AN ANALYSIS OF EUROPE´S CHANGING RESEARCH LANDSCAPE FOR THE FIVE YEAR ASSESSMENT (1999-2003) PANEL

JOÃO CARAÇA
November 2004

> *«Naught happens for nothing,*
> *but everything from chance and of necessity»*
> **Democritus**

CONTENTS

0. INTRODUCTION. SCOPE OF THE ANALYSIS

The **Five-year Assessment** of Community research activities enables the achievements and impacts of past and ongoing activities to be evaluated and appraised, contributes to making implementation of these activities more transparent and plays a significant role in defining the future direction of research, technological development and demonstration activities. The current Five-year Assessment covers the period 1999-2003.

The present analysis was developed to provide information to the panel of high level experts conducting the Five-year Assessment. Its objective is, from a research policy perspective, to describe and analyse Europe's research landscape, paying particular attention to the role and contribution of Community research activities.

The document is structured as follows. The first chapter deals with the most important transformation occurred in the mechanism of technological creation in the recent past: the emergence of science-based technology. Its relation with the performance of the innovation systems that structure modern knowledge-based economies is emphasized. The second chapter addresses the changing policy context for research in Europe, namely by considering changes in approaches and priorities, the need of a supra-national vision, the growing internationalisation of R&D, European enlargement and integration and the Lisbon strategy. The third chapter addresses the changes to science and technology, namely the importance of new and emerging fields, scientific performance and competitiveness, the centrality of learning and research in terms of a strong policy for qualified human resources and, finally, the need to favour scientific practices in contemporary world.

Data indicating long-term trends have been preferred.

1. THE MEANING OF SCIENCE-BASED INNOVATION

In the words of Karl Polanyi, transformations in society are the outcomes of processes exhibiting a dual nature: first, that of **change** and alteration of the established pattern of interactions between the members of that society (e.g. through technological progress); second, that of **adjustment** and adaptation of the population to the changed conditions of operation (e.g. through education and learning and the establishment of new institutions and organisations). It is this second character that sets the pace of development. «The time-rate of change compared with the time-rate of adjustment will decide what is to be regarded as the net effect of the [transformation]» (Polanyi, 1957).

Too much change is socially unbearable in the absence of adequate adjustment mechanisms, and only after being properly assimilated and accepted can the new conditions lead to a new cycle of change and adjustment. In the language of complex systems, **innovation** is an emergent property of the successive cycles of societal development (see Figure 1.1).

---- FIGURE 1.1 ----

So, we have to start by understanding the changes brought about by a new process of technological production, based on science, that was initiated no more than three generations ago. Its impacts have nevertheless been tremendous and only by perceiving its implications can we be able to cope with contemporary transformations and attempt to devise solutions that unfold into the future.

In the past and during millennia, through a long and slow transformation process, technology always emerged from existent artifacts and devices, being tested and verified in the framework of the prevailing technical culture. It was in the course of everyday life that new ideas were suggested and tried, in a procedure that looked like a slow accumulation of knowledge about the usage of the forces and substances of nature. It has been always like this until the introduction of the railways and, to a certain extent, of the telegraph.

However, in the course of the 20th century, the mechanism of technological creation was drastically altered.

The industrial research activities grew stronger with the development of new industries in the sectors of rubber, oil, glass, metallurgy, transportation and instrumentation; and science left the relative isolation in which lived until then (in laboratories, academies and universities) when it was summoned during World War II to develop technologies with direct and immediate military application. The effort of post-war alignment propelled national budgets for scientific and technological research to values which had never been attained before. With the first artificial satellites launched by the end of the 1950's, the public character of science and its technological applications became definitely established.

The emergence of industries of high technological intensity in the second half of the 20th century, such as nuclear power, aerospace, semiconductors and computers, and more recently the pharmaceutical and biotechnological ones, reveals the critical importance of science applications in the societies of the industrialized world. Business and societal practices now strongly depend on new ideas which have an origin intimately related to the scientific effort, i.e., that does not derive from natural language nor common knowledge. This procedural change was not straightforward; it implied a thorough transformation and a deep institutional reorganisation in the societies that assumed it.

Wealth creation became dependent on the capacity of society to generate more endogenous change. Advanced economies adopted structured processes of transformation where innovation was envisaged as the only answer to economic survival in the framework of fierce market competition. The new science-based technological creation process was the driving force behind the stage.

BOX 1.1

Science–driven changes

It is important to perceive the main science-driven changes that took place in the last 50 years.

The first consequence of the new process of technological creation originated in the 20th century was the emergence of new sectors in the manufacturing industry. These **hi-tech** or sectors with "high technological intensity" all have a high added value associated to them. New enterprises were created in these sectors, which generated powerful multinational enterprises, in order to manage the new wealth that these industries generated. The world, today, would not be possible without its products: airplanes, missiles, satellites, space vehicles, computers, lasers, antennas, electronic networks, genetically modified products… In turn, the products of these sectors enabled the deployment of a full package of new and revamped services.

The second consequence was the emergence of **science studies** as a new discipline within the social sciences. Originally conceived as a mechanism to enhance scientific activity in the direction of technology production --- a new science-based technology --- the success of science policy led it to be a template for a series of new policies, which appeared later in the 20th century, such as innovation policies and knowledge policies. Science, technology and innovation studies thus became an established area in the university structure.

The third consequence was the creation of a new political need: the information of public opinion about the great issues that science confronts society with. This need of **public diffusion of science,** of enlarging the scientific culture of the citizens, of massively introducing experimental teaching of the sciences, is related to the fact that science directly influences everyday life through new technological processes and products that are consumed. It is necessary that the public understand the value and efforts that these innovations entail.

The fourth consequence was the introduction of the concept of “science and technology” or **S&T**, when before just the words “science”, or “technology”, were mentioned, and seldom their interactions. The need to closely link science with technology only arises when the new essential function of modern science becomes evident: to produce technology. The term **R&D** also dates back to this period, legitimating the whole creative scientific process, which offers since then countless commercial advantages.

The fifth consequence is the advent of direct relations between industry and universities. That is, between the industries of high technological intensity and the universities where the research is done at the frontier, of course. Why? Because there exist numerous scientific researchers in the new hi-tech sectors who need to communicate with their colleagues in the academic community. The **industry-university relationships** take place between researchers in industrial laboratories and in university centers who speak the same languages and share the basic knowledge on their subjects.

The sixth consequence was the emergence of a new structure in economic activity: the **scientific and technological system** (STS). This system encompass the overall interactions between entities and institutions involved in the process of technological creation from a scientific base. It is the STS system that conveys the possibility of generating innovations from research at the frontiers of scientific knowledge. As the impact of its performance in advanced economies became acknowledged, the concept of STS was in turn used as a template for the (emerging) concept of the “national system of innovation” institutional complex.

The seventh consequence was the birth of a new type of university: the **research university**, the central node of the communicating and interactive networks that generate technological innovations in the sectors of high technological intensity. In this type of university research activity is critical and post-graduation assumes a central role in the financing and stability of the university structure. Without surprise, this new model of university emerged in the U.S. after World War II, as an American response to the effort of the cold war. In these universities the total number of post-graduate students is about the same as the undergraduates, and the quality of scientific productivity a sensitive evaluation parameter balancing the competence-building of their bachelor degrees.

Three more consequences can be listed briefly.

The eighth consequence was the creation of a new academic degree: the **research Ph.D**, i.e., a doctorate obtained at the beginning of active life, as an entry qualification for scientific research.

The ninth consequence was the appearance of a new profession: the **scientific researcher**. Until then, scientific research was the work of inquisitive, highly gifted geniuses or academics. The notion of full-time scientific researcher is a by-product of the creation of national research laboratories and of research centers in the private sector.

The tenth consequence was the appearance of a new craft or skill --- **technology management,** responding to the management needs of economic units organized around a considerable percentage of highly skilled workers.

An early impact of these changes was the issue of the **two cultures,** the humanistic-literary and the scientific-technological ones, and their role in advanced societies. Today, however, with globalisation and social exclusion looming, we see that we have to go far beyond the differences between the two cultures and their disciplinary conflicts.

The corollary of the processes of science-driven change was the recognition of the existence of a mode of knowledge creation that differs from disciplinary research: a **Mode 2** --- an applied, transdisciplinary and reflexive mode of knowledge production proposed by Gibbons and collaborators (Gibbons et al., 1994), which legitimizes thematic research.

Advanced societies adapted themselves to science-driven technological change and adjusted to change by creating innovation systems based on science. These changes are part of today's reality and we can assert with confidence that the level of transformation --- being measured by the density of new institutions, procedures and networks --- indicates the potential of wealth generation and innovation that characterizes each society or nation.

To be able to perform and develop in the globalised economy of the 21st century any community must deploy distinctive marks of science-based innovative capacity and build competences through science to reach that threshold. Concurrently, it must generate instruments and institutions capable of articulating scientific with relevant non-scientific fields of knowledge such as law, management, finance, marketing, software, design… all adding up to a deeply changing research landscape.

Globalisation has however induced along and beyond these transformations the surge of another powerful driver of change: the existence of a very affluent demand, providing a sheltering environment to competition. Strong effects are thus being felt today in scientific practice which may have profound implications.

2. A CHANGING POLICY LANDSCAPE FOR RESEARCH

The U.S. led the western world during the last sixty years. This leadership was associated to a period of extraordinary development in scientific and technological activities and to the emergence of a whole range of institutions and mechanisms devoted to the promotion, planning, coordination, evaluation and control of science applications.

In fact, the transformations induced in advanced societies --- starting with the U.S. --- through the continued and improved usage of new products arising from the hi-tech sectors, concurred in pushing a new wave of technical change or, in the analysis of Christopher Freeman «a new techno-economic paradigm» that was installed after the “oil-shocks” of the 1970’s (Freeman and Louçã, 2001). The progressive **computerization** of the entire society is the main characteristic of this transformation, brought about by leading branches in the most innovative economies, such as computers, software, telecommunications and (later and more recently) biotech and biopharmaceuticals. Information and knowledge surged as central resources.

The technological leading role of the U.S. was overall maintained and reinforced throughout this big transformation as we can see from the data displayed in Figure 2.1, showing the productivity of European countries relative to the U.S. in the period 1960-2005 (Delanghe et al., 2004).

--- FIGURE 2.1 ---

In the “systems of innovation” perspective, Europe’s divergence was accentuated by the deployment of the new techno-economic paradigm led by the U.S.

The decades of 1970 and 1980 were the stage of a profound transition in economic performance and of a fierce political debate, which brought, towards their end, the announcement of the first policy for innovation (by the U.S., in 1977). The depth of the transition was, for the first time in history, due to the direct use and application of basic science.

Changes in policy perspective

So science policy (at the time called “science and technology policy”) had first to adapt to this major change of landscape. No longer the development of “strategic sectors” nor the support to “national champions” were the central preoccupations of policy but rather the effect of liberalising national markets and the spread of deregulation, i.e., the first glows of the dawn of globalisation. The 1990’s, by welcoming the end of the cold war, surfaced as the decade of globalisation: the information society and the knowledge-based economy were born in its wake.

Thus the early instrumental conception of scientific endeavour --- the generation of wealth and economic development through science-based technology, gave way to a more “nuanced” (or complex) notion of the “embeddeness” of scientific activities in the social context in which they are conducted; therefore the nature of research policies changed in order to accomodate more **diffusion-oriented** goals, stressing the mechanisms of knowledge circulation and transmission, of technology management and exploitation, of science awareness and public engagement in science.

This change has also been motivated by the then rising questioning of the character of public intervention in the economy, namely that the role of central government is not amenable to the conduction of operations too close to the market. Public policy and actions should be concentrated in the regulation of competition, the building-up of infrastructure (including the development of human resources), the stimulation of networking activities (and hence the concept of mobility), the financing of research programmes in basic “pervasive” technologies (prompting the notion of generic technologies), and the provision of S&T services, norms and standards. The rising role of S&T services and their importance to society have helped the introduction of concepts such as scientific literacy at first, then public understanding of science, scientific culture and social acceptance of new technologies.

To understand fully how these external, societal, constraints interacted with the internal structures (and capacities) of research policy institutions in the several western countries, we must look at the most decisive indicator of this sector --- the gross expenditure in R&D (GERD) in the U.S. The reason for this is simple: the influence of the big U.S. Government agencies, and of the leading multinational corporations and research universities was determinant for the development of S&T in the world since 1950.

The U.S. generates today about one-third of the world’s research articles, a multitude of technological innovations and numerous successful hi-tech industries (NSF, 2004). Further, the U.S. GERD represented up to the end of the 1970’s more than 50% of the total of OECD countries, even if by 2001 this value had decreased to approximately 43% of the OECD total, close to the combined share of the EU (29%) and Japan (16%) (OECD, 2004). Since 1953, U.S. GERD in constant dollars has increased almost ten-fold. But this rise has not been uniform --- the Korean and Vietnamese wars as well as the space exploration programmes have clearly affected its rate of growth --- as the war on terrorism launched at the end of 2001.

BOX 2.1

Science-policy regimes

If the U.S. GERD curve can serve as a proxy for the new science-based system of innovation that supports our knowledge-based economy, then the graph of the U.S. Federal R&D funding by performing sector, especially to industry, is a perfect indicator of research policy changes and adjustments in the last 50 years --- as shown in Figure 2.2.

------- FIGURE 2.2 ------

We can distinguish in Fig. 2.2 five different regimes, each corresponding to a different research policy goal and preoccupation. Let us indicate them briefly by the decades in which they occurred.

The 1950's corresponded to a period of **promotion** of S&T, in the wake of Vannevar Bush's seminal report "Science, the Endless Frontier", in which science was an important matter in the political agenda. Research policy was mainly determined by the scientists perspective of the further development of science and its applications.

The 1960's, with massive financial transfers to industry, helped install the S&T system with the notion that science was the engine of economic growth. The need to rationalise public spending led to widespread efforts of **planning** of S&T financial and human resources, bringing along an emphasis on the perspective of engineers and systems specialists.

In the 1970's, however, crisis and questioning of the model of growth led to tighter programmes of the public agencies concerning the private sector and to the need of integrating S&T policies in economic policies fostering innovation. In this climate, technology assessment and technology management emerged and the optic of **management** emerges in research policy. Managers began then to integrate the staff of policy units.

In the 1980's the world watched the intensification of the globalisation of finance and of the economy, of science and technology. Innovation was the key word then and once again public money flew more abundantly to industry. The notion of **evaluation** then surges as it becomes politically necessary to assure that public funds are being transferred to the private sector in a "useful" way. Science is now envisaged as an activity that generates strategic opportunities for business and the perspective of economists illuminates the spectrum of research policy options.

The 1990's watched the end of the cold war and again public funding to industry contracted. The art of **technology foresight** was rescued from the attic of science policy instruments and applied with renewed vigour as the building-up of the information society helped in lending to social scientists techniques an important role in the procedures of research policy machinery.

The first decade of the 21th century has sent until now mixed and troubled signals. Globalisation is with us, even if its impetus may seem as halting. Thus, research policy priorities may continue to be dominated by preoccupations related to competitiveness and market efficiency, namely through the influence of the deployment of successive waves of new **intellectual property rights**. We thus risk an invasion of lawyers, their perspective looming over the definition of the next packages of research policies.

The need of a supra-national vision

The European nations naturally suffered differentiated impacts caused by this evolution as they also participated in the overall process of societal development that led to the present. The establishment of the European Common Market and of the EU were important landmarks in the recent history of our continent.

The European Commission launched a wide range of research policies (RTD policies, in the European policy jargon), from R&D training and pre-competitive collaborative R&D to infrastructure oriented actions, including not only equipment but also innovation and knowledge transfer mechanisms. The Framework Programme (FP) is just one of the elements within the EU research policy.

Since the reforms of 1989, Structural Funds have become more oriented towards R&D and innovation. They attempt to make a major contribution in the context of EU research policy and for the cohesion of the European construction. Investments in R&D mechanisms were used as a means of stimulating self-sustained endogenous development. Further, other horizontal EU policies, such as competition policy, mobility, etc. interact significantly with overall research activities of Member Countries (MC). Their induced effects should not be overlooked.

The FP is the most visible instrument of EU research policy, though. What makes the FP different from other existing research funding programmes is the **European dimension**, the collaborative requirement and the scope of its strategic objectives. The FP has been growing in volume and relevance to the scientific communities of the MC, corresponding now (with the 6th FP) to a level of 5% of public investment in R&D in Europe. However it is very difficult to assess its overall contribution to the increase of the EU S&T potential and to the competitiveness of European industry, mainly because of the diversity of the national characteristics of MC and their systems of innovation. This is in clear contrast to the situation in the U.S., or in Japan.

Introducing a recent book on sectoral systems of innovation, Franco Malerba states that the «relationships between national institutions and [innovation environments] are quite important. First, national institutions --- such as the patent system, property rights or antitrust regulations --- have different effects on innovation in different sectors. Second, the same institution may take on different features in different countries and thus may affect innovation differently. Third, the characteristics of national institutions often favour specific sectors that fit them better. In some cases national institutions may constrain the development of innovations in specific sectors, with the result that mismatches between national institutions on one side and sectoral [European-prone] institutions and agents on the other side may take place. (…)» (Malerba, 2004). Thus the European landscape appears full of dimples that hamper the efficient circulation of our main resource --- knowledge. Radical innovations and novel preferences and values need thus an **early** recognition and a deft public **intervention** and support --- an attitude that is difficult to implement in the absence of well-established constituencies. National fears and ghosts always enhance the seeds of fragmentation.

The EC strived thus at stabilising the FP, since its inception in 1984, in the context of the strong constituency of industrial lobbies. The nuclear power industry, naturally, helped at first in assuring that energy would be a main priority in the FP's (45% of FP1, 22% of FP2); the information technologies and telecommunications sector leaders stressed the importance of ICT (23% of FP1, 42% of FP2); and the federation of chemical industries made sure that materials technologies, environment and biotech were not forgotten (22% in FP1, 32% in FP2).

FP priorities were essentially maintained during the 1990's, with relative changes in the financing of thematic areas, adapting their titles and work programmes to changing societal needs. FP6 (2002-2006) still allocates 11% to Euratom, 32% to Information Society Technologies and 21% to LifeSciences, Genomics and Biotechnology for Health; Nanotechnologies and Nanosciences account for 11%, Aeronautics and Space for 10%, Food Safety and Quality for 6%.

FP6 allocates 19% to Sustainable Development, Global Change and Ecosytems, and 2% to Citizens and Governance in a Knowledge-based Society, the societal preocupations brought about during the 1990's.

A significant change in FP constituency occurred as a result of the EC recomposition of 1999, during the exercise of the 5th FP (1998-2002). The Commission began to stress the role of the scientific communities in fostering innovation and European scientific competitiveness, and explicitly welcome the seeds of an European scientific community, searching actively for new future research constituencies for the FP.

As a result, the concept of the European Research Area (ERA) emerged, with the need of implementing its structures, mechanisms and coordination instruments to define coherent research and innovation policies. FP6 is allocating an amount equivalent to 22% of the funds that support thematic research (and in addition to them) to steer in that direction. And it introduced new mechanisms such as "Networks of Excellence", "Integrated Projects" and "Programmes Implemented Jointly" to help in structuring the projects in priority thematic areas with the same objectives.

Further, in the discussions engaging the establishment of FP7, the EC suggests the creation of a support mechanism for basic research projects through competition between teams at European level, an "agency" that could take the form of an European Research Council (ERC), functioning on the basis of scientific excellence only, assessed by peer review (COM, 2004).

This "basic science drift" has the merit of making us reflect on the fundamental objectives of the FP. Is the FP well-adapted to contribute to the accomplishment of the Lisbon strategy? And if yes, by how much?

Internationalisation of R&D

At the end of the 1990's the EU was voicing worries about the widening of the gap in performance with respect to the U.S. By then, the notion that the knowledge-based economy was the central factor of growth, competitiveness and employment, was established. And the admission that research and innovation were at the core of the new economy (or techno-economic paradigm) prompted the need to define a new strategy towards the future.

R&D expenditure overall in the EU during the 1990's had been relatively stable around 1.9% of GDP. Continuing that trend, the best the EU can hope for is 2.2.-2.3% around 2010 (EUR, 2003). Fig 2.3 displays this "best-case" scenario in the triadic context.

---- FIG. 2.3 ----

At the Lisbon European Council in 2000 the EU announced the ambitious goal of becoming by 2010 the most dynamic and competitive knowledge-based economy in the world. One of the projects launched at the Lisbon Council was the European Research Area (ERA), as a means to establish a reference framework for research in Europe --- recognizing that EU was behind the U.S. and Japan in research and innovation performance. GERD was 1.9% of GDP by then, compared with 2.7% in the U.S. and 3.1% in Japan.

Two years later, in the Barcelona European Council of 2002, the EU set itself the objective of increasing the European research effort to 3% of its GDP by 2010, with the (unfortunate) provision that two-thirds should come from private investment and one-third from the public sector.

But posting the EU in an open contest with the U.S. and Japan, being armed with the FP and the infant ERA together with a collection of national research policies loosely coordinated with EU policies and European organisations --- and without defining strict implementation mechanisms, was just a timid step in that direction. The issue is, really, to what extent is Europe an articulated territory in terms of policies and institutions to allow the monitoring of convergence to an average value, say "3%", has any meaning?

We know that we cannot compare the EU to the U.S., nor the U.S. to the individual European countries (because of their dimensions) nor even States in the U.S. to European MC (because they lack the wholeness of nation-states). But to get away from well-known averages, which are useful but hide dynamics and change, let us build a table for the indicator GERD/GDP for territories that have some political coherence and somewhat comparable population size: countries in Europe and states in the U.S. The results are displayed in Table 2.1.

----- TABLE 2.1 -----

From Table 2.1 we see that in the U.S. the national average is only meaningful in terms of overall resource allocation, probably the same situation being also true for the EU as a whole. For instance, would we disaggregate the national EU data at a regional level (NUTS II) we would get for Braunschweig, Stuttgart and Oberbayern, in Germany, the values of 6.34%, 4.84%, and 4.76%, respectively (EUR 2003). Maybe for large countries this disaggregation is useful. But how large is “being large”?

So, the achievement of the 3% target has to be considered in more detail, as we sense that, in Europe, new kinds of public interventions and policies must be called to play central roles in the process. The reason for this conviction stands on the perception that EU enterprises are not able to steer solely by themselves the collective endeavour towards a goal that was defined without a firm explicit commitment from their side; certainly new “rules of the game” have to be set.

The top 500 international R&D performers, which capture 60% of business R&D expenditure in the OECD area, include 132 companies which are EU-based, 208 U.S.-based and 127 Japan-based. The R&D share of U.S. firms is 44% of this amount. But the important question is: in which sectors?

«The ICT sector with 27.4% is the most important target of knowledge investment among the 500 top R&D performers, while in Europe its share comes up only to 16%. In Europe, automobiles rank first with 24% and pharmaceuticals second with 16%. In the world ranking the reverse order is seen.» (EUR, 2003).

With the belief in innovation, globalisation brought along the importance of services in the economy. In Europe, services account for roughly two-thirds of GDP and employment; a trend toward an increasing share of R&D by service-sector industries is visible in recent years, however with its value remaining below 15% of the total industrial R&D performed (NSF, 2004). In contrast, in the U.S. the service sector R&D volume rose during the late 1980’s and again at the end of the 1990’s to represent 35% of U.S. industrial R&D (see Figure 2.4).

---- FIGURE 2.4 ----

A more connective and interactive knowledge-based economy, naturally reinforces the role of services. This stems from a tendency to engage in longer interaction times between producer and user, namely from the more sophisticated ones, where the duration of communication is seen as the key-element in the relationship. Changes in regulation and technological change have created new opportunities for services provision, at a distance. Thus the rise of R&D in services is certainly associated with the spread of networking. NSF states that «[t]he R&D environment has changed in response to global markets; closer links between R&D and the creation of new products, services, and markets [have been established]; and the opportunities offered by advances in information and communication technologies [surged]. Industry has responded by outsourcing R&D both nationally and internationally, opening overseas operations, forming strategic alliances with U.S. and international partners, and engaging in both divestiture and acquisition of strategic technology units» (NSF, 2004).

These international R&D activities led by big companies may have mixed readings. The economic reach of U.S. multinational corporations is considerable. Two-thirds of the R&D performed abroad in 2000 by them took place in six countries: the United Kingdom, Germany, Canada, Japan, France and Sweden. Europe accounted for 12.9 billion U.S. research dollars, whereas research performed by European-owned companies in the U.S. amounted to 18.6 billion dollars (see Fig. 2.5).

---- FIGURE 2.5 ----

Foreign-owned R&D in the United States is performed primarily in manufacturing: chemicals, computer and electronic products, and transportation equipment --- practically the same three sectors that account for most of research performed by U.S. companies in Europe, which implies a high degree of internationalisation of research in these industries (NSF, 2004). This carries policy implications and presents policy-makers with renewed preoccupations, as it is not clear if outward R&D investments **complement** or **substitute** domestic R&D expenditures.

Issues for Europe

The completion of the Lisbon strategy is also influenced by European enlargement. Europe cannot be seen as mere wish, or as a target based on an average, which some have overtaken, others not, and which fluctuates as countries in different stages of economic and social development are associated politically with the core of the Union. To become a performing knowledge-based economy in the world, the conditions of societal adjustment must be in phase in all MC. **Fragmentation** has to be avoided at all costs.

Therefore we need to develop along with ERA a new set of European institutions and organisations --- ERC launched alone will be like the NSF standing in the desert without the NIH, NASA, DOE, NIST and, last but not least, the Pentagon. A new framework of European institutions and organisations must encompass the strategies of CERN, ESA, EMBO, ESO, etc. and articulate them in an overall blueprint for the European future.

Otherwise, enlargement will be seen as an opportunity on a one-to-one basis, and of building a whole equal to, or even minor than, the sum of its parts. And objectives like the Barcelona target will be difficult to implement due to the need of articulating a whole set of new policies (innovation, human resources, etc.) together with research policy. Society, with its finely-woven fabric of interactions, has also been changing and adapting in novel and unexpected ways. We must understand their breadth and implications. Shall the **social sciences** be kept aside the crucial mechanisms implementing the information society?

ERA is a starting point of a large assembly of people who believe that knowledge and learning are the central resources and mechanisms of our renewed nations and communities. Research policy has to be articulated intimately with innovation policy and closely linked to policies in other sectors, especially education and international cooperation. Otherwise, how can we feed ERA with the new 500,000 - 700,000 researchers it needs to perform at a 3% level in 2010?

Further, implications of the free circulation of knowledge will have to be recognised and fostered: scientific disciplines can only evolve in the context of a strong communicative framework involving technologies, specialised crafts, laws and regulations, business management and fine arts. And the diffusion of new learning abilities throughout European civil society, leading to the build-up of more adequate competences to cope with change, will have to follow.

New directions have to be attempted if the EU wants to steer this crucial adjustment phase. All these changes indