and societies, they acquired a set of technical and technological responses of their own, appropriate to their context, and processed by the social organization forms prevailing at the time. Therefore, now that the predominant forms of Western technological responses are being questioned, it becomes important to study the alternative configurations of the technological base in societies that have not been completely Westernized as yet.

Transformations in Productive and Service Activities

The modification and expansion of productive activities has as its principal motivation the satisfaction of the needs of the members of a social group. Over time, all societies 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 between societies —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.

The expansion and modification of productive 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 societies and civilizations until the expansion of European capitalism— include securing food stocks and reserves; constructing temples, palaces and defence 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, which were associated with Western capitalism, spread during the late Middle Ages and the Renaissance, and were consolidated during the expansion of the European empires. These included: opening commercial routes, discovering natural resources, increasing labour 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.

Productive and service activities grew through the 15-17th 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 productive activities— made it rather difficult to distinguish between them. Only 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 number of them were to be put in practice.

A variety of institutional arrangements, mostly related to 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 by hierarchical authorities, provided the institutional underpinnings for transactions in traditional economies (Polanyi, 1968).

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 productive and service activities. Property rights and contracts allowed economic agents to receive the benefits and pay the cost of their productive 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 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 market transactions that spanned long distances and required rather long times.

Productive 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 labour between economies in Europe and in other parts of the world.

Surpluses obtained from trade, agriculture and the colonies began to be channelled 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 need not maintain the full amount of deposits. 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. From these beginnings, a full range of financial institutions, primarily banks, 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. 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.

Productive 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 labour, 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 (Polanyi, 1957).

The swift expansion of European empires in Africa, Asia and Latin America made it impossible to consider in these parts of the world the evolution of knowledge production, acquisition, distribution and use, as well as the institutions associated with these activities, without reference to the West. 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), and would eventually lead to the emergence of "colonial science" in various parts of the non-Western world (Basalla, 1967; Vessuri, 1993).

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 have coexisted uneasily during centuries with their transplanted counterparts from the West. In contrast with colonial empires, 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 , signalled 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 productive 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 labour 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 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 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.

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These changes in the social organization of production, which are a consequence of the way the surplus is used and the direction of the accumulation process, interact mutually 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 surplus available constitutes a challenge to human inventiveness and stimulates the development of new technologies. On the other hand, the emergence of the secular concept of reason, the desacralization of nature, and the rational conception of the world that finds its expression in thinkers like Descartes and Bacon, gave the ideological support to the organization of production in accordance with the demands of the process of accumulation, and also with the appropriation of the surplus associated with the emergence of capitalism. 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 instrumentalist vision of "rationality" which expanded its scope progressively, reaching even the very conception of human relations.

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A constant in the process of evolution of productive 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 relatively uniform consumption patterns, superimposed over a variety of local forms of consumption --corresponding to much lower levels of in come and resource use-- in the underdeveloped societies.

A central issue in the discussion of the development problematique refers to the paths that countries of the Third World, which lack the capacity for accumulation of the Western industrialized nations, should follow in order to expand their productive and service activities and satisfy the needs of the population. While it is clear that the process of development, whichever its conception, entails the satisfaction of material needs at a level compatible with human dignity, the evolution of productive and service activities need not follow necessarily the same path as that followed by the highly industrialized nations, particularly with regards to the volume and diversification of goods. Concepts such as "another development" question this premise and seek to propose different options that would involve a redefinition of needs, and even the revaluation of productive and service activities of societies outside the European-American sphere.

The Baconian Program and the Rise of the West

Perhaps the best way of explaining the knowledge and institutional transformations of the late 16th and early 17th century is in terms of what has been called the Baconian program, whose main architect was the philosopher Sir Francis Bacon, Lord Chancellor of the British Crown. Bacon was and still remains a controversial figure, but he was the first to put forward a coherent view on how to use the power of modern science for the benefit of humanity. More than three and one half centuries after he put forward his program, our lives and thoughts are deeply influenced by the visions of this extraordinary man.

The Baconian program has been defined 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). Several features distinguished this program from other views on the production and use of knowledge that were current in Bacon's time: (i) a keen awareness of the importance of appropriate procedures to generate knowledge: scientific method and of scientific research; (ii) a clear vision of the purpose of the knowledge-generating scientific enterprise: improving the human condition; and (iii) 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 a God-created 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 (Sagasti, 1997a, b).

The Baconian program and the worldwide expansion of Western civilization proceeded hand in hand during the last four centuries and have affected all other cultures and civilizations. However, the success of the Baconian program has had many negative consequences, which could not be anticipated in Bacon's time. Two of these are of particular importance at present: the fact that improvements in living standards were achieved at the cost of severe environmental disruption, and the concentration of the benefits of scientific advances and technological progress in a minority of the world's population.

The triple crisis at the end of the 20th century

The proposed conceptual framework suggests some lines of thought that can throw light on the nature and present manifestations of the phenomena of development and underdevelopment. As an initial step, it is necessary to recognize that in every society each of the three current mentioned above, their contexts, and their interactions undergo a series of transformations in time.

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 man about himself and about his relation with the physical world is transformed, and the new conception gradually permeates and encompasses the technological base and the structure of productive activities.

At the other extreme, considering the relatively short span of several decades, the structure of productive and service activities plays the protagonic role in shaping social behavior. It defined 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 productive 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 productive 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 conceptualising 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 productive and services activities undergo.

Thus the three current evolve at different speeds, with the changes in productive 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 productive and service activities generate tensions that accumulate and pressure for changes in the technological base; in a similar way, the transformations of the technological accumulate and generate tensions that facilitate and induce major qualitative changes in the nature of speculative thought. Therefore, any account of the evolution of these three currents must take into consideration both the 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.

A given social group experiences a period of instability and adjustments when making the transition from one to another structure of productive activities, a process that can take one or two decades. Greater upheavals and instability can be expected when there are major changes in the technological base, which take place over several decades and induce changes in the structure of productive activities. Finally, revolutionary upheavals, turmoil and turbulence accompany the transition from one to another dominant form of speculative thought, a process taking a century or more, and which prompts concomitant changes in the technological bas and in the structure of productive activities.

Thus the evolution of social groups over time can be characterized as a complex, interactive and dynamic phenomenon. Any adequate interpretation of these evolutionary process should take into account these characteristics, resisting the temptation of advancing simplified, incomplete and unidirectional causal explanations.

Interactions among the Three Currents [NOT IN THE OUTLINE]

The interactions among the different stages in the evolution of these three currents, visualized against the background of the social, political and cultural organization, would characterize the degree of development of a given 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 support of many technological advances that contributed to the scientific enterprise. Productive and service activities found increasing support in the new technologies related to science, to the extent that at present, productive activities that employ technologies with scientific origin are clearly superior and dominate the scene. All of this takes 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 which feeds on the technological and scientific advances and which, in turn, gives the stimulus and the material resources to support them. This process has been called the emergence of an endogenous scientific and technological base in the highly industrialized countries.

The emergence of an endogenous scientific and technological base is accompanied by changes in values, with a new vision of the physical, social and intellectual world, and with a set of changes related to the diffusion of the by-products of the scientific activities. All of this gives its specificity to Western culture. In parallel, other cultures and societies have developed their own ways of linking these three currents and of relating them to the social, political and cultural context. For example, China showed great achievements in the evolution of speculative thought about nature and in logic and mathematics, was able to generate technologies based on abstract and systematic conceptions, and developed an efficient social organization of production. As Needham has pointed out, the philosophical and intellectual tradition of China at the time of the Renaissance was "much more congruent with modern science than the Christian conception of the world".

However, a variety of social, economic, and political factors --which emerged as a response to the specific environment of Chinese culture-- did not conduce to modern science and to an endogenous scientific and technological base. Similar considerations can be applied to India, the Islamic world, and to cultures of other regions. Examining their transformation it would be possible to identify the variants or the different "models" of societal development, without falling into a spurious comparison with the achievements of Western civilization taken as a frame of reference. In this way it would be possible to develop a proper perspective for examining the achievements of the West, for understanding its limitations and the nature of its present crisis, and for exploring new roads to the progressive acquisition of one endogenous scientific and technological base in Third World countries.

Towards a new cultural context [NOT IN THE OUTLINE]

Seen in this light, the progressive establishment of an endogenous scientific and technological base in the non-Western countries requires a new cultural context, different from the one that characterized the emergence of industrial civilization. For this it would be necessary to transcend the narrow or rationalistic vision characteristic of that civilization, avoiding the almost complete subordination of creativity and of knowledge generation to the logic of the productive process. The new cultural context must leave ample room for the idea of emancipation as the directionality for the evolution of human groups, should accommodate the diversity of products of social inventiveness, and should also restructure the pattern of values of industrial civilization that privileges the means and embraces instrumental rationality (emphasis on "how"), rather than the ends and the conception of a human destiny (emphasis in "why").

The new cultural context required for the establishment of an endogenous scientific and technological base in the Third World would seek to rescue creativity from its subordination to the productive process, to diminish the importance of instrumental rationality, and to counteract the homogenizing tendencies associated with industrial civilization. In this way, taking into account the reassertion of a diversity of finalities, which is the counterpart of these changes, there will be place for a greater variety of ways of articulating speculative thought with the technological base and with productive activities.

To combat the threat posed by a growing division of the human race into two distinct and antagonistic camps, it will be necessary to advance towards a "third civilization" in which the achievements of modern science could be integrated with the cultural heritage of non-Western societies in a harmonious fashion. This search for a third civilization, which must be considered as a general frame of reference within which each society could explore its own paths, requires many conceptual changes and a refocusing of our perception of Western culture:

THE KNOWLEDGE EXPLOSION

The emergence of knowledge society

Scientific advances and technological innovations are at the root of the complex transformation processes that have taken place during the last half a century. The success of the Baconian program, whose culmination we are witnessing in our times, has found one of its most clear expressions in the explosion of scientific knowledge and the flood of technological innovations that have led to momentous changes in all areas of human activity.

The rise of what Fritz Machlup called the "knowledge industries" has made us focus on the great variety of types of knowledge that exist, and on the roles that these play in human activities. In a pioneering work, and later in a monumental multi-volume treatise, Machlup undertook to classify the different kinds of knowledge into a multiplicity of categories, showing that knowledge acquired as a result of scientific research is but one of the many forms of knowledge that exist.[1] The thoroughly Western character of the modern scientific enterprise has also prompted a renewed interest in non-Western forms of knowledge, often referred to as traditional knowledge, and on the ways it can complement, modify and enrich science.[2]

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[1] See Fritz Machlup, *The Production and Distribution of Knowledge in the United States*, Princeton, Princeton University Press, 1962; and *Knowledge: Its Creation, Distribution and Economic Significance, Volume 1: Knowledge and Knowledge Production*, Princeton, Princeton University Press, 1980. Four volumes were published before Machlup's death, who was in his late seventies when he began the series. In the preface to the first volume he thanked the director of Princeton University Press for his "encouragement, counsel, and confidence in me and my longevity."

[2] For an excellent review of the debate on Western and non-Western science see: Andrew Jamison, "Western Science in Perspective and the Search for Alternatives," in Jean Jacques Salomon, Francisco Sagasti and Celine Sachs-Jeantet, *The Uncertain Quest: Science, Technology and Development*, Tokyo, United Nations University Press, 1994. The more than 100 references in this article cover practically every aspect of this debate.

Since World War II, the products of scientific research and technological innovation have become more and more deeply enmeshed in all aspects of human activity, to the extent that a "knowledge society" has been seen to have emerged during the last several decades. This has profound implications for the organization of human activities, and will introduce radical modifications in the relations between those workers involved in the production and distribution of knowledge and those who are engaged in various forms of manual labor.[3] Moreover, according to Peter Drucker, the emergence of "information capitalism" has already caused profound social transformations in the industrialized world. The coming "information society" will be qualitatively different from all that came before:

> "Despite the factory, industrial society was still essentially a traditional society in its basic social relationships of production. But the emerging society, the one based on knowledge and knowledge workers is not... This is far more than a social change. It is a change in the human condition."[4]

While advances in the capacity to generate and utilize knowledge have been linked to the conduct of war throughout history, the scale and impact of the mobilization of science for military purposes during World War II was extraordinary and unprecedented. Not only the development of the atom bomb --with all that this heralded for the future of humanity-- was a product of this mobilization, but also the development of the radar, of microelectronics and the modern computer, in addition to advances in operations research, psychology and in understanding group dynamics.[5]

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. 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 and more deeply enmeshed in all aspects of human activity. One of the leading features of the contemporary scene in science and technology is the increased interpenetration and

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[3] See Peter Drucker, *The Age of Discontinuity*, New York, Harper and Row, 1968, in which he refers to the "knowledge society." His article "The Age of Social Transformation," *The Atlantic Monthly*, November 1994, pp. 53-80, describes the changes that are taking place in the structure of occupations:

> "The emerging [knowledge] society is the first society in which ordinary people --and that means most people-- do no earn their daily bread by the sweat of their brow. It is the first society in which 'honest work does not mean a callused hand. It is also the first society in which not everybody does the same work, as was the case when the huge majority were farmers or, as it seemed likely only forty or thirty years ago, were going to be machine operators."(p. 57).

[4] Peter Drucker, "The Age of Social Transformation." *The Atlantic*, November 1994, p. 54.

[5] For accounts of the American and British perspectives on the mobilization of science during World War II see: James Phinney Baxter III, *Scientists Against Time*, Cambridge, Mass., MIT Press, 1968; and R. V. Jones, *Most Secret War: British Scientific intelligence 1939-1945*, London, Coronet Books, 1979. The preface by Vannevar Bush to the Baxter volume contains interesting appreciations on the importance of scientists for the victory of the Allied effort. See also: the preface "After Twenty-five Years" to the second edition of J. D. Bernal, *The Social Function of Science*, Cambridge, Mass, MIT Press, 1967, (first published in 1938), pp. xix-xxii.

cross fertilization between scientific research, technological innovation and the transformation of productive and service activities. "Science is transformed more and more into technology and industry, technology is becoming more and more science."[6]

Three features of science and technology merit particular attention as we enter a new century: the changes taking place in the conduct of scientific research, the increasingly systemic character of technological innovation, and the emergence of a new techno economic paradigm. All of these have a profound impact on the prospects for developing countries.

The new character of scientific research

In the five decades since World War II, knowledge has grown at an astonishing pace. The explosive growth of knowledge has been described by David Linowes in the following terms:

> "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."[7]

The growth of scientific research, supported by advances in information and computer sciences, has been primarily responsible for this explosion of knowledge. There has also been an increased inter-penetration and cross-fertilization between scientific research, technological innovation and the commercial exploitation of research results.

The multiple and complex interactions between research, innovation and commercialization 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 incorporated into productive and service activities. Instead, it is now clear that the accumulation of technological innovations provides a base of observations for science to delve into, technological progress plays an important role in defining the agenda for scientific research. High-technology industries, as well as innovations in health care, agriculture, energy and other related sector, continuously identify new problems to be addressed by science, and techniques of observation, testing,

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[6] Ricardo Petrella, "Le Changement dans l Environement Externe a la R&D: la Dimension Europeene," Forecasting and Assessment of Technology (FAST) Occasional paper No. 64, May 1983, p. 8. In a similar vein, Melvin Kranzberg, in "The Dynamic Ecology of Innovation," in M. Kranzberg, Y. Elkana, and Z Tadmor (eds.), *Innovation at the Crossroads Between Science and Technology*, Haifa, Israel, Neaman Press, 1989, p. 13, argues that:

> "... The old distinctions between basic and applied science, between science and technology, are no longer meaningful. And, indeed, where does science end and technology begin --and viceversa-- in such fields as bioengineering, genetic engineering, information and computer sciences, superconductive materials, and the like?"

[7] David F. Linowes, speech delivered to the While House Conference on Libraries and Information Services, October 1990, quoted by Carl Dahlman, "The Third Industrial Revolution: Trends and Implications for Developing Countries," paper presented at the Foro Nacional International Conference on the New International Order, Rio de Janeiro, Brazil, April 13-14, 1994.

measurement and instrumentation are also a major determinant of scientific progress.[8] All these interrelations have dramatically reduced the time between scientific discovery and economic exploitation of research results.[9]

The institutional settings for the conduct of basic research, applied research, and the development of new products and processes are experimenting significant changes, particularly because of shifts in the sources of funding and because the private sector are playing a more prominent role in the financing and conduct of research. Links between universities and industries are being strengthened, collaborative industrial research and technological alliances have become an imperative in certain 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 primarily in the rich countries, although several newly industrializing nations —particularly those in South East Asia-- are also moving in this direction.

Institutional settings for the conduct of scientific and technological activities have 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 research have become increasingly dependent on advanced and expensive 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 high cost of advanced instruments and financial constraints have been creating a difficult situation for university laboratories in industrialized nations, and have effectively put many fields of research out of the reach of the vast majority of scientific institutions in developing countries.[10] At the same time, however, the innovations in

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[8] Beatrice Montamedi, "Computer Designed Pharmaceuticals", *Hemispheres*, November 1993, pp-51-52.

[9] See: David Mowery and Nathan Rosemberg, *Technology and the Pursuit of Economic Growth*, London, Cambridge University Press, 1989; and Nathan Rosemberg, *Inside the Black Box: Technology and Economics*, London, Cambridge University Press, 1982.

The transition from basic science discoveries to practical innovation is accelerating in many fields of science and technology. While it took over 50 years between Faraday s 1830 finding that a moving magnetic field con produce electricity and the first practical generation and distribution system for electric lights in 1881, and 40 years for Einstein s 1905 discovery of the formula that describes the relations between matter and energy and the detonation of the first Atomic bomb in 1945, it took 20 years between Watson and Crick s discoveries of the structure of DNA in 1953 and the first transplant of genes in 1973, and only six years between the discovery of the electron tunneling effect by Esaki in 1957 and the first commercial application of semiconductor diodes in 1963. The time between the creation of new knowledge and its incorporation into new products and processes is shortening even more rapidly, particularly in the fields of microelectronics and information sciences.

[10] U. S. National Academy of Sciences, *Outlook for Science and Technology: the Next Five Years*, San Francisco, W. H. Freeman and Co., 1982. According to this report:

> “... Advances in electronics, optics, analytical techniques, and data processing have provided the chemist with an array of sophisticated instruments that have added new dimensions to his abilities to unravel complex structures, to gain intimate understanding of reaction mechanisms, and to design synthesis procedures. Much of the recent progress in chemical synthesis has been

information technology may be reversing some of these trends: relatively inexpensive "virtual" advanced instruments use software that can run on a standard personal computer, and their use is flowering in the mid 1990s. In some cases, the virtual version of an instrument can cost 20 times less than a conventional scientific instrument, and is often more versatile.[11]

Also, advances in microelectronics, computers and telecommunications have opened up new possibilities for the active participation of researchers from all parts of the world, including the poorer regions. Not only there is greater access to libraries and other sources of written information, but also it is possible to interact in almost real time with peers from all over in electronic conferences and to send the results of tests for analysis to centers with advanced facilities. While these opportunities are still being explored, it is clear that there is still ample scope for developing countries to become actively involved in many aspects of scientific research, even in areas that would appear at first sight closed to them.[12]

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 high-level professionals are in short supply. It has been pointed out that, in order for developing country science to flourish, it is imperative to assure the transmission of knowledge through up-to-date books, journals, CD-ROM, which are sorely lacking in their libraries. Access to these is, according to Abdus Salam, truly an issue of "science transfer," in the same way as the training abroad of developing country scientists.[13]

The systemic character of technological innovation

The nature of the innovation process has also changed significantly, particularly in science-intensive industries, and is acquiring a more complex and systemic character, becoming more expensive, involving greater sophistication in management techniques, giving rise to new forms of appropriation of technological knowledge, intensifying both international collaboration and competition, and transforming the role of governments in the support of innovation.[14]

> strongly dependent on the kind of information that is obtained with modern analytical instrumentation." (p.455).

However, this report also cautioned that "the very high cost of these advanced instruments may be a constraint on realizing the full potential of scientists working on chemical synthesis."

[11] The Economist, "Roll Your Own: Scientific Instruments." *The Economist*, Feb 3 1996, p. 71-72.

[12] Abdus Salam, *Science, Technology and Science Education in the Development of the South*, Trieste, The Third World Academy of Sciences, July 1991.

[13] Abdus Salam, "Spreading the Word." *Nature*, Oct 3, 1991, p. 457

[14] For an analysis of innovation studies in industrialized economies and their relevance to the developing countries see: Charles Cooper, *Are Innovation Studies on Industrialized Economies Relevant to Technology Policy in Developing Countries?*, Maastricht, UNU/INTECH (Institute for New Technologies), 1992.

Where innovation was until recently seen as a process of "breaking through the boundaries of existing technology," a very different interpretation is emerging as,

> "Recent innovations ... make it more appropriate to view innovation as the *fusion* of different types of technology rather than as a series of technical breakthroughs. Fusion means more than a combination of different technologies: it invokes an arithmetic in which one plus one makes three." [15]

The systemic nature of the innovation process is manifested in at least two ways: 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. New technologies are differentiated from old ones by their greater combinative and contagious character, for individual advances in information technology, automation, new materials, chemical synthesis and biotechnology, among many others, cannot be applied on their own without complementary inputs from other technologies. This has become clearly noticeable in automation and computer aided manufacturing, where microelectronics, computers, telecommunications, optoelectronics and artificial intelligence are fusing together into an integrated technology system, as well as in fields like aircraft production and the development of new drugs.[16]

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[15] Fumio Kodama, *Emerging patterns of innovation: Sources of Japan's technological edge*. Harvard Business School Press, 1995. p. 9

[16] The tendency to combine technological advances in specific fields, and its implications for developing countries, had been clearly recognized in a report prepared by the United Nations Industrial Development Organization (UNIDO) in early 1980s. See: "Report on the International Forum on Technological Advances and Development," Tbilisi, USSR, 12-16 April 1983, Doc. No. ID/WG.389/6; and "Strengthening of Scientific and Technological Capacities for Industrial Development in Developing Countries," Background Paper for the Fourth General Conference of UNIDO, Vienna, 2-18 August 1984, Doc. No. ID/CONF.6/6, p. 86, where it is stated that:

> "In the 1980s and 1990s technological advances in a number of fields ... Are expected to converge leading to a significant measure of technological change. These advances are unique in their intensity and wide ranging impact and lend themselves to rapid commercial application, given the infrastructure of the developed countries. Though estimates of the extent and time horizons of expected changes may vary, the directions are clear. The advances are expect to alter the rate and pattern of industrial production in the present and coming decades... To widen the technological gap between developed and developing countries and accentuate the technological dependence of the latter, and to change the lifestyle of their people."

For an analysis of the systemic character of innovation in the case of automated industrial production see, for example, Raphael Kaplinsky, *Automation: The Technology and Society*, Harlow, U. K., Longman, 1984, who argues that:

> "Increasingly ... The direction of technical change in the industrially-advanced countries is assuming a*systemic* character, involving the mating together of disparate islands of automation. The organizing thread of this new era of automation is the control of information, the rapid processing and communication of which is vastly facilitated by the utilization of electronically-controlled equipment. The ... systemic nature of these technological developments ... Has important consequences for the pattern of innovation." (p. 17).

The technological convergence implied by the systemic character of innovation has made it necessary for 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.[17]

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. In addition to the firms directly involved in this process, there may also be subcontractors, suppliers of inputs and equipment, laboratories and other organizations that provide technological services, 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" has been put forward to account for the growing complexity of the institutional arrangements required to facilitate the innovation process.[18]

This growing complexity of science and technology-related issues, regarding policymaking in particular, was revealed in the late 1970s by the Science and Technology Policy Instruments (STPI) project. A distinction was made at that time between explicit and implicit policy instruments:

> "Explicit science and technology instruments are those intended to affect directly the decisions having to do with the growth of local S&T capabilities; implicit ones are those that affect decision-making indirectly through second-order effects. The great weight, both in number and influence of the latter limits the potential impact of the former." [19]

The complexity and interconnectedness of innovation processes, as viewed from a national perspective, is again illustrated in the 1990s by Nathan Rosenberg, Ralph Landau, and David Mowery:

> "... many of the policies that are most important in affecting the innovative performance of nations lie well outside of the conventional boundaries of "science

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[17] David Mowery and Nathan Rosemberg, *Technology and the Pursuit of Economic Growth*, London, Cambridge University Press, 1989.

[18] See Richard Nelson's preface to Part V, which deals with national systems of innovation, of Giovanni Dosi, Christopher Freeman, Richard Nelson, Gerald Silverberg and Luc Soete (eds.), *Technical Change and Economic Theory*, London, Frances Pinter, 1988, and the articles included in this part of the book. See also: Richard Nelson (ed.), *National Innovation Systems: A Comparative Analysis*, Oxford, Oxford University Press, 1993.

[19] Francisco Sagasti, Science and Technology for Development: Main Comparative Report of the Science and Technology Policy Instruments project. IDRC, 1978. (p. 16)

> and technology policy," and include macroeconomic, international financial, regulatory, and tax policies." [20]

As a result of the more complex and systemic character of innovation, the costs of incorporating research results into productive and service activities, and of bringing new products to the market, have been steadily increasing during the past few decades. The higher costs of innovation and the larger risks faced by firms in a more competitive environment have in effect increased barriers to entry in many fields of industry.[21] 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.[22]

New technologies make 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.[23] Low labor costs are no longer the dominant criterion to locate production sites, 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 those 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 the tools.[24] A well developed physical infrastructure is also required to support innovation, including a good network

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[20] Nathan Rosenberg, Ralph Landau, and David Mowery, *Technology and the Wealth of Nations*. Stanford University Press, 1992. P. 14

[21] Dieter Ernst and David O'Connor, *Technology and Global Competition: The Challenge for the Newly Industrialized Economies*, Paris, OECD Development Center, 1989.

[22] See: Groupe de Lisbonne, *Limites a la Competitivite: Pur Un Nouveau Contrat Mondial*, Paris, La Decouverte, 1995, pp. 69-78; and C. Freeman and J. Hagedoorn, *Globalization of Technology: Global Perspective 2010 and the Tasks for Science and Technology*, Science Policy Research Unit, University of Sussex, June 1992.

[23] For a review of the impact of information technology, biotechnology and new materials on developing countries see: UNESCO, *World Science Report 1996*, Paris, UNESCO Publishing, 1996; and Paulo Rodriguez Pereira, "New Technologies: Threats and Opportunities," in Jean-Jacques Salomon, Francisco Sagasti and Celine Sachs-Jeantet, *The Uncertain Quest: Science and Technology for Development*, Tokyo, UNU Press, 1994.

[24] Nagy Hanna, "Informatics and the Developing World," *Finance and Development*, December 1991; and Kurt Hoffman, "Technological Advance and Organizational Innovation in the Engineering Industry: A New Perspective on Problems and Possibilities for the Developing Countries," Washington D.C., The World Bank, Industry and Energy Department Working Paper No. 4, March 1989.

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.

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 technologies.[25] 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, which may ease to a certain extent the pressures exercised by the taxing demands of innovation processes in more competitive fields.

Change in the techno-economic paradigm: from energy to information

The interactions between science, technology and economic growth after World War II can be interpreted as the latest manifestation of a series of cyclical phenomena, which have characterized the history of economic activity during the last two hundred years. The alternation of phases of rapid growth and stagnation, has given rise to five "long waves" with a periodicity of about 50 years. Such an interpretation builds on the work of economists and historians who have focused on the cyclical nature of economic activity, whose proponents include Nikolai Kondratieff and Joseph Schumpeter.[26]

Carlota Perez and Christopher Freeman have proposed the most widely known and accepted interpretation of long waves in recent times. They suggest that the transition from one long wave to another involves changes in the dominant "techno-economic paradigm." A techno-economic paradigm is a combination of interrelated product and process, technical, organizational and managerial innovations, embodying a significant

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[25] See: Agit Bhalla, Dilmus D. James and Y. Stevens, *Blending of New and Traditional Technologies: Case Studies*, Dublin, Tycooly International Publishing, 1984; Agit Bhalla and Dilmus James (eds.), *New Technologies and Development: Experiences with Technology Blending*, Lynne Rienner, Boulder, 1998; and Agit Bhalla, "Technology Choice and Development," in Jean-Jacques Salomon, Francisco Sagasti and Celine Sachs (eds.), *The Uncertain Quest: Science, Technology and Development*, Tokyo, The United Nations University Press, 1993.

[26] The first proponent of a theory of economic cycles appears to have been the British economist Stanley W. Jevons, who suggested that variations in the level of economic activity were related to the appearance of sunspots that affected the weather, which affected agriculture and harvest, which, in turn, had an influence on the level of economic activity. For a survey of the contributions to long wave analysis through history see: Christopher Freeman (ed.), *Long Waves in the World Economy*, London, Butterworths, 1983, and particularly the chapters by Jos Delbeke, J. Tinbergen, Hans H. Glisman *et. al.* Michele Salvati and Gerrit van Roon. See also: Robert U. Ayres, *Technological Transformations and Long Waves*, Vienna, International Institute of Applied Systems Analysis, 1989.

jump in potential productivity for all or most of the economy and opening 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 the initial industries and services to the economy as a whole.[27]

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 left behind is energy (especially oil), whose falling cost, apparent unlimited supply and widespread utilization reorganized the production of goods and services at the world level from the 1930s onwards. Transport related industries (automobiles, trucks, tractors, aircraft, motorized armaments), consumer durables, and oil-based products (petrochemicals, synthetic materials), 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 Kondratieff wave." This wave extended through the 1980s and early 1990s, and included the 1950-1973 "golden age" of economic growth, a period of unprecedented economic and trade expansion following World War II.[28]

A new techno-economic paradigm began to emerge in the 1980s and 1990s. The microelectronic chip is replacing energy as the key factor, while information and telecommunications industries and services (computers, electronic capital and consumer goods, robotics, telecommunications equipment, optical fibers, ceramics, software and information services) are taking the lead in the process of economic growth. Satellites, digital telecommunications networks and special purpose computers are providing the infrastructure for the expansion of information and communication services which will continue well into the 21st century.[29]

This transition has profound implications for the way in which production is organized in enterprises, for competitive strategies and even for the institutional arrangements to support productive and service activities at the national and international level. The well proven set of common sense managerial guidelines, derived from decades of successful experience in increasing efficiency within the framework of the techno-

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[27] See; Christopher Freeman and Carlota Perez, "Structural Cycles of Adjustment, Business Cycles and Investment Behavior," in Giovanni Dosi, Christopher Freeman, *et. al.*, *Technical Change and Economic Theory*, London, Frances Pinter, 1988.

[28] Angus Maddison, *Monitoring the World Economy 1820-1992*, Paris, Development Centre, Organisation for Economic Cooperation and Development (OECD), 1995, pp. 73-78.

[29] Freeman and Perez, *op. cit.*

economic paradigm based on energy, is giving way to a new set of efficiency principles and practices associated with the new possibilities opened up by the microelectronic chip.[30]

According to Carlota Perez, 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 access to the sources of competitiveness. Firms and countries face an unusually favorable situation: a "double window of opportunity" provides access both to what until recently was private knowledge in the fully deployed paradigm and to what will soon become private knowledge in the new techno-economic paradigm. Moreover, there are usually lags in the diffusion of the technological innovations associated with the transition from one paradigm to another, which could extend the window of opportunity for longer than a decade. This could allow firms and countries to enter well-selected areas of new products and technologies, and also to successfully compete in international markets with rejuvenated old products.[31]

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 in terms not only in terms of technical capabilities, but also with regard to managerial skills, institutional adaptability and creativity. In the end, those countries that take advantage of this opportunity may not be the most advanced in technological terms, but those that arrive at the best match between technological potential, institutional framework and social consensus. Moreover, because of the speed of scientific advances and technological innovations in information technology, this window of opportunity is likely to be small and may be closing soon for many developing countries and their firms.

Broad socio-economic characteristics of a country may in fact be crucial factors in successfully seizing such a window of opportunity. The success of Japan in the emerging techno-economic paradigm is interpreted by Fumio Kodama as ultimately stemming from its unique socioeconomic characteristics, which put it in a position to excel in the creation of knowledge:

> "Through an empirical analysis of the generation, innovation, and diffusion of Japanese high technology, I believe that a paradigm shift in technology innovation, driven by the rapid evolution of science and engineering, is occurring and favors the Japanese system." [32]

Kodama offers a reading of the emerging high technology era, where knowledge creation is central, that has policy implications for both firms and countries." In the

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[30] For a description of these changes in managerial and engineering common sense as we move from the energy to the microelectronics techno-economic paradigm see: Carlota Perez, *Technical Change, Competitive Restructuring and Institutional Reform in Developing Countries*, Discussion Paper No. 4, Strategic Planning and Review Department, The World Bank, December 1989, pp. 17-28, and particularly Table I, p. 25.

[31] Carlota Perez, *op. cit.*

[32] Fumio Kodama, *op. cit.*(p. 3)

high-tech era, the key issue of technology policy is not how to make possible unprecedented technological capabilities, but how to put technology to the best possible use." Investment priorities change in the emerging era:

> "When R&D investment begins to exceed capital investment, the corporation can be said to be shifting from a place for *production* to a place for *knowledge creation*." [33]

These three sets of changes in scientific research, technological innovation and in the techno-economic paradigm are creating a new setting for developing country efforts to mobilize science and technology to improve the human condition. It has become increasingly evident that without at least a minimum level of science and technology capabilities and access to knowledge and information, developing countries cannot expect to improve significantly their standards of living.

Some implications in light of the conceptual framework

[Conditions for the emergence of the endogenous scientific and technological base at the beginning of the 21st century]

[33] *Ibid.*, p. 5.

THE KNOWLEDGE DIVIDE AND ITS POLICY IMPLICATION

The fractured global order and the knowledge divide

Together with other consequences in the realms of politics, economic, society and culture the success of the Baconian program has led to the emergence of a "Fractured Global Order." This is an order that is global but not integrated; an order that puts all of us in contact with each other, but simultaneously maintains deep fissures between different groups of countries and between peoples within countries; an order that is benefiting a small percentage of humanity and segregating a large portion of the world's population (Sagasti, 1989).

The emerging fractured global order is characterized by a multiplicity of fault lines of political, economic, social, environmental, cultural, scientific and technological nature; these faults overlap partially and often shift direction; they sometimes reinforce each other and at other times work at cross purposes. The overall picture they paint is one of turbulence and uncertainty in which a variety of contradictory processes open up a wide range of opportunities and threats that defy established habits of thought. However, because of the profound consequences it has for all the other aspects of the global order, it is necessary to highlight the importance of the knowledge fracture that is leading to a knowledge divide between peoples and nations.

The last four centuries, what may be called the Baconian age, have been marked by the rise of science as the superior and dominant method for generating knowledge about the world that surrounds us, about ourselves and about human interactions. Scientific advances, the evolution of technology and the transformation of productive and service activities have become closely intertwined in the dynamic sectors of the world economy, which are an almost exclusive preserve of today's highly industrialized nations. In the rest of the world, knowledge, technology and production have remained wide apart, with local forms of knowledge generation relegated to a marginal role at best.

The role that knowledge now plays in all human activities is so critical that the concepts of development and progress need to be redefined in terms of the capacity to generate, acquire, disseminate and utilize knowledge. The presence or absence of this capacity constitutes thus a crucial divide between rich and poor nations and societies; between those parts of the world in which individuals have the potential to decide and act with autonomy, and those in which people are not yet empowered to realize their full potential as human beings.34

Key factors affecting a nation or society's position relative to the knowledge divide are its scientific and technological capabilities, as well as its people's ability to access and utilize information. These are critical variables in the generation, acquisition, dissemination and utilization of knowledge.

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[34] Francisco R. Sagasti, "The Two Civilizations and the Process of Development," *Prospects*, Vol. X, No. 2, (1980), pp. 123-139; "International cooperation in a fractured global order," *Impact of Science on Society*, No. 155, Vol. 39 (1990), No. 3, pp. 207-211; "Cooperation in a fractured global order," *New Scientist*, 14 July 1990; and "Knowledge and Development in a Fractured Global Order," *Futures*,

That the widely varied scientific and technological capabilities of nations are closely related to this gap in living standards that divides rich and poor has been suggested in previous decades:

> "Today, the Third World is only slowly waking up to the realisation that in the final analysis, creation, mastery and utilisation of modern Science and Technology is basically what distinguishes the South from the North. On Science and Technology depend the standards of living of a nation." [35]

Specifically, developing endogenous scientific and technological capabilities has been pointed out as crucial to overcoming the gap that is now clearly a knowledge gap:

> "... it is impossible to conceive an advance towards emancipation without a minimum level of autonomous capabilities to generate or adapt scientific knowledge, to transform it into technology, and to incorporate this technology, linked to scientific discoveries, into productive and service activities. This capacity has been called an endogenous scientific and technological base, and to take it into account becomes an indispensable requisite for the process of development." [36]

An endogenous science and technology base has thus been recognized as a distinctly fundamental instrument for development, but building one is a complex task involving cultural changes:

> "The new cultural context required for the establishment of an endogenous scientific and technological base in the Third World would seek to rescue creativity from its subordination to the productive process, to diminish the importance of instrumental rationality, and to counteract the homogenising tendencies associated with industrial civilisation. In this way ... there will be room for a greater variety of ways of articulating speculative thought with regard to the technological base and productive activities."[37]

The need for adequate scientific and technical literacy in a nation's workforce, an important element in the development of science and technology capabilities, has been recognized as nations strive to raise their living standards. This is now perceived as such a fundamental factor that it can be said that, "... scientific literacy, understood as an everyday working knowledge of science, is as necessary as reading and writing

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[35] Abdus Salam, *Notes on Science, Technology and Science Education in the Development of the South*. The Third World Academy of Sciences, 1988. p. 19

[36] Francisco Sagasti, "Reinterpreting the Concept of Development from a Science and Technology Perspective." in Erik Baark and Uno Svedin (editors), *Man, Nature and Technology: Essays on the Role of Ideological Perceptions*. Macmillan Press, 1988.p. 42

[37] *Ibid.,* p. 52

(literacy in the commonly understood sense) for a satisfactory way of life in the modern world."[38]

In an era where economic growth based on the production of primary goods is proving to be increasingly uncertain and difficult to sustain, the call for improved human resources that can competitively turn out ever more sophisticated goods and services rings true in rich and poor nations alike.

Moreover, the ability to generate and apply knowledge effectively is seen in the 1990s as directly conducive to economic growth, and then to increased prosperity, especially in the industrialized countries. The United States Government, through the 1994 "President's Official Science and Technology Policy," explicitly follows the assumption that "Technology is the Engine of Economic Growth," a motto that intimately links economic and science and technology policy. One of the five fundamental goals of the current policy is to "raise the scientific and technology literacy of all Americans." [39]

The last decade of the twentieth century is one in which constant and rapid advances in science and technology, valuable achievements in themselves, should also constitute a source of preoccupation for much of the developing world. As time passes and knowledge continues to expand at an explosive rate, the cumulative impact of imbalances in science and technology capacities is likely to create almost impenetrable barriers for those who wish to cross the knowledge divide and mobilize knowledge to improve the condition of most of humanity.

Types of developing countries in terms of science and technology capabilities

Differences in science and technology capabilities, which have persisted over a long time and are rather difficult to surmount, constitute a distinguishing feature of the emerging international order. These differences in scientific and technological development are marked between rich and poor countries but also within the developing world:

> "It is increasingly accepted by the mainstream of development agencies that the capacity of developing countries to manage ... processes of technical change to their advantage increasingly defines the divide between industrialized and

[38] Francisco J. Ayala, "Introductory essay: The case for scientific literacy." *UNESCO World Science Report 1996*. p. 1

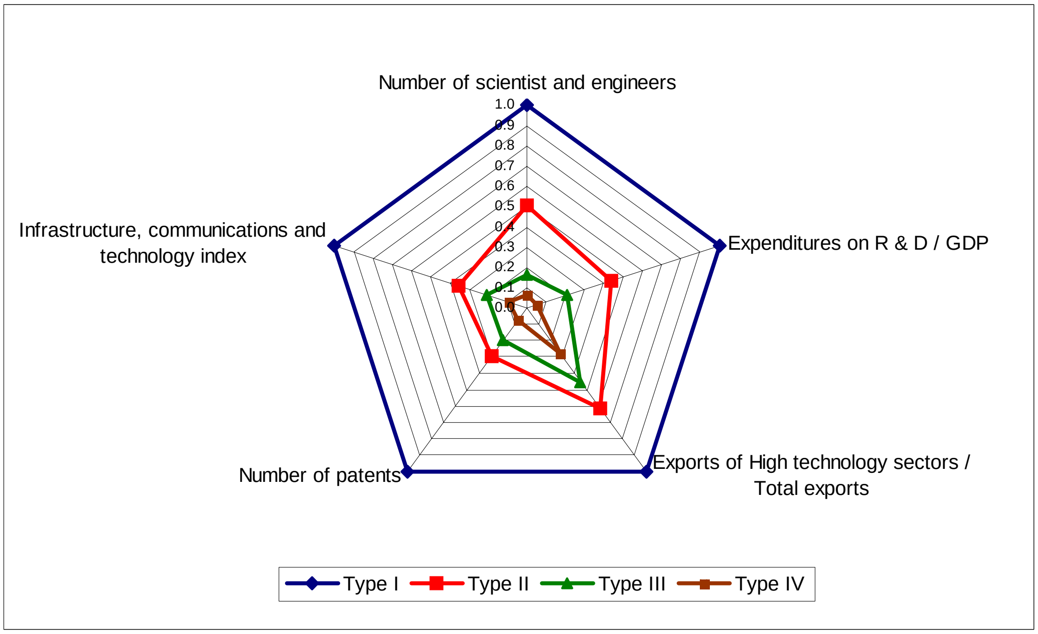
[39] See *The President's Official Science and Technology Policy*, United States Government public document from 1994. The five goals of the policy are:

1. "To maintain leadership across the frontiers of scientific knowledge.
2. Enhance the connections between fundamental research and national goals.
3. Stimulate government, industry, and academic partnerships that promote investment in fundamental science and engineering and effective use of physical, human, and financial resources.
4. Produce the finest scientists and engineers for the twenty-first century.
5. Raise the scientific and technology literacy of all Americans."

developing countries. And the ability to manage technical change is itself highly differentiated both within and between developing countries." [40]

The level of development of a science and technology base is difficult to quantify homogeneously because of differences in factors such as the size and culture of nations. Nonetheless, we propose a typology of four countries.

FIGURE 2
Typology of countries related to S&T capabilities
(Type I = 1)



Sources: UNESCO, *World Science Report 1998*,París, Unesco Publishing, 1998
UNESCO, *Statistical Yearbook 1999.* Charts available on Unesco web site http://www.unesco.org
World Bank, World Development Indicators 1999, CDROM.
Red Iberoamericana de Ciencia y Tecnología (RICYT), *Indicadores de Ciencia **y Tecnología Iberoamericanos / Interamericanos***. Web site http://www.ricyt.edu.ar
Francisco Rodríguez and Ernest J. Wilson, *Are poor countries loosing the information revolution?,* Infodev working paper, available in http://www.worldbank.org/infodev

[40] Andrew Barnett, *Knowledge Transfer and Developing Countries: Global Perspective 2010 and the Tasks for Science and Technology*. Paper for the EC-FAST Program. May 1992. p. 7.

TABLE 1
Average per type
(selected indicators)

	Number of scientist and engineers	Expenditures on R & D / GDP	Exports of High technology sectors / Total exports	Number of patents	Infrastructure, communications and technology index
Type I	3 081	2.27	18.5%	100 313	58.7
Type II	1 554	0.99	11.4%	29 501	20.8
Type III	508	0.48	8.3%	19 949	12.3
Type IV	202	0.12	5.2%	7 661	5.5

	Scientists and engineers (per million people) **1985-1995**[1]	**Expenditures for R&D** (% of GNP) **1985 - 1995**[1]	**High-technology exports** (% total exports) **1997**	**Patents** (from residents and non-residents) **1997**	**Infraestructure, communication and technology index** **1992 – 97**[2]
TYPE I					
Sweden	3 714	3.4	21.8%	83 441	84.17
Japan	6 309	2.9	31.9%	401 251	78.29
Korea, Rep.	2 636	2.8	26.9%	113 994	25.1
Switzerland		2.8	16.2%	78 275	57.76
Finland	2 812	2.5	18.2%	64 818	95.6
United States	3 732	2.5	21.1%	223 419	100
France	2 584	2.4	18.8%	98 508	43.37
Germany	2 843	2.4	19.0%	155 095	53.47
Israel		2.2	22.7%	13 535	40.22
United Kingdom	2 417	2.2	26.1%	129 353	55.34
Netherlands	2 656	2.1	26.7%	66 842	53.97
Denmark	2 647	1.9	12.8%	74 603	20.38
Norway	3 678	1.8	4.3%	27 178	89.51
Australia	3 166	1.7	7.7%	43 321	78.04
Belgium	1 814	1.7	15.8%	60 455	38.35
Slovenia	2 544	1.7	11.8%	21 987	21.75
Canada	2 656	1.6	13.4%	49 254	62.82
TYPE II					
Austria	1 631	1.5	14.0%	78 491	46.65
Ireland	1 871	1.4	43.1%	53 332	40.19
Ukraine	3 173	1.3		26 502	10.22
Croatia	1 978	1.2	6.9%	615	12.32
Czech Republic	1 159	1.2	8.5%	25 479	
Belarus	2 339	1.1		21 048	
Guatemala	99	1.1	2.9%	104	3.37
Italy	1 325	1.1	10.5%	80 852	38.19
New Zealand	1 778	1.1	2.4%	28 368	58.56
Singapore	2 728	1.1	47.7%	38 618	50.5

Slovak Republic	1 821	1	9.5%	23 066	23.1
Pakistan	54	0.9	2.8%	798	1.62
Spain	1 210	0.9	9.1%	83 983	30.02
Cuba	1 606	0.84		4 918	
Hungary	1 033	0.8	23.4%	24 979	20.84
India	149	0.8	6.0%	8 292	1.47
Benin	177	0.7			
TYPE III					
Chile		0.7	2.3%	1 960	11.28
Moldova	1 539	0.7	1.5%	20 535	8.15
Poland	1 299	0.7	5.6%	27 316	12.81
Romania	1 382	0.7	4.9%	23 970	6.44
Russian Federation	3 520	0.7	3.7%	46 287	11.93
South Africa	938	0.7			8.43
Brazil	168	0.6	8.6%	32 106	10
Estonia	2 018	0.6	12.6%	21 156	19.01
Greece	774	0.6	4.6%	52 805	18.64
Peru	625	0.6	1.2%	617	4.99
Portugal	1 185	0.6	6.8%	71 649	21.35
Turkey	261	0.6	3.4%	20 035	9.57
Bulgaria		0.57		22 553	11.18
China	350	0.5	16.1%	52 714	6.99
Egypt, Arab Rep.	458	0.5	0.7%	1 210	3.69
Iran, Islamic Rep.	521	0.5			4.88
Latvia	1 189	0.5	5.2%	21 695	15.52
Venezuela	208	0.5	1.0%	2 004	3.32
Argentina	671	0.4	4.8%		11.66
Malaysia	87	0.4	42.5%		
Mauritius	361	0.4	0.8%	22	15.5
Mexico	213	0.4	24.4%	30 694	9.14
TYPE IV					
Vietnam	308	0.4		22 243	7.32
Kazakhstan		0.32		21 088	
Yugoslavia, FR		0.31	8.2%	809	6.99
Burundi	32	0.3		5	
Jordan	106	0.3	4.7%		5.16
Lithuania		0.3	9.5%	21 350	12.17
Tunisia	388	0.3	6.0%	174	4.65
Central African Rep.	55	0.25	0.0%		
Azerbaijan		0.21		16 635	
Costa Rica		0.2	2.1%		
Libya		0.2		35	
Madagascar	11	0.2	0.1%	20 807	
Philippines	157	0.2	15.5%	2 797	4.29
Syrian Arab Republic		0.2	0.1%		2.14
Thailand	119	0.13	24.5%	4 558	8.34
Colombia		0.12	4.5%	1 259	9.46
Ecuador	169	0.1	0.9%	361	6.52
Nigeria	15	0.1			
Burkina Faso		0.08			
Jamaica	8	0.04	19.5%		10.24
Rwanda	24	0.04			

Bangladesh		0.03	0.1%		
Mongolia	943	0.02	0.2%	20 996	2.32
Congo, Rep.		0.01	0.3%		
Gabon	189	0.01	0.6%		2.77
Kyrgyz Republic	703	0.01	7.0%	20 305	
Panama		0.01	0.2%	173	

(Preliminar)
(In red = some anomalies)

Despite the inevitable shortcomings of such a typology, it is a helpful starting point to illustrate the position of nations relative to the knowledge divide and also to design science and technology policies.

Scientific and technological capacities are distributed in an even more lopsided way than economic power. The high income countries of the Organization for Economic Cooperation and Development (OECD) account for about 85 percent of total world expenditure in science and technology, India, China and the newly industrializing countries of East Asia account for a further 10 percent, while the rest of the world accounts for only about 4 percent.41 In terms of Research and Development, it can be said that 95% of all expenditure is carried out in the North, if Eastern Europe is included therein. 42

Moreover, while the average income per capita of the 24 rich countries of the OECD is about 60 times greater than that of the about 50 poorest countries classified as "low income economies" by the World Bank, average science and technology expenditures per capita in the former are 250 times greater than those of the latter. Regional differences in Research and Development expenditures relative to GDP are indicative of a probable growth in the gap between rich and poor countries' science and technology bases: in Latin America and Sub-Saharan Africa the percentage is 0.4 while in the US and Japan, with much higher GDPs, it is 2.8.43

In contrast, the distribution of human resources devoted to science and technology is more balanced: about 50 percent of the world s supply of scientists and engineers is concentrated in the OECD countries; 17 percent in Central and Eastern Europe, and in the Commonwealth of Independent States; 15 percent in India, China and the newly

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[41] See: UNESCO, *World Science Report 1996*, Paris, UNESCO Publishing, 1996, p. 15, where it is stated that:

> "When measured about against gross domestic product (GDP) --for which OECD countries account for only 62 percent-- another characteristic of expenditures in science and technology emerges: they are more concentrated that economic activities in general."

For a detailed analysis of international statistics on science and technology expenditures see: Jan Annderstedt, "Measuring Science, Technology and Innovation," in Jean-Jacques Salomon, *et. al.*, *op. cit.*, pp. 96-125.

[42] T. G. Whiston, *Global Perspective 2010-- Tasks for Science and Technology*. A report to the Commission of the European Communities' Forecasting and Assessment in Science and Technology (FAST) Programme. August 1992. p. ii.

[43] UNESCO, *World Science Report 1996*. UNESCO Publishing, 1996. p. 13

industrializing countries of East Asia; and the rest mostly in the developing regions. In terms of absolute numbers, there were in 1994 approximately 949,300 scientists and engineers in the United States and 740,900 in the European Union, compared to, at least, 391,000 in China and 106,000 in India. Nevertheless, when one looks at the relative number of research and development scientists and engineers in the population, a gap is once again evident: there are 3.7 per thousand population in the US and 4.1 in Japan, but only 0.3 in China and 0.1 in India. [44]

Furthermore, the fragility and vulnerability of most research and development organizations in poor countries, which face the constant threat of losing their best people to institutions and firms in more advanced economies, makes it difficult to consolidate and sustain the growth of the scientific and technological activities.[45]

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. Nearly 80 percent of world scientific output is produced by nine highly industrialized countries and India, the OECD countries and Eastern Europe contribute 94 percent of the indexed scientific literature, and measures of inequality between countries are more pronounced in scientific publications than in income, population or land. Similar degrees of concentration are found in patent indicators: over 96 percent of patents are registered by the United States, the countries of Western Europe and Japan.[46]

These imbalances, which have been sustained for many decades, have prompted calls to use the scientific and technological potential of rich countries to address the problems of the poor regions of the world. The 1970 "World Plan of Action on Science and Technology for Development," prepared by the United Nations Advisory Committee on Science and Technology (ACAST), suggested that 5 percent of research and development expenditures in rich countries should be focused on the problems of poor nations, a request that was repeated in many international gatherings in subsequent years. However, with the notable exception of a few fields such as health care, the mobilization of developed country scientists to deal with problems found mainly in the developing world has not been very successful.[47] In this sense, the need for local capabilities to deal with local problems is now more widely recognized, as "... the current stock of knowledge in industrialised countries has very largely evolved to meet

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[44] *Ibid*. p. 14

[45] See: Carnegie Commission on Science, Technology and Government, *Partnerships for Global Development: The Clearing Horizon*, New York, Carnegie Corporation, 1992; UNESCO, *World Science Report, 1993*, Paris, 1993; Jan Annerstedt, *op.cit.*; and Jacques Gaillard, "The Behaviour of Scientists and Scientific Communities," in Jean-Jacques Salomon, *et. al.*, *op. cit.*

[46] See: Jan Annerstedt, *op.cit.*; and Wesley Shrum and Yehouda Shenhav, "Science and Technology in Less Developed Countries," in S. Vasanoff, *et.al.*, *Handbook of Science and Technology Studies*, Newbury Park, Sage Publishers, 1995, pp. 633-635; and UNESCO, *op. cit.*

[47] A report of the Carnegie Commission on Science, Technology and Development, *Partnerships for Global Development: The Clearing Horizon*, New York, Carnegie Corporation, 1992, contains many useful suggestions for revitalizing international cooperation in science and technology, and for directing the capacity to generate knowledge of the United States towards the problems of poor countries.

the needs and values of these countries, particularly those needs that are backed by purchasing power." [48]

International initiatives specifically aimed at fostering the formation of endogenous scientific and technological capabilities in developing countries have not yet been truly effective. The United Nations General Assembly adopted the Vienna Program of Action on Science and Technology for Development in 1980. In addition to providing guidelines for the creation of endogenous science and technology capabilities in developing countries, the Vienna Program also aimed at restructuring international science and technology relations, at the improvement of the effectiveness of UN institutions in this area, and actually suggested mechanisms to provide financial resources for international cooperation in science and technology.[49]

Although it was considered a landmark in development cooperation for science and technology, the Vienna Program's recommendations were not realized in the subsequent decade. The "Goa Report," published by the United Nations on the tenth anniversary of the Vienna Program, did not find substantial progress in the previous decade:

> "The essence and implications of creating an endogenous or local capacity ... have continued to elude many countries and hence have not been sufficiently addressed in the mainstream of policy making, of planning or of execution of strategies for overall socio-economic development." [50]

All of this suggests that the science and technology capabilities of most developing countries are far too limited to deal adequately with the challenges of economic advance, social progress and environmental sustainability.[51] With the exception of a few large countries (India, China, Brazil, Mexico) and some newly industrializing countries (South Korea, Singapore, Taiwan, Malaysia) that have built a significant base of scientific and technological activities, low and middle income countries do not have the capabilities to generate knowledge, or to effectively select, absorb, adapt and use imported knowledge.

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[48] Andrew Barnett, *op. cit*. p. 7.

[49] See: United Nations Conference on Science and Technology for Development, "The Vienna Programme of Action on Science and Technology for Development." United Nations, 1979. In its preamble, this report states that:

> "The necessary resources and technological potentials exist for eliminating the under-development of the developing countries and for improving the well-being of humanity as a whole. The achievement of this goal presupposes that developing countries exercise full control over their own resources. It also presupposes an equitable distribution and creation of scientific and technological capabilities of the world."

[50] United Nations Advisory Committee on Science and Technology for Development, "A report on the occasion of the Tenth Anniversary of the adoption of the Vienna Program of Action." UNACSTD, 1989.

[51] Professor Abdus Salam, one of the few developing country Nobel prize winners, speaks of "the subcritical size of science and technology in the South," when arguing for a more equitable distribution of the world scientific and technological effort. See: Abdus Salam, *Notes on Science, Technology and Science Education in the Development of the South*, Trieste, Third World Academy of Sciences, 1989.

Mobilizing knowledge to meet development challenges

Social Development. *Some issues to address:*

- Beyond the traditional poverty-alleviation strategies to address basic needs problem: A local basic-needs approach calls for a greater emphasis on domestic technological management, a greater absorptive capacity among the poor for the benefits of S&T, and a wider spread of the fruits of growth through descentralized production and consumption planning, as well as popular participation.
- Address marginalization / exclusion: To achieve the goal of technology for basic needs, a fundamental condition is the fashioning of avenues, bridges, or linkages through which poor populations can breach the expanding knowledge and technology gap that perpetuates their economic, political, and sociocultural marginalization.
- Focus must be squarely on human beings: Technology and knowledge are important insofar as they relate to human beings and only to the extent that they are deployed and manipulated for the betterment of the human conditions and further sustainable human development.
- Issue of attitudes: The battle concerning attitudes entails moving from passivity, a sense of inferiority, and a feeling of helplessness to active participation, with confidence based on collective and individual achievements. These and perhaps other matters of value will interact powerfully with access to and deployment of S&T for the alleviation of poverty
- Three technology-related approaches to solving basic-needs shortfalls: (1) emphasis in the informal sector as experience indicates that a substantial number of micro and small scale enterprises could undertake technical innovations; (2) emphasis on alternative levels of technological sophistication: appropriate technology and technology blends; (3) technological pragmatism.
    - Informal Sector: The capacity of the informal sector to absorb the rapidly growing urban labour force and generate income to enable the urban poor to satisfy their basic needs, its application of technologies appropriate to local factors; and its role as producer and supplier of basic goods and services at prices affordable to the poorer sections of the populations; renders the informal sector one of the most important components of any basic-needs strategy.
    - Alternative technologies: Use of appropriate technologies and technology blending. Appropriate technology has the following attributes: labour intensive, its productivity is on a smaller scale, more ecologically friendly, requires less demanding worker and managerial skills, uses more local inputs, requires a lower investment per job created) for combating extreme poverty. High impact appropriate technologies include systems for delivering micro loans, bamboo tube wells in Southern Asia, and improved cook stoves in China. Technology blending entails the constructive integration of emerging technology[52] into low-income, small-scale economic activities in developing countries, with the important proviso that, as the word blending implies, the introduction of the emerging technology should blend with and

[52] Emerging technologies are relatively new technologies and primarily science driven.

preserve at least some of the prevailing traditional production techniques. Current technology-blending efforts include the application of microelectric innovations in traditional small-scale manufacturing in Latin America, "bio-village" and "information-village" projects in India, a variety of projects being implemented in Malaysia, and other development of artificial intelligence software suitable for solving problems in developing countries.
    - Technology pragmatism: refers to the search for the best technological means to satisfy basic needs given the prevailing set of constraints and opportunities inherent in each situation. The application of conventional and emerging technologies can, under the proper conditions provide the goods and services to satisfy basic needs: advanced technologies were involved in developing oral rehydration salts; sophisticated computer techniques were used to develop wind-powered generators for developing countries and to get the correct degree of porosity for small dams in India
- The effort to tackle basic needs fulfilment rests on a sound S&T policy foundation which should be based on the following pillars: education, access to information, participation, health, basic infrastructure, and small-scale economic activities.
    - Education: intended to enable the poor to gain access to and understand technology. The following objectives are suggested: (i) education about ways to increase production and productivity of small-scale economic activities; (ii) education enabling the poor to participate effectively and constructively in community life; (iii) education enabling the poor to practice policies and programs of preventive medicine, indispensable for improving levels of health and nutrition; and (iv) education of the poor that gives impetus to a process of sustainable development, to preserve and protect the environment.
    - Access to information: Students and teachers on low-income communities, striving to keep abreast of the changing economic, political, social, and technical configurations affecting their lives, require access to information. Information is basic to participatory action and movements to enterprises that need to know how to apply for credit or to learn about possibilities for product diversification, market conditions for their products, availability of inputs, transportation alternatives, and alternative techniques of production. The S&T community can be of great value in consultations with targeted groups to identify and facilitate access to such information. The information should be structured and made intelligible to poor populations, and the flow of information should not be unidirectional.
    - Participation: When poor populations are introduced to technologies, the chances for successful outcomes are improved markedly if the prospective users are directly involved in selecting adequate technologies, properly adapting them to prevailing economic activities and conditions, disseminating the technologies among themselves, and mastering and improving on them. Agents responsible for upgrading technologies and skills in poor communities should build a strong participatory dimension into such programs. Participation in a more generalized sense could have equally important beneficial effects on

innovativeness, incentive to risk experiments with new technologies, and ability to recognize opportunities.
    - Health: Countres should be encouraged to give greater emphasis to preventive medicine and less to curative health measures. Work in the field of sanitation and waste management is proving critical for the through its promotion of technologies affordable to low-income communities, as promoting technology in vaccines and diagnostics. In addition, Countries should review the geographic configuration and gender equity of their health programs to determine whether the investment brings optimal social returns and meets basic needs.
    - Basic physical infrastructure: is needed to support the other pillars of the bridge leading from poverty to prosperity. It provides an environment in which innovative behavior van be meaningful and facilitates the necessary inputs and the marketing of products. Because work on such basic infrastructure is often construction intensive, every effort should be made to mobilize local resources and provide income-generating employment.
    - Small-scale economic activities: will for the foreseeable future, be the primary source of employment and income for poor populations. As such they are one of the critical pillars of the bridge between unmet basic needs and prosperity. The State, international and non-government organizations should work to provide micro-credit, technical assistance to low-income entrepreneurs. In the long-run the S&T community should be encouraged to take the initiative in linking (in a participatory fashion) its technologies and smaller scale entrepreneurs.
- Support stakeholders dialogue (dialogue between people who make decisions about S&T and development, who generate or use technology, or who are involved in education, training, financial support for S&T aid, and so on). The results of these dialogues should be supported by diagnostic studies to elucidate S&T needs, options, and priorities, and should provide the raw materials for a portfolio of initiatives for strengthening endogenous capacity in S&T needs, options, and priorities

Information Poverty. Closely linked to a nation or society's scientific and technological capabilities and to the issue of scientific literacy, is its people's ability to access and effectively utilize the rapidly growing flow of information. Despite the ongoing knowledge explosion, however, entire nations and millions of individuals, particularly in the developing world, are ill-equipped to be part of an emerging global "information society" due to factors such as inadequate education, social and political exclusion, and sheer lack of financial resources.

It should be noted that access to and utilization of information are increasingly linked to areas that have an impact on living conditions. Beyond the issue of building an endogenous science and technology base, access to information is now crucial to financial and commercial success, for instance, especially in the context of globalized markets, financial interdependence, and the rapid advances in information and communications technology.

At the social and political level, increased access to information is also linked to the weakening of repressive regimes, the consolidation of democracy, and to improved governance through the participation of civil society. [53] In analyzing international politics, too, one can see that "knowledge, more than ever, is power." As Joseph Nye and William Owens have noted, in the context of the information revolution the most powerful country will tend to be the one which has a comparative advantage in "its ability to collect, process, act upon, and disseminate information." [54]

The contrasts in access to information worldwide are striking, even at a relatively unsophisticated level. For example, in 1992, daily newspaper circulation in Japan amounted to 577 per 1000 inhabitants; in Bangladesh, the number was 6, and in Burkina Faso it was barely 0.3. There were only 27 radio receivers for every 1000 Tanzanians and 80 for every 1000 Indians, but 992 for every 1000 Canadians.[55]

Advances in information technology, and a rapidly growing number of homes with personal computers and access to the "information highway," may in fact be widening the knowledge gap between those that can afford to access these and those who cannot. This is true of both ordinary individuals and business enterprises. Furthermore, the reality of interaction within computer-generated environments like Internet, with all its proclaimed potentialities, is available to an increasing number of people but is certainly out of reach for an even larger number.

A noticeable gap between rich and poor nations undoubtedly exists in access to modern information technology. Worldwide, there were 338 million computers in use in 1997, but while in the United States there were nearly 400 computers for every 1000 people, in India the figure was only around 1.1. By the year 2000, there will be around 580 computers per 1000 people in the United States while the world average will be 90.[56] Overall, there were 18.7 personal computers per 100 inhabitants in northern countries and only 0.7 in the South in 1996. Of course, the expansion of information technology will not be uniform: the government of China expects such growth that 1 in 10 homes will have a personal computer by the year 2000.

The prospects for greater access to the Internet computer network, with all its commercial, political, and educational potential, also vary widely. Besides the diversity of regulatory environments and availability of personal computers, telephone lines are not equally available everywhere: there are 52.3 telephone lines per 100 inhabitants in the northern countries and only 5.2 in southern countries.[57] It is interesting to note that, most intriguingly, the breakthroughs in computer and telecommunications technology

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[53] See Marc Nerfin, "Neither Prince nor Merchant: Citizen." *Development Dialogue,* 1987:1. pp. 170-195. Nerfin believes that civil society, at a global level, should be an engine for development and improved governance and that, in order to fulfill this role, it should take full advantage of emerging information technologies that allow increased networking of citizen associations.

[54] Joseph S. Nye, Jr. and William A. Owens, "America's Information Edge." *Foreign Affairs*, March/April 1996. (p. 20)

[55] United Nations, *United Nations Statistical Yearbook 1994*. New York, 1996. p. 101-122

[56] Edward Mozley Roche, "Computer Industry Almanac: Data on Computer Usage." *Information Technology in Developing Countries*, vol. 7, No. 1, January 1997. p. 6.

[57] *Ibid.* p. 8.

may be opening the doors for some to a completely new environment for human involvement, a “virtual reality” with a degree of independence from the physical world.[58]

Environmental protection

Productivity and Governance

Institutional, social and cultural innovations to build endogenous science and technology capabilities.

Strategies and policies to bridge the knowledge divide

At the national level

- Shift in public policies to foster technological innovation: In recent years there has been a gradual evolution from policies where the State was the principal actor towards one where the State acts as facilitator of initiatives coming from the private sector, academic and research institutions, which provide technical services to the productive sector. This evolution has also been evident in the construction of innovation systems for the provision of social services, where the State has given ample room to a wide range of civil society organizations, academic centers, entities linked to local governments, and private firms. The following are several policy instruments available to countries:
    - Creation of “technological parks” by the central and regional, and municipal governments. These parks would count with the adequate physical infrastructure (transportation, energy and telecommunication) and technological support services, and would serve as nucleos around which innovations systems are articulated.
    - Creation of “technological business incubators” by the universities and other academic institutions, oriented towards specific sectors and capable of providing services and support to entrepreneurs interested in exploring new business venues. These incubators would provide technical, business and technological management assistance.

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[58] The rapid innovations in, and increasing pervasiveness of, computer technology have brought along the singular notion of *cyberspace*. The term was first introduced by the author William Gibson in the early 1980s to refer to a “total electronic environment in which people can interact with data.”(cited by Michael Heim) Philosopher Michael Heim has described cyberspace as:

> “The juncture of digital information and human perception, the “matrix” of civilization where banks exchange money (credit) and information seekers navigate layers of data stored and represented in virtual space” (Michael Heim, *The Metaphysics of Virtual Reality*. Oxford University Press, 1993. p.150)

Cyberspace emerges as a challenge to the dualistic (mind and matter) conception of reality that has prevailed in the West since Descartes. Potential effects of cyberspace interaction on areas as varied as business, politics, and even human sexuality have been hypothesized. Indeed, high expectations have certainly been placed on this new medium; however, the negative aspects of “virtual reality” environments have already been pointed out by some. (See Mark Slouka, *War of the Worlds: Cyberspace and the High Tech Assault on Reality*. Basic Books, 1995)

- Promotion of clusters and networks of medium and small enterprises in specific sectors and localities, specialising in specific aspects of productive services, which exchange products and services in a very intensive manner, and share a series of supporting services to achieve greater collective and individual eficiency.
- Promotion of linkages between national firms and transnational firms that would purchase local products to make them available in global markets, as these buyers frequently provide technical and financial assistance, help in the design of products and in quality control, as well as provide marketing management assistance.
- Promotion of strategic alliances between national enterprises in key sectors for the transformation of national resources, principally those linked to productive forward and backward linkages to create entrepreneural nucleus able to compete in the global market.
- Establishment of risk capital funds and financial mechanisms to facilitate financing of technological innovation, generally through private banks and with the aid of state agencies and international financial organizations.
- Creation and promotion of capacity-building and professional training specialized for the productive social priority sectors, as well as Master-level programs in business administration and innovation management.
- Promotion of quality control and the use of international technical norms and standards so as to guarantee appropriateness of national products and their acceptance in international markets. These include environmental norms, which are acquiring importance with commercial globalization trends.
- Measures to facilitate the import of technology and its adaptation and absorption by firms and priority sectors. In particular, it is necessary to eliminate bottlenecks to the import of equipment and programs linked to information technologies and telecommunication.
- Measures to protect intellectual property, with the double objective of stimulating the import of technologies and protect local generated technological knowledge, in particular to the use of natural resources and biodiversity.

These policy instruments indicate a wide range of possibilities for promoting the creation of innovation systems and makes evident the central role the State plays in creating a favorable environment that would facilitate technological innovation.

- Technology Innovation Systems: capable of articulating a set of institutions and organizations which contribute to the development and dissemination of new technologies. The design and execution of public policies for technological innovation should be oriented towards promoting the convergence of initiatives of economic, political and social agents involved in the creation, import, adaptation and absorption of knowledge, as well as in the provision of services, capacities and resources associated in the processes of technological innovation.

At the international level

PERSPECTIVES FOR THE FUTURE