SCIENCE & TECHNOLOGY IN THE NEW WORLD ORDER[1]

Georges Ferné
Organization for Economic Cooperation and Development (OECD), Paris

Summary

---

[1] Paper prepared for a science policy study carried on by the Escola de Administração de Empresas, Fundação Getúlio Vargas for the Brazilian Ministry of Science and Technology and the World Bank, within the PADCT II agreement. The opinions expressed in this text are the sole responsibility of its author. November, 1993

Three major forces operate to define the main characteristics of post-industrial societies:

-- the new technological dimension of all economic and social processes, stemming as much from the increasingly effective mobilisation of Research and Development (R&D) resources as, more generally, from the improved capacity of society to exploit opportunities generated by new knowledge.

-- the cascade of problems and demands resulting from past economic and technological accomplishments, that require decisions while increasing uncertainty about the future implications of choices.

-- the rapid transition to a global economic system characterised by new forms of interdependence.

Although these three forces define the general features of "modernity" and represent a major break from the past, they are deeply rooted in a long history of changes in the scientific and technological systems. Recent historical milestones in this process include the industrial revolution of the XIXth century, the two World Wars, the Cold War and the energy crisis, but the chain of events extends far back to the dawn of human history and the initial relations between man and technique: the age-old movement that produced modern technology led to a marriage of knowledge and action bringing together the scientific and economic worlds - to the extent that any technological advance can now be simultaneously viewed as an investment and the generation of new knowledge. It is this unprecedented combination that defines technology (the deliberate mobilisation of knowledge) as something different from "technique" (the fruit of experience or, according to Braudel, the "taming" of man by man)[2].

The change was enormous, as evidenced by the difficulty of expressing it with the available words:

> "Technology is a word which is taken for granted in English -- all the more since 'technique' refers to something quite different, skills or methods. On the Continent, in French, German or the Slavic languages, la 'technologie' seems redundant beside la 'technique' which covers all activities associated with things technical; 'technologie' is much more specialised and refers to more advanced stages of 'technique'. English

[2] Fernand BRAUDEL (1986), *Civilisation matérielle, Economie et Capitalisme*, Tome 1, p. 291, Armand Colin, Paris .

has no real equivalent of 'technique' and uses 'technology' to cover what on the Continent would be both 'technique' and 'technologie'... Recently English has been forced to recognise the inadequacy of its vocabulary: the terms 'high technology' or 'technology-intensive' products began to appear in the economic literature in the late 1960s in relation to the analysis of the basis of comparative advantage in international trade by advanced economies; a 'high technology' or 'technology intensive' industry is one which has 'above average' levels in R&D expenditure and in the employment of scientific and technical manpower Thus, English has coined a new label to describe the most advanced category of technologies, as opposed to those which are produced by the so-called 'mature industries"[3].

This label, however, has become less and less significant in recent years, since "mature industries" have undergone massive changes and have often become highly R&D intensive, following a pattern of redeployment of innovation discussed below.

If "technology" thus differs from "technique", it is not in view of their respective objects -- since both tend to combine accumulated knowledge, effort, and the use of instruments -- , nor because of the peculiarities of some industrial branches that would be more "technological" than others, but because of its nature: the alliances established with science and with the industrial system in order to open the way for common undertakings[4].

These alliances have been made possible by a series of historical developments that can be summarised with three words:

- Institutionalisation of research, through the creation and diversification of a wide array of specialised organisations such as universities, public and industrial laboratories, technical centres, etc. These organisations provide scientists with an institutional "menu" so that each type of research can find its most appropriate setting.

- Professionalisation, because of the existence of career possibilities, so that scientists can reconcile research with personal interest, within the framework of the scientific "ethos".

- Industrial development, which has made it possible to establish dynamic sets of relations

[3] Jean-Jacques SALOMON (1984), What is Technology? The Issue of its Origins and Definitions, History and Technology, Vol. 1, pp. 113-156

[4] Ibid.

between research and the market.

Technological development and the improvement of production structures and processes are thus now intimately linked and dependent on each other. These interactions reflect the following formula, which illustrates the two challenges being met by technology: the challenge of applying new knowledge produced by scientific research, and the challenge of taking account of the economic constraints under which technique evolves.

Technology = Technique + Research

This is why it would be impossible to give an account of modern technology without referring to a whole archipelago of evolving ideas, practices and traditions as well as know-how that often are more implicit than explicit and cannot be easily brought to light by even the most detailed examination of the successive changes of technical objects throughout a given historical period. If the discussion of modern technology has long tended to focus mainly on R&D, it is because this hard core of technology-related activities is easier to identify, classify, describe and measure. Today's innovation policies are developed in most countries with broader technological horizons: employment and productivity, structural adaptation, industrial relations, flexibility of production processes, development of human resources, social selection of innovations, etc.[5].

Growing awareness of the complexities of the task does not necessarily mean, however, that national policies are better equipped, and better able, to deal with the difficulties of the day. The more so in view of the fact that it may no longer be realistic to seek national solutions to problems that may be universal.

---

[5]OECD (1988), New Technologies in the 1990's: A Socio-Economic Strategy.

PART ONE: SCIENCE FOR THE NATIONS

The history of the "marriage" of science and politics is too well-known to require extensive treatment here. It is sufficient to recall that the marriage was celebrated in wartime (with the Manhattan Project), thus establishing clearly the new nature of science as an instrument of power; that subsequent years were to witness an extension of the instrumentality of science and technology, to extend to the economic sphere; and that the capabilities for extensive exploitation of these new strategic opportunities were essentially concentrated in a relatively small number of rich Western countries.

The concentration of scientific resources

In opposition to the layman's view - and to the occasional claims of scientists - the world-wide research and development (R&D) effort is far from being a truly international one. Research capabilities are concentrated in a small number of countries. More than 90% of these capabilities (measured in terms of R&D expenditures) have always been concentrated in industrial countries.

Throughout the crucial period since World War II (which has witnessed the increasingly systematic harnessing of science and technology capabilities to serve strategic and economic goals), the small "club" of highly industrialised countries have kept their dominant position while strengthening their R&D capabilities. If changes have taken place, they are essentially due to the emergence of a handful of new members such as Japan, Brazil, India, and the "Dynamic Asian Economies". All these countries have significantly increased their research efforts during the period. One of them at least - Japan - has emerged as a technological leader world-wide and has challenged the pre-eminence of the "old" industrial powers.

It remains that, if one considers the relatively small number of countries scattered around the world that have both a full-scale S&T enterprise and the ability to take full advantage of it to serve political, economic and social objectives, R&D capacities remain a "local" phenomenon. This "local" phenomenon, however, has had and will continue to have, enormous global implications.

A "local" Phenomenon

The total of the world resources allocated to R&D (as measured by R&D expenditures) amounted to about US$435 billion in 1988. More than 96% were spent in industrialised countries, while all others (essentially the developing countries) merely accounted for the remaining 3.9% of global R&D finance.

This static picture does not pay justice to changes and fluctuations that have taken place in recent decades. Taken as a whole, the developing countries had achieved significant progress in this area until the early 1980s, where their combined R&D budgets reached almost 7% of the world total.

However, these efforts have not continued to expand but have been reduced as a result of major constraints, such as the debt crisis and overall economic difficulties. The select group of industrialised countries has thus demonstrated that its pre-eminence cannot easily be challenged, and that the long-term development of an effective S&T base will remain shaky as long as it is not supported by a modern and competitive industrial infrastructure.

Of all the members of this group, Japan and South Korea have been the most forceful in strengthening their R&D efforts. Their annual R&D budgets nearly trebled (in current US dollars) between 1973 and 1980. By 1980, these two countries in east Asia together accounted for considerably more than the whole Third World R&D spending. According to more recent statistics, their gross domestic spending on R&D in 1980 represented a tenth of the world funding of R&D in 1980, but had almost reached 20% of it eight years later.

The R&D expenditures of western European countries have grown almost as rapidly as those of Japan in the 1970s, and their share in the world total went up from 21.6% in 1973 to 24.2 in 1980. The average growth rate of many of the European countries remained high in the following years but has shown signs of slowing down It might be increasingly difficult for Western European countries to retain their strong international position

Countries of Eastern Europe and the CIS have steadily lost ground as big R&D spenders. In 1973 their gross national R&D expenditures were estimated (in fact, probably over-estimated) as representing a third of the global total, but only 27% in 1980 and less than 20% by the end of the 1980s. This decline will undoubtedly continue, at least for several years yet.

In relative terms, the North American region accounted for nearly a third of the world's R&D expenditures by the end of the 1980s. There had been a period or relative decline in the 1970s and the early 1980s, but there are clear indications that the new Democratic administration will assign a new priority to R&D efforts.

This overall picture underlines the fact that the strategic importance of S&T capabilities is now taken for granted in industrialised countries. It remains, however, that fluctuations over time reflect the difficulty with which political agenda with necessarily shorter-term horizons can accommodate the long-term requirements of R&D efforts. When resources are limited and budgets established on more stringent bases, these countries find it difficult to safeguard the broad continuity of efforts and, even more so, their renewal and diversification to explore new frontiers.

Science in the rest of the world

One striking lesson to be drawn from the developments of the last decades in this area, however, is that the R&D activities of the industrialised countries have grown far beyond the threshold below which their survival, or at least their influence world-wide, could be jeopardised. Whether their combined R&D activities amount to 93% rather than 97% of the world total will not fundamentally affect their capacities to exploit new S&T opportunities. By contrast, the rest of the world can be viewed as much more vulnerable in this respect: its share of the world total managed to reach a peak of 7% at the beginning of the 1980s, followed by drastic reduction. And here the difference - from 7 to less than 4% - entails major reductions in the national capacities to take advantage of S&T. The more so in view of available data relating to R&D personnel rather than expenditure, since non-industrialised countries were reported to employ, at the end of the 1980s, 18 to 19% of the world's researchers (scientists and engineers engaged in R&D). This is a much larger share than for R&D expenditure, and it shows how thinly R&D resources are spread. Any reduction in funding probably means that the average scientist in these countries will be confronted with a situation where he (or she) can no longer work effectively as a researcher.

This discussion of average aggregate statistics should not, however, ignore the fact that the non-industrialised world is not homogeneous in terms of access to R&D resources. Some efforts have been made to develop a science and technology-related typology that would bring to light the various levels of S&T bases, reflecting several parameters such as the economically active population; the relative importance of education in science and technology; the sectoral distribution of specialised manpower in relation to science and technology; and the size and structure of the domestic product (GDP) including the share of R&D[6].

It has thus become possible to tentatively identify countries (A) with no science and technology base, (B) with fundamental elements of a science and technology base, (C) with a science and technology base well established, and (D) with an economically effective science and technology base, notably in relation to industry. The last grouping (D) refers to the highly industrialised countries, while the three others relate to the developing world.

(A) The first grouping of developing countries numbers about 55, including most

[6] see: International Council for Science Policy Studies (ICSPS), Science and Technology in Developing Countries, pp. 55-77, UNESCO, 1992

African countries. These are countries with no science and technology base, which still are at the initial stage of development, with low GDP per capita, low science and technology manpower potential, and a low share of manufacturing of total production.

(B) The second grouping of countries, which have the essential elements of a science and technology base, are in the process of industrialisation. With moderate GDP per capita, they have developed a limited endogenous industrial production. Some of them may have a relatively high percentage of science and technology manpower that could be involved in R&D, but the potential is low in absolute terms. This second group represents nearly 40 developing countries and includes Algeria, Ghana, Indonesia, Iraq, Malaysia, Paraguay and Sri Lanka.

(C) The third group of countries, with a high percentage of potential science and technology manpower, have a solid science and technology base and a functioning industrial system. Their GDP per capita is relatively high. This grouping covers about 40 developing countries, including the "newly industrialising countries" (the NICs) in Asia and some Latin American countries such as Argentina, Brazil, Mexico and Venezuela.

Two developing countries are difficult to fit into any of the above categories or groupings of countries. China and India have to be treated separately: they both have a low GDP per capita; at the same time, due their size, they have a huge science and technology manpower potential in absolute terms, but low as a percentage of total population or in relation to the economy. However, manufacturing represents a large share of their total production.

This typology of countries based on S&T capabilities underlines the fact that the heterogeneity of the developing world. Most of its R&D effort (nearly two-thirds in terms of expenditures) was implemented by countries in Asia in 1980, particularly by those with relatively large R&D systems such as China and India, but also by Indonesia, Taiwan and Thailand. Other countries with small or medium-sized R&D systems, e.g., Pakistan and Malaysia, have also expanded their R&D activities to some extent. By 1988, it was estimated that 75% of the resources allocated to R&D in the developing world were spent by east and south-east Asian countries. Today, more than 60% developing country researchers are Asians. Africa, and to a lesser extent Latin America, have lost some of the ground they had previously gained. The countries with the largest R&D systems, e.g. Brazil, Argentina and Mexico, had managed to retain relatively high rates of expansion even when confronted with severe fiscal problems. But it is increasingly difficult for them to keep up with the pace set by the leading Asian countries.

The growing market-orientation of Western science

This pattern of concentration of the world scientific resources in Western countries has a number of consequences for them (individually and as a whole), as well as for others.

Science as a national resource

Since World War II, the relationships between science and technology on the one hand, government and economic actors on the other, have been essentially characterised by the fact that they developed in national contexts to produce a unique set of integrated institutions and mechanisms designed to produce and exploit knowledge on an unprecedented scale.

The institutional chain draws its effectiveness from the continuity of activities and organisations involved: various types of laboratories (academic and industrial as well as governmental) that mobilise professional research-workers; systems of education, and in particular higher education, where research plays an essential role in the training of scientists and future managers; large public agencies specialising in the promotion of science as a public good, thus serving special collective interests that would not be sponsored by market forces alone (for example with respect to health or defence, or to basic research and generic technologies); and an extensive and highly diversified tissue of industries, ranging from small and medium-size firms to multinational corporations, each of which plays a role in the generation, diffusion and gradual adaptation of innovation.

The mechanisms include a broad array of funding instruments and incentives enabling public agencies to extend support to various types of R&D activities: individual grants, project and programme grants, contracts, fiscal privileges for R&D activities, provision of risk-capital, etc. They also include various procedures designed to encourage, for example, standardisation, conformance-testing and quality control, in particular in relation to public procurements. All these mechanisms taken together play a crucial part in fostering variety as well as coherence in the generation of new scientific and technological knowledge.

Another mechanisms that plays an essential role in the generation and diffusion of innovations is, of course, the market. Its signals and its rewards, and the ways in which is modulates the prices of various factors, will directly determine the extent to which incentives operate that encourage entrepreneurship and risk-taking. The ways in which various industrialised countries have developed systems that can balance the market requirements and broader political, strategic and social considerations will differ. All of them, however, have singled out domestic, and to varying extent international, competition as a major source of future growth. In the process, the market has become much more than an economic mechanism, to become embedded in the ways in which a national culture will develop its own approaches to risk-taking and innovation.

This cultural dimension adds to the difficulty of emulating the successes of the more advanced countries: the collapse of the Eastern Block in Europe, and the subsequent difficulties in its transition to a new economic system, underline the magnitude of obstacles to be overcome. These obstacles become all the more formidable when cultural misunderstandings are coupled with major structural deficiencies. Lack of resources, low levels of skills, few training opportunities, inappropriate curricula in higher education, weak technology supporting institutions, etc. may prevent many countries from taking full advantage of their stock of S&T resources.

By the end of the XXth century, only a small number of countries have thus been able to create and maintain comparatively strong national S&T capabilities, in terms of research potential and an effective system for the exploitation of research results[7]. Most other countries do not possess the broad range of resources, instruments and abilities that are needed to take part in the international race for innovation. They have to follow other approaches to draw some benefits from available knowledge and improve the way they utilise and further develop their productive potential.

Most of these countries must thus seek to copy, imitate or simply import incremental technical change. Technical advances in products and manufacturing processes thus depend in general on ideas, capital and consumer goods, services, production methods and know-how, patents and licences originating from abroad.

If the ability to take full advantage of the opportunities generated by scientific and technological progress is thus restricted to a small number of countries, the ways in which these countries (the "Triad" of Western Europe, North-America and the Asian Pacific Rim countries).choose to organise and orient their S&T efforts thus have world-wide impacts. The rest of the world must adjust to them (in terms of organisation, priorities, applications, etc.). These activities have become the core of the modern "ecology" of technological progress.

It is no wonder that these achievements are usually seen from outside as a formidable monolith of technological power, so formidable that it is difficult to see how it could be emulated, or how alternative strategies could be developed. The accomplishments are undeniable. There are, however, many weaknesses, and not all industrial countries are equally well-equipped to meet the challenges of the emerging world economy.

The weight of the past

[7] For a discussion of the notion of the "system of exploitation of research results", see: OECD, Major R&D Programmes for Information Technology, Paris, 1989

The history of the progressive embedding of S&T into the production and social processes of industrial countries is, as noted in the introduction, an old one. As a result, the S&T systems that operate to-day can be compared to geological landscapes whose structure includes a number of heterogeneous strata. Furthermore, today's industrialised countries have not followed the same historical paths, and have pursued different objectives. The similarities and differences will affect the ability of each country to meet present and future challenges.

Some of the major landmarks that have designed these S&T, systems as we know them to-day, are:

i) The chronology of industrialisation and the related nature of infrastructures, with each country following a particular path as a leader or a follower in this or that field..

ii) The ways in which pre-World War II science has emerged as a profession centred in the universities (USA) or outside universities (France)

iii) The impacts of World War II in terms of destructions (Western Europe, Japan) or of investments (USA).

iv) The importance of national strategic objectives assigned to S&T activities, that have led to the development of major military R&D establishments in certain countries, as diverse as the USA, France, United Kingdom or Sweden.

v) The importance of the role traditionally assigned to the State as an economic actor, leading to important differences in the relative weight of the government research sector and the statutes of research-workers, as well as in the structure and importance of "national programmes" in S&T.

vi) The degree of internationalisation of the national economies, that has determined the range and degrees of the international outlook of scientific communities and industry, and may have in particular been shaped in the past by the opportunities offered by the vast colonial empires of certain countries.

vii) The nature and the evolution of the national consensus about the scope of social concerns to be taken into account by government, as illustrated by the very large social dimension assigned to technological policies, for example, in Scandinavian countries.

All these features are blended in different ways in different countries, so that each has developed its own specific approaches in embedding science and technology in the economy and society. Some of these features - for example, early industrialisation coupled with the opportunities offered by colonial possessions and strategic priority assigned to military technologies - may have been a major asset in attaining world leadership in the past, only to become a handicap more recently. This is due to the new trends in technological developments that underpin international trade.

The post-Second World War era has been largely characterised by major advances in technology whose development and applications required enormous investments over a long period of time, as has been the case for example with nuclear energy (in both the military and civilian spheres), space and aeronautics, the major wave of innovation in railroads, new mass production processes, and even sectors such as health if one takes into account the massive research programmes and the costs of making effective use of preventive techniques and medication. Central management of technological programmes was an asset in such a context, allowing governments to work hand in hand with large corporations to sponsor the long-term efforts then required, in terms of R&D, institutional innovation, creation of human resources, etc.

These efforts could take place in an institutional and economic setting inherited from the past that could readily meet new challenges and adapt to the new opportunities.

A new era started in the mid-70s with the economic recession following the rapid increase in the costs of oil and other raw materials, at a time when new industrialising countries, in particular in Asia, appeared on the world scene as major challengers to the "old" industrial countries in their traditional economic strongholds, in sectors such as textile, steel, shipbuilding, automobile, etc. It very quickly became evident that Europe and North America could no longer take their economic pre-eminence for granted in any area, but must found new competitive advantages on their innovative capabilities[8]. The ability to stay ahead of competitors, with ever more effective production processes and a growing range of better products had become the driving force in international trade. This new market-orientation assigned to technology implied that the factors of success were linked to the ability to exploit research results rapidly, adjust quickly to market changes and demand shifts, and shorten the lag between the emergence of new ideas and their application. The ability to mobilise large cohorts of scientists and engineers under the umbrella of national programmes, in highly centralised institutions, was no longer a condition of success. Just the opposite, in many cases: as in the theatre, cumbersome processes and machinery slow down the action...

Countries such as Germany and Japan, that had not acquired major government-sponsored technological establishments, emerged rapidly as the new champions of world trade. Corporations that were managed according to dogmatic principles, had been excessively centralised, discouraged local initiative and felt secure with their market shares -

---

[8] OECD, <u>Technical Change and Economic Policy,</u> Paris, 1980.

from Westinghouse to IBM - were confronted with major difficulties. Others flourished.

The 1980s became a period of major structural change. Monopolies were challenged, either by the market forces at work, or by government decisions to divest, deregulate and decentralise. Attempts were made to re-orient large technological programmes that were ill-adapted to cope with the new requirements.

In the United States, for example, the Department of Defence set up a number of projects and new bodies to respond to the Japanese challenge of the "Fifth Generation Computer Programme", as did the French with the "Filière électronique" or the British with the "Alvey Programme". These attempts met, at best, with mixed results. When they were launched under a defence umbrella, such programmes could not be exploited on the civilian market as quickly and as effectively as might be needed. In other cases, the technological results of these government-sponsored programmes were not sufficient to generate new industries.

In fact, these programmes came to be criticised not only for their inefficiency in the promotion of commercial innovation, but also in view of the fact that their very existence drove the overall costs of research upwards: such programmes, for example, generated a demand for skilled researchers that had a direct impact on the labour market and the salaries of scientists and engineers. Government programmes could thus be seen as indirectly creating disincentives for firms to undertake R&D activities.

It became rapidly clear that the firm - and not the government - had to be recognised as the main actor on the innovation stage, but that the industrial tissue of the "old" industrial countries often did not provide sound bases for the entrepreneurship needed on the new technological frontier. The government was not in a position to identify markets and promote commercial applications, but would often find itself confronted with gaps in the industrial issue - and the lack of front-rank industrial actors to take up the task.

The major task of public authorities was then to shift to the creation of a general framework of economic conditions, institutions, laws, incentives and basic structural conditions (such as the provision of adequately trained manpower) that would create a favourable environment for industrial adaptation and change. However, the heritage of the past - in terms of attitudes, structures and commitments - could not be dismissed so easily and would probably plague countries for years, if not decades.

The decisive change is that leadership in technological accomplishments does no longer suffice - and may even be self-defeating when pursued as an objective in itself. New economic and commercial rules prevail, which assign a decisive importance to the ability to identify, organise and exploit new knowledge and know-how, wherever it comes from.

Scientific knowledge and technological know-how thus become commodities, and success in processing them will often result from the ability to comprehend or imagine all the dimensions of their potential relevance for diverse branches and sectors. Commercial breakthroughs are thus often generated by the recognition of new combinations of technological functions that had not been anticipated (as was the case with Sony's walkman, or with most applications of laser technology), rather than as a product of a well-structured programme covering all stages, from research to application. This type of innovation stems from creative insights, unrelated to research as such, that are not well understood.

The overriding market logic

When drastically new economic conditions emerged in the mid 1970s, such as the rising price of energy, and new competitors from the developing areas, the industrial world sought to formulate a response based on its innovative capabilities. What was not clearly seen at the time was that the new "high technologies" (in particular the information and communications technologies) were going to have such a major impact on the world markets and accelerate a globalisation process that will be discussed below. Another major change overlooked at the time was that market forces would increasingly become instrumental in shaping future progress in the most strategic fields where technological expectations were the highest. As a result, the margins of choice of countries could not but be reduced in considerable proportions.

The logic of the market could not easily be reconciled with other requirements, in the political, social, environmental or cultural spheres. The process of gaining new competitive advantages in terms of economic effectiveness entailed giving up in other areas. The leading countries, such as Japan, and the large multinational corporations active world-wide set standards in terms of innovation rates and productivity that could not be ignored. To meet their challenge meant structural change and reduction of public interventions in the economy, slimming down of the work force with the introduction of more effective production processes, concentration of efforts towards the most promising or vulnerable areas, etc. The results of these single-minded efforts were to become gradually more and more apparent, with steadily increasing unemployment; impoverishment of the State, that could no longer be taken for granted as a source of support for public goods and long-term efforts; or the reluctant but unavoidable trend towards interdependence of the national economies. The economic recession of the early 1990s was to bring all these structural problems to the forefront, because they had by then become major political issues.

The process is still under way, and its consequences for the industrial societies are not clear, although it has become obvious that the very fabric of these societies is threatened, for example, by the rising tide of unemployment, the difficulty of meeting national commitments in public services such as education, health, relief, etc., the dislocation of the rural communities, and the degradation of the urban environments.

At the same time, however, the challenges and opportunities generated by high technologies become ever more pressing. New materials and biotechnologies have already had enormous impacts, and hold the promises of many more to come. However, it increasingly seems that the full exploitation and management of these breakthroughs, as well as, more generally, the future bases of the economy, will be primarily shaped by information technologies.

A little less than five decades ago, it was universally taken for granted that the world had entered a new technological era - the atomic age - that would characterise the second half of this XXth century. And, indeed, nuclear energy has had, for better and for worse, an enormous impact that cannot be underestimated. However, as the end of the second millennium approaches, another technology comes to the fore, with ever more general and far-ranging effects, to the extent that many would define the present era as the dawn of the information age.

Information technology (IT) is traditionally defined as the convergence of electronics, computing and telecommunications. However, data processing capabilities are growing and spreading at such rates that many other technologies can be viewed as having reached a new stage, where they depend on the treatment of information rather than on physical manipulations. This is the case, for example, with new materials or biotechnologies. Furthermore, a growing variety of more and more powerful sensors will probably accelerate this trend. IT thus, provides new instrumentalities, that make it possible to replace old processes with more effective ones, and to develop entirely new functions and modes of production.

It is indeed astonishing how rapidly the new technology has taken roots and how pervasive its influence has been. This change of emphasis in our view of the contemporary scene has taken place fairly recently. Most certainly, this new awareness is related to the wide-ranging impacts of the new information systems, based on a world-wide telecommunications infrastructure that has come to be characterised as "the largest machine in the world". Recent years have witnessed, for example, the establishment of specific networks for essential services such as banking, financial markets, airlines or data banks to operate in real time. Unprecedented possibilities for data gathering, processing, sharing and distribution have brought new dimensions of global management and flexibility to industry and services.

These technologies thus achieve their full potential only by forming networks, and have two particular characteristics[9] as a result - "increasing returns of adoption" and "network externalities" - that are intimately related to their interplay with market forces.

The increasing returns of adoption are an outcome of cost structure (heavy investment, moderate operating costs) and the nature of the information technology networks themselves. As opposed to most technological systems of the past (where both the initial investment and the operating costs were very high, as in the case of railroads or energy production and distribution), once a base system is installed (for example telephone lines), it is usually fairly cheap to connect a new subscriber into the network. But the more subscribers there are, the more attractive the network becomes, as illustrated by the history of telephones and fax machines as well as data banks, etc. Technical improvements have enabled these systems to be connected with existing telephone networks. As a network expands, the cost of connecting new customers diminishes. Increasing returns also occur due to familiarisation - the expanding use of a network generates improvements and diversification of services.

Increasing returns can be related to another economic concept, that of externalities, or side-effects. A new subscription to a network entails advantages that are not limited to the subscriber, since all other users also benefit from the simple fact that the network is being expanded. And while these 'externalities' are helpful to both firms and individuals (each new subscriber increases the general usefulness of the telephone system), they also benefit the equipment and what it can do (adding fax facilities, for example, makes telephone lines more useful to subscribers).

These fundamental features of the economy of networks define a new economic environment where the diffusion of innovation is accelerated and expanded by "bandwagon effects". Increasing returns operate in such a way that there are in theory no other limits to the diffusion of modern innovation than the available infrastructure (telephone lines, or broad-band networks in the near future). These underlying forces are precisely those that generate "globalisation", and drive the world economy towards the establishment of a world system of networks. Belonging to this system will be a necessary condition for participation to world trade: not to belong will mean dropping out of the race.

From both the supply and demand side, these varied factors exert strong pressure in favour of standardisation. Standards guarantee that succeeding generations of equipment will be compatible with one another and so ensure a satisfactory return on heavy initial outlay. They mean that networks can be interconnected (so profiting from even higher increasing returns) and give users an assurance that their network will continue to improve and grow. Manufacturers and service providers are often understandably reluctant to give in to these

---

[9] See: OECD, Information Technology Standards, the Economic Dimension, Paris, 1991

[10] Brian Arthur, "Competing Technologies: an Overview", in: Dosi et al., Technological Change and Economic Theory, London,
Frances Pinter, 1988.

Yet the role of governments in this environment is far from clear. There is little choice but to do all that is possible to remove obstacles that might slow down or stifle the "bandwagon" of innovation which is the compulsory route to full fledged participation in the new global economy. This entails deregulation (and occasionally reregulation), as well as the adaptation of the education and training system and of other social infrastructures. There is also a great temptation to assist in facilitating choices of specific technologies, and to select national "industrial "champions". There are many examples to show that this is a dangerous strategy: at a time of rapid technological change, the immediate future is far from predictable. Wrong choices carry the penalty of wasted investment, if not "lock-in", loss of competitive advantages, and sooner or later the obligation to acquire foreign technologies.

Yet governments are major economic actors. In most countries, public purchases (especially when technological progress generates the need for massive investments in new infrastructures) have a great influence on the emergence of dominant technologies. This indirect governmental responsibility cannot be ignored, and compels governments to become "smart buyers" who will make choices that do not foreclose future options and that will not sacrifice future gains (in terms of possible technological advances) for the sake of limiting costs in the short term. A basic mode of behaviour emerging in many countries (for example in Western Europe) is thus to diversify purchases (in order to safeguard the greatest possible variety of technologies and skills available on the domestic market) while assigning a high priority to compatibility between the various technological options retained.

Additionally, governments play an increasingly important role in ensuring that potential users of new technologies are fully informed of the various alternatives to be considered and of the implications of the selection of each system. It has also become more and more necessary for governments to support actively the participation of national interest groups in the relevant international discussions, ranging from GATT negotiations to fora where technical standards are being discussed.

The challenge of trading

Networking thus takes place at different levels. There is the technical infrastructure of communications lines combining hardware, standards, protocols and software to evolve gradually into the "information highways" of the next century. There are local networks that have always existed in one form or the other but nowadays increasingly operate in "real time" within electronic communities having common interests. And there are socio-economic networks that use the new information media to establish novel alliances cutting across the boundaries of institutions and specialisations in order to develop common strategies.

This new fabric of relations will be enhanced and reinforced by the major priority assigned in all industrial countries to the development of a system of exploitation of research results[11]. Such a system implies the establishment of information and collaboration linkages between a growing number of actors in research, industry, services and trade.

In all industrial countries, governments have tended to shift, in recent years, to indirect actions intended to promote the development of a trade-oriented research environment: legislative and regulatory measures considered to be obstacles to the diffusion and application of knowledge have been lifted (for example, various anti-trust regulations were removed in the United States to facilitate pre-competitive research co-operation between firms); new rules were adopted to encourage scientists to take a more active interest in the exploitation of their work (for example by allowing academic research-workers and institutions to apply for patents, even when the invention had been the result of federally sponsored programmes, or by relaxing academic rules so that professors could participate in commercial ventures); incentives multiplied in order to promote science-based industrial activities (i.e. fiscal incentives, schemes to develop employment of scientists by firms of all types, research funding instruments for industry-university collaborative ventures, etc.).

This focus has been accompanied by gradual re-direction of the public research support towards new types of programmes, in order to channel efforts onto areas of greater economic relevance. This has affected all types of research activities. For example, institutions that have traditionally been bastions of fundamental research (from the CNRS in France to the National Science Foundation in the United States) devote more and more attention to applied research and strategic research justified by its economic implications. Pre-competitive research activities have multiplied to bring together academic and industry scientists. Certain disciplines receive renewed attention and expanded support, when they relate to the "sciences of the artificial", or "transfer sciences", ranging from mechanical and chemical engineering to medicine and pharmacy[12]. And economic relevance increasingly becomes an essential yardstick in the assessment of research proposals everywhere.

The rising tide of economic concerns has many consequences. The main point, in a science and technology policy perspective, is the growing influence of industrial considerations on research pursued in academic and government research establishments. Inter-sectoral collaborations have rapidly increased, to the extent that there are fears about the future integrity of academic institutions. In "sensitive" areas (that is, promising areas in terms of economic potential, as in biotechnology or computer sciences), unprecedented modes of behaviour and attitudes have appeared within universities, and affect the diffusion

---

[11] Major R&D Programmes, op. cit.

[12] See: OECD, Technology and the Economy, the Key Relationships, Paris, 1992, pp. 35-37.

of research results, and even of ideas, in order to protect patentable discoveries and trade secrets.

The development of a "system of exploitation of research results" is thus coupled with the transformation of the research system into a "system for the production of exploitable results". Such a shift would significantly affect the traditional professional bases of scientific work. In terms of substance, shorter time-horizons would prevail at the expense of undirected, longer-term basic research in the natural sciences. In terms of behaviour, the free flow of information and research results that had been a fundamental feature of Western science since the XVIIIth century would be threatened. Scientific "cliques" would multiply, thus limiting the scope for open discussion of methodologies and conclusions within the scientific community. Ultimately, both the orientations and quality of science could be at stake.

PART TWO: THE GLOBAL FORCE

Science as a commodity

In many disciplines, scientists seem to publish less than they used to. In most cases, the support extended to research teams by industry entails some restrictions on the extent and moment of publication of the results. It has become more and more frequent for publication to be explicitly delayed by the contract, so that the sponsoring firm can take a decision with regard to the patenting of any result. In Europe, firms would thus require fairly long periods of time - up to two years - to reach a decision, while the delay is usually much shorter (around six months) in the United States. Overall, various studies have brought to light a decline in the publishing rates in certain disciplines, between the mid-seventies and the mid-eighties[13]. This trend is especially striking in certain key areas, such as electrical engineering or biotechnology, that have enjoyed expanded funding during the same period.

New strategies are being developed for the management of scientific information in the "computer age". New instrumentalities open the way for easy screen-to-screen communication between researchers. The "grey literature" used to be unpublished material circulated under the form of manuscripts for discussion with colleagues. It has now become electronic, and a substitute to publication when its access is restricted to members of a network that includes industrial and non-industrial scientists whose interests extend to commercial applicability at least as much as to the advancement of knowledge as such.

---

[13] Georges Ferné, "La science, une nouvelle marchandise", in: La Recherche, Mars 1989.

Thus, commercial success may now be less a direct function of the ability to produce new knowledge, than of the ability to access the right information (and hence to belong to as many productive networks as possible) and to recognise the relevance and potential synergies of scattered elements of information. New industrial structures based on "flexible specialisation" make it possible to adjust to new results and integrate them rapidly in order to acquire a temporary monopoly that will undoubtedly be challenged soon by other actors. Hence the relentless quest for ever newer data and ideas. No single organisation can hope to master alone the expanding flow of results stemming from international research, the more so when the circulation of these results is increasingly channelled by their producers. It thus becomes unavoidable to trade with others the possibilities of gaining access to vital information. This constraint explains the development of co-operation schemes between industrial competitors ("coopetition"), where each participant stakes its future on its felt greater ability to manage and exploit the results that <u>might</u> become available. It also explains the extraordinary development of industry-university relations since the end of the 1960s: industries do not support academic research merely to benefit directly from its results, or to establish a channel for the recruitment of graduates, but rather to create, through the team under contract, a scientific channel to the relevant research world-wide.

It is no wonder, in these circumstances, that governments have attempted to step in and take part in the "management and control" of the precious and short-lived resource that scientific information has turned out to be.

Government controls were first implemented in connection with transfers of technologies considered to have military, or both military and civilian, implications. COCOM was thus established in 1949 to monitor technology flows towards the communist countries. Since 1989 and the collapse of the Eastern Bloc, the list of strategic exports under control has been shrinking, and the days of COCOM are obviously numbered.

Other concerns, stemming from the potential dangers of exports of sensitive technologies to countries of the South, however, have prompted the creation of additional control mechanisms. The Nuclear Suppliers Group (NSG), or "London Club", was established in 1975 to promote nuclear non-proliferation. The Australia Group was created in 1984 during the Iran-Iraq war, in connection with chemical and biological non proliferation. Another group was established in 1987 in the area of missiles technology non-proliferation (Missiles Technology Control Regime - MCTR). All these committees suffer from the fact that they have different memberships mainly limited to Western industrial countries. The issue of extending world control to allow for the participation of Eastern European countries, and of others such as China and India, is now on the agenda.

This type of control focuses in principle on technology that has military implications, although it is not always easy to draw a clear line between "military" and "civilian" technologies. The non-proliferation efforts of industrialised countries have occasionally been suspected of also striving to protect economic monopolies and interests. A counter-argument is that major industrial firms, in industrial countries, often claim that these controls are excessive.

This debate is far from being exhausted, since a new dimension of government monitoring of the circulation of information, however has resulted from growing awareness of its economic stakes. More and more countries have been attempting to limit the "leaks" of scientific information that were thought to benefit competitors. In the United States, for example, foreigners have occasionally been refused access to scientific conferences. A controversy has developed over the allegedly excessive number of foreign students taken on by universities. The restrictions placed by sponsoring firms on the publication of research results are also intended to prevent the early disclosure of economically strategic information.

The rapid advances of computer sciences, materials and biotechnologies challenge traditional concepts relating to intellectual property rights. Patenting of living organisms or of gene sequences, the extent of software protection through copyrights, the regulations covering appropriation and access to data bases are among the major issues debated, for example, in the framework of GATT. Issues such as data banks, data flows and data networks, privacy protection, patents and trade secrets, copyrights and service delivery, standardisation and information security are also increasingly debated in national and international fora. Another important aspect is related to technology transfers, and the various restrictions that often accompany the provision of a new technology.

The trend is unmistakably towards a multiplication of rules governing appropriation of information and the information market. Scientific knowledge cannot be expected to remain untouched by this world-wide evolution, with many major implications for all countries, and in particular for developing nations. The new system of control of the diffusion of information, which is gradually being developed world-wide by the major owners of new technologies, is still rapidly evolving, and remains characterised mainly by implicit modes of behaviour rather than explicit regulations. Its impacts are, therefore, very difficult to assess.

They are, however, at the heart of a globalisation process that redistributes power and influence, as well as the bases of power and influence. The conversion of a number of countries, in Eastern Europe and in the developing world, from central planning to market economies illustrates spectacularly the end of a bipolar world and the growing impact of international trade. It provides, in fact, an illustration of the relentless pace and unprecedented nature of the "globalisation" process.

Developments in IT have already had a major impact on international relations, in a wide range of fields extending from cultural to economic exchanges, and including areas of concern affected by the new technologies (such as the legal issues mentioned above, connected to privacy protection, transborder data flows, security, etc.). IT has played, and continues to play, an essential role in world trade and the current development of "globalisation". This is not merely due to the rapid expansion of IT-related trade[14], but also reflects the strategic role increasingly played by computer-to-computer relations as a basic infrastructure for international exchanges of all types. National policies cannot ignore this world-wide dimension: there are global problems to be addressed by IT, and new challenges resulting from the development of an IT-based world market, that can only be met through international action.

The global nature of many problems that call for IT-based adjustments and responses, provides a powerful stimulus to international co-operation:

-- environmental problems are drawing increased attention and the magnitude of the threats is such that joint international action is required.

-- there is a need to avoid costly duplication of R&D efforts that could be more effective if undertaken under multilateral co-operation schemes.

-- The greater integration of national economies generates new trade patterns and the emergence of transnational industrial alliances and information flows, that may call for the formulation of new international understandings and rules of the game.

-- International efforts are also needed to involve late-industrialising countries in the development of new world IT infrastructures, and allow them to benefit from the resulting growth opportunities.

It remains, however, that the new global economy is not homogeneous and that a relatively small number of regions and countries exercise enormous influence.

The new centres of economic power

If the world economy has become much more integrated and interdependent, several well-defined centres of science and industrial technology exercise a major influence.

It has become more and more apparent that three dominating regions of the world economy largely determine the patterns of R&D, innovation, and high-technology trade. Each

[14] OECD, Trade in Information, Communication and Computer Services, Paris 1990.

of these regions represents a coherent system of industrial development and production, even though it may be increasingly dependent on the others.

There is a Western European economic space, a North American one, and an East Asian industrial space with Japan at the centre. Each has its own sizeable industrial base and technological "strong points", and each has developed ambitious policies to retain its lead in certain areas, and to regain lost ground in others. Based in these regions, about one thousand major corporations control more than half of the world's manufacturing and almost two-thirds of international trade.

From a statistical point of view[15], little is detectable of the “global reach” of large industrial corporations which operate from these three major industrial regions. No indicators are available at firm or at industrial branch level to bring to light the role of science, technology and innovation in the penetration of corporations in the different regional markets for products and services. Nor are there statistics of the transfer of technology and other knowledge generated by the need of these firms to gain access to foreign supplies and new sources of production. The operations by corporations on patent protection, licence agreements and royalty issues are not recorded in any data bases.

Yet these corporations based in the three main economic regions are the most important actors that operate world-wide by way of modern technology. Foreign investment, sub-contracting and outsourcing have become standard practices for these companies, and provide a channel by which small and medium-sized firms in the three regions - and beyond - have little choice but accept linkage to the same systems. New technologies are at the root of these developments.

The new patterns of global competition

Information technology promotes the internationalisation of production and markets because it makes it possible to achieve new levels of economies of scale and scope; because, through flexible systems, it provides instant adaptive capacities to adjust to market fluctuations; because it removes barriers to the smooth flow of services and finance across borders; and because it allows for real time monitoring and management of the most distant facilities. These features have generated a dynamic process of internationalisation of economic activities that affects industry, finance, services, culture, etc., on such a breadth and so comprehensively that there is a clear discontinuity with respect to the past. Hence the notion of "globalisation", a notion that has been strengthened by the emergence of a number of

[15] See: Jan Annerstedt, "Measuring Science, Technology and Innovation", in: Jean-Jacques Salomon et al. eds., The Uncertain Quest, United Nations University Press, Tokyo, 1993

"global problems" resulting from threats to the planetary environment.

The rapid diffusion of IT thus fosters a new regime of interdependence in international relations. Each country becomes more and more vulnerable to the impact of decisions taken elsewhere - by other countries or by multinational firms. Informatisation and computer-to-computer communications provide decisive instruments for the development of this new world structure that arms giant firms with the techniques required to manage, transfer and process technical and economic information world-wide and on an interactive basis. This will obviously affect the international division of labour and production as well as international trade, changing the patterns of industrial ownership and control, altering the competitive standing of individual countries and creating new trading partnerships.

The impact of these new technologies cannot but become more and more extensive. This is not surprising. "Information activities of one kind or another are a part of every activity within an industrial or commercial sector, as well as in our working and domestic lives. Almost all productive activities have a high information intensity (some involve little else, such as banking or education), so information technology is capable of offering "strategic" improvements in the productivity and competitiveness of virtually any economic or social activity. Information technology is universally applicable"[16].

Mutual adjustments are taking place world-wide, between technological change, industrial organisations, financial and labour markets as well as governmental and non-governmental institutions. They will obviously affect all nations: those that will be able to take full advantage of the new opportunities, those that will lose ground in the competition for global technological pre-eminence, and those that will find it ever more difficult to close the gap that separates them from the more affluent societies. A number of consequences are already clearly apparent:

-- The complex pattern of industrial alliances for research, production or marketing, which ignores regional groupings to establish pragmatic coalitions of interests that raise the threat of uncontrollable cartellisation at world-scale.

-- The difficulty of regulating "transborder data flows", that may include, for example, strategic information as well as speculative funds that can be transferred without control through a broad variety of proprietary communications systems.

-- The general weakness of governments when confronted with this "globalisation" process

[16] See: Paulo Rodrigues Pereira,"New Technologies: Opportunities and Threats", in: Jean-Jacques Salomon et al., eds., The Uncertain Quest, United Nations University Press, Tokyo, 1993

that obviously holds the key to future growth while challenging the sovereign rights of nations.

-- Significant changes in the blend of skills required by the new technologies, accompanied by new possibilities for the de-location of plants and acceleration of automation, thus generating simultaneously unemployment and labour shortages.

-- The growing importance of software and service activities relative to more traditional manufacturing.

-- The proprietary nature of much of the new information technologies: key technologies cannot be acquired by new entrants, even if they had the skills; and, even if the technologies in question could be acquired and mastered, established markets could not be penetrated.

At the same time, however, there are many features of the IT technologies that threaten the industrial world with major disruptions and threats. The process of structural adaptation, in itself, generates immense social difficulties that cannot be easily overcome, as shown by the rising unemployment rates.

However, there may be even more basic and fundamental forces at play. The multiplication of all forms of network that seem to extend world-wide the marketing capabilities of the industrial countries may come to operate in unexpected directions. As noted above, the labour markets of most industrial countries are characterised by the coexistence of unemployment and shortage of certain skills. Yet these skills are available elsewhere and the new computer-to-computer communication infrastructures make it possible to employ these skills, wherever they are, without delocation of industries. Some Western European firms, for example, have already taken advantage of "teleworking" to employ accountants in the Philippines, or software developers in Hungary and India.

These new trends illustrate what may be a dominant pattern in international competition in years to come, characterised by the disappearance of many traditional links between employment and location. In such a new configuration, education systems, low salaries, and the availability of adequate skills and competence, may become a decisive competitive advantage as such. But what are "adequate" skills? The ability to choose wisely in what areas to specialise, and how, may well turn out to be the essential key to economic success in years to come.

PART THREE: THE FUTURE OF NATIONS

Compulsion and liberty

No country can at present afford to isolate its scientific and technological effort from those of others. Yet, in order to be able to follow the international progress of knowledge and skills, each country must retain its own specific capabilities, that will often require the creation and maintenance of an R&D base in the areas considered essential for its future..

It would thus appear that any national technology policy must acknowledge that the existence of "margins of liberty" (that is, areas where it can decide to acquire strength or not), is conditioned by the acceptance of "compulsory choices" (in other words, "core" technologies that must be mastered in order to have minimal access to the technology in question.

Looking across major national and international scientific and technological programmes, in Europe, North America or Asia, one in fact discovers quickly that they all have a common core reflecting the need to acquire control of a basic technology. However, once this is acquired, different degrees of autonomy and specialisation can be exploited.

This can be illustrated by the examples of information technology, biotechnology and materials.

i) Information technology is a heterogeneous grouping of areas such as microelectronics, data processing, telecommunications, and computer-assisted manufacturing. In microelectronics, the common thrust is to design smaller chips while minimising the production costs through greater circuit integration, improvements in semiconductor design and fabrication, or silicon and gallium arsenide applications. In data processing, applications are turning to expert systems (intelligent machines), intelligent robots and speech recognition. Each of these applications must be mastered by anyone wishing to be in the running in future, if only to be able to take full advantage of the diffusion of new products as soon as they come on the market. Whether concerning Japan's INS programme, or the European RACE programme, or the more recent Clinton initiative in the US, the major objective in telecommunications seems to be the establishment of integrated services digital networks (ISDN) that will in future meet the requirements of all users (firms, services, administrations and consumers) by carrying sound images and texts at very high speed and very low cost. Computer-integrated manufacturing is now based on numerical control machines, industrial robots, computer-assisted design and manufacturing systems and visual tactile recognition devices. A large number of national and international programmes reflect these priorities.

ii) Biotechnology also is not a unified discipline, but a combination of different research areas and techniques based on joint contributions from biology, chemical engineering, medicine, plant and animal physiology, etc. Exploiting the full potential of these advances essentially requires mastery of recombinant DNA, cloning and fermentation.

iii) New materials result from the increasingly varied and sophisticated demands of modern industry, coupled with the potential of information technologies applied in design and production processes. Basic technologies must be acquired to generate key materials such as composites, ceramics and polymers.

These three areas have become as many compulsory gateways for access to the arena of modern industrial development. They have striking common characteristics that underline the difficulties of the task:

-- in all cases, sophisticated applications of information technologies are required;

-- there is never a single scientific discipline or technological speciality at stake, but a broad range of different areas of knowledge and know-how, requiring advanced skills on a large and heterogeneous front of interdisciplinary expertise.

-- the application of new knowledge in these areas does not involve a straightforward relation between research and a particular sector of the economy, since all three technologies have implications for all spheres of human activity.

-- Research in these three areas is predominantly "problem-oriented", and the major breakthroughs of the last decade have mainly resulted from socio-economic pressure to provide answers to specific questions.

-- all these parameters are not stable, but evolve very rapidly with world-wide advances in research.

-- much of the relevant knowledge, however, is of a proprietary nature and either cannot be acquired cheaply, or cannot be acquired at all at the appropriate time.

If the economic future of all countries depends on their ability to master at least some key elements of these technologies, the task is by no means easy. It will require a high level of skills in a great variety of fields - and hence substantial adaptations of the educational and training systems. It will also require the development of research capabilities in strategic areas, at least at a level that allows the effective transfer and adaptation of knowledge from abroad. To be productive, these efforts will need to be pursued in close relation with social and economic actors, in order to facilitate the transfer of questions as much as of results. And, finally, it will also be necessary to develop appropriate channels to remain continuously informed of world developments in research. Such channels will depend on the establishments of networks and collaboration between the national industrial and scientific efforts and their international counterparts. Hence a paradox: in order to acquire or retain a competitive edge (a condition for the safeguard of national identities), any country must actively explore all possible channels of co-operation with others, in research perhaps even more than in other areas. This is as much a consequence of the proprietary nature of a great part of the research results in high-technology than of the rapid rate of production of new knowledge in these fields.

Towards new forms of research co-operation

The rapid development of a global economy has reinforced the belief that the days of the nation-state are numbered. And yet, simultaneously, there is no lack of evidence world-wide of the resurgence of many forms of nationalism, often leading to conflict and open warfare. It would seem that progress in achieving world growth based on the exploitation of the potentialities of economic interdependence will depend on the ability of the international community to achieve a working compromise between the requirements of the global system and the preservation of national identities.

Thus, governments everywhere attempt to define their new role. One thing, at least, has become ever more clear: no country can expect to be an effective actor on the world economic scene without the scientific and technological resources required to keep up with, and even to generate, an uninterrupted flow of innovations. And all countries also find that the ability to compete effectively goes hand in hand with the ability to cooperate. The collapse of the Eastern Bloc at the end of he 1980s is a dramatic illustration of the penalties to be paid, even when scientific and technological resources are in principle abundant, for isolation from world trends, information channels and trade.

Western European countries began their march to economic unity by joining forces in the key sectors - coal and steel - of the post-war world, gradually to extend this co-operation to nuclear energy, space, and subsequently to the whole range of science and technology activities, in education as well as in research. The recent creation of the North American Free Trade Area represents another milestone in this trend towards co-operation at the scale of continents. Japan has multiplied collaborative ventures with other Asian countries through the Asian Pacific Economic Co-operation (APEC system, and often demonstrates its desire to join forces with other members of the "Triad" to explore the most advanced frontiers of knowledge. And it is probably no coincidence if other countries that lag behind, economically as well as technologically, are often those that have not managed to generate and join effective regional co-operation schemes.

For, once again, co-operation and competition, in to-day's world, are two sides of the same coin. Co-operation is, of course, an unavoidable route when resources are limited and a single country cannot bear the full cost of the large R&D investments that are often required in key areas. In less tangible ways, co-operation is also required in order to develop in common the basic rules that will make it possible to benefit fully from a "regulated" globalisation process: common understanding and joint decisions at international level are necessary in order to remove barriers to the expansion of trade and establish a world trade system whose excesses (in the form of excessive monopolies, or savage competition) could only generate adverse national reactions taking the form of open or hidden protectionism. To "tame" globalisation will require that greater attention be paid to developing more fair and effective international "new rules of the game" in areas as diverse as intellectual and industrial property rights, transborder data flows, privacy protection, anti-trust, standardisation, technological risks, environmental hazards, access to data, etc.

Discussion of many of these questions are time and resource-consuming, as well as highly technical. These negotiations are often left to technicians representing a small number of countries. Others might be well advised to take more active interest, so that their specific interests are fully taken into account at the appropriate time. The future of nations depends on this ongoing process of development of new rules for the global society;, that is intended to establish the general framework within which each country should be in a position to define its own approach to economic and technological progress.

In relation to research, for example, the absence of common rules has serious implications. The exploitation of the findings, which is the normal outcome of any co-operative scheme - at national as much as at international level -, must be shared out on an equitable basis. When the project is concluded, it must be possible to measure the input and benefits for each concerned: for instance, a line must be drawn between the knowledge and know-how initially supplied by each participant, or "<u>background</u>", and the results of the shared work, or "<u>foreground</u>".

This distinction becomes even more blurred when the partners are reluctant to disclose the extent of their skills in detail for the simple reason that they do not wish to say too much to potential future competitors. Japanese firms taking part in R&D projects have been known to consign information on their background knowledge in sealed envelopes to be opened only in the event of disagreement over the allocation of results.

The procedures used for sharing out the results are of vital importance for determining the patent rights or potential licensing rights of each party concerned. The diversity of approaches currently used in different national and international programmes is therefore likely to lead to conflict.

This is compounded by the fact that programmes are evolving. At the start, most programmes result from a strategic plan for advanced research. The intent is to pool knowledge and research means among teams of researchers from private firms, university or public laboratories in order to generate basic knowledge in a new technological field. The aim is to move ahead in a generic technology (e.g. genetic coding, or superconductivity) without any specific commercial outlets in mind at the start. Research is viewed as "pre-competitive". However, technology - even of he most "generic" nature" - is never totally divorced from strategy and commerce. As the project develops, economic implications and application opportunities will become more and more obvious. The co-operative programme tends to shift to more market-related goals, and will thus meet ever greater difficulties in sharing out research findings. The future of the participants - be they countries or firms - depends on their ability to anticipate such situations and solve these problems equitably.

The challenge of defining priorities

"There was a time - not so long ago - when governments hoped to be able to programme, and even plan, scientific and technical progress with the aim of being able to control the whole chain of initiatives and events leading from the production of knowledge to the launching and diffusion of products"[17]. The common assumption that there actually was such a chain, mechanically linking basic research to innovation, was certainly naïve oversimplification. It remains, however, that the overall context in which science and technology policies are made has changed drastically since the 1960s and 1970s, to a large extent as a result of the progress achieved in the new "high-tech" sectors. For many observers, the world has entered a new "techno-economic paradigm", and is presently engaged, as a result, in a process of major change comparable to the industrial revolution of the last century, but which may turn out to have even deeper implications, in view of its global nature.

The world economy is thus being remodelled, and the interplay of technological, economic, social and political factors is so complex that even the immediate future is difficult to forecast. Instant adjustments to unexpected shifts have become a daily requirements for individuals, firms and other institutions, as well as for governments. In this climate, the stress is on structural adaptation, flexibility, deregulation, decentralisation, initiative... In the absence of clear markings of the road to be followed, it becomes indeed very difficult for each country to arrive at rationally defined priorities.

And yet such priorities are unavoidable in science and technology, with regard to

---

[17] Major R&D Programmes, op. cit., p. 12

education and the provision of skills as much as with respect to research-related activities, ranging from the selection of programmes to be launched and implemented domestically, to the choice of areas where co-operation and/or licensing would be needed. Such choices will be all the more difficult in view of the fact that they may only be expected to have a medium-term or even long-term impact.

New types of approaches to the day-to-day monitoring of rapidly evolving technologies are needed. As noted above, a careful analysis of the main trends in each of the new major technological areas will bring to light "margins of liberty" and areas of "compulsory choices". This understanding is of essential importance to all countries since it will set the technological framework against which decisions can be arrived at. In other words, the challenge is "to bring out the extent to which the options that can be envisaged are in fact circumscribed by a certain number of lines of force that do not allow very much diversity in the choice of objectives and impose a certain logic on all approaches"[18].

The identification of these "lines of force" has been referred to as an exercise in "technological landscaping"[19], whose task is to identify peaks that cannot be scaled, mountain ranges that must be crossed, and valleys that might make it possible to circumnavigate obstacles. In order to be effective and contribute to the formulation of the national technological strategies, it is clear that such an effort should be developed on a continuous basis, since it is concerned with a constantly shifting landscape; that it should be established in close communication with the highest levels of government concerned with industrial and technology policies; and that the results of its work should be broadly publicised and available to all relevant public and private actors whose decisions are affected by, or will have an impact on, technological change.

Finally, such an activity needs to be directly articulated with more circumscribed efforts undertaken by different groups to explore certain aspects of technological change. These related efforts range from the technological "search" activities of firms hoping to keep abreast of the "state of the art" in their specific branches, to technology assessment attempts reflecting environmental and social concerns[20].

Technological landscaping, however, cannot be expected to make a real contribution

---

[18] *Ibidem,* p. 13

[19] *Ibidem*

[20] See: Harvey Brooks, "Technology Assessment", in Salomon et al., op.cit.

if it serves merely to collect and re-distribute data on innovation. Landscaping implies a construction, an effort to make apparent chaos intelligible. Thus, the main challenge of technological landscaping is probably to organise the information collected in a way that will facilitate insights in areas of national interests. There are, at present, no ready-made recipes or formulas for such an achievement, and one may hope that practice will gradually improve. But the magnitude of the theoretical and practical difficulties should not deter any country from launching this type of effort, in the direction most appropriate in view of its national endowments and concerns.

CONCLUSION

All countries have to adjust to an international environment which has become more and more volatile and less and less predictable. The ability to mobilise science and technology is now broadly acknowledged as an essential asset, but technological advances proceed so rapidly and on such a broad front that they contribute to increasing uncertainty about the future. Brazil has in the past devoted considerable resources and energy to the development of scientific and technological resources. In several cases, the country has followed strategies of its own, which have given the national S&T effort some unique features and have succeeded in placing Brazil as a world leader in several areas.

Although the author of this chapter is very far from being fully informed of the many dimensions of Brazilian science and technology, it would seem to him that the major and most urgent task ahead is to take advantage of these accumulated resources (in terms of qualified personnel, institutions, expertise, skills and know-how) as competitive advantages for successful participation in international trade. The difficulty of the challenge is to seek greater integration in international exchanges of technology, goods and services, while seeking to strengthen the contribution of S&T resources to the development of the Brazilian economy and society as such.

The very first priority should be to encourage and strengthen the institutional chain that unites the system of production of scientific and technological knowledge with the economic and social systems where the results will be considered for application.

In order to increase the general effectiveness of the national research system, the professionalisation of science and technology still needs to be encouraged and advanced. Broadly speaking, the research profession needs to be even more explicitly recognised as a legitimate and essential activity within society. On the one hand, this will require systematic efforts to facilitate public understanding of the specific needs and national implications of scientific work. On the other hand, public recognition should be translated, from the perspective of the scientist, in terms of adequate salaries, career prospects, a sense of belonging to a national scientific community, etc.

Professionalisation of research also requires effective institutional settings (universities, government research establishments, industrial laboratories), where the basic requirements of scientific work are satisfied (in terms of equipment, technical assistance, facilities, etc., while supplementary funding can be obtained for specific projects. In spite of the high priority assigned to applications-oriented work, pluralistic funding will be essential to leave the way open for the support of different types of research in a great variety of sectors. This sort of diversified support is an essential condition for the development of a flexible research system, that will be able to reflect the variety of national needs while allowing space for undirected, more basic research which is the breeding ground for future innovations.

In this connection, special attention should be paid to university research, as a focal point for the training of future researchers and the pursuit of non-oriented research.

The federal structure of the country should provide an opportunity to foster decentralisation and diversity in research and training approaches. It is also at this decentralised level that initiatives could be taken to reinforce various "bridges" between research, the society and the economy, in order to encourage application of results to the solution of local needs. This type of linkage is all the more essential, because it should often provide a favourable setting for the emergence of new ideas, experimentation and demonstration based on generic technologies that are nationally available. When appropriate incentives are available, such local environments can become hatcheries for innovations that draw upon the national stock of knowledge and know-how to respond to specific economic and social demands. The potential of such innovations for lucrative marketing abroad should not be under-estimated.

The diffusion of new results and technological developments also needs to be systematically pursued at national and local levels, to be brought to the attention of small and medium size firms, farmers and forest managers, exporters, etc. In each case, specific arrangements will be needed to ensure effectiveness in reaching the target group. Extension services developed in other countries in rural areas could provide a model to be adapted. In any case, policy analysis and evaluation should be conducted on a continuous basis to bring to light areas of possible convergence between research applied to national needs and market-oriented research and applications. Various schemes will be needed (from "factory-nurseries" to venture capital opportunities), in order to encourage a new export-oriented spirit and facilitate the commercialisation of new products.

These efforts should, in particular, be closely related to technological landscaping activities conducted in close relations with policy-makers. These activities should provide essential inputs for the definition of national priorities in research and training. Their results should be broadly available to the public.

Export-oriented attitudes should in any case be systematically encouraged in research institutions. This might require deliberate efforts to promote industry-university relations in education and research and to provide assistance to scientists for the filing of patents, etc. Scientists and engineers should be able to contribute directly to innovative industrial ventures.

Export-oriented institutions should be reinforced in areas such as standardisation, quality control and conformance testing. Special measures should be implemented to ensure that the responsible bodies are adequately funded for their national and international activities, and remain closely connected to both science and industry.

The implications of the major goal of creating a "networked society" - both nationally and extended internationally - should be explicitly recognised in all areas of public policy. Special decisions will probably be required in order to promote "open systems" in government informatisation programmes.

Greater attention will need to be paid to the implications of public purchases at national and local levels. The public purchases system should be established on a basis that fosters technological creativity as much as economy of resources. All sectors of government activity should, in particular, be invited to explicit and articulate their technological requirements. The overall requirement of "vintage compatibility" (between different generations of technologies) will be especially important in connection with the development of social infrastructures (in urban as well as in rural areas): initial investments, even when modest, should be designed not to preclude subsequent additions of, and integration with, more modern and extensive components. A basic principle to be strictly adhered to would thus be to always "leave future options open".

All these decisions will usually involve substantial contracts with suppliers and constructors. It should be remembered that contracts allocated competitively (on the basis of a "bids and proposals" procurement system) have a positive effect on innovation capacities. While non-competitive procedures for the allocation of public contracts usually do not.

Beyond the large but still limited area covered by public purchases, all industrial societies need to increase deliberate efforts to generate more diversified demands for the application of new technologies in industry and services. Various incentives and technical assistance schemes will be needed for this purpose.

Finally, adequate resources need to be specifically allocated to the pursuit of international efforts, as natural extensions of national activities in science and technology. Careful consideration, however, needs to be given to the procedures and mechanisms most appropriate to maximise returns.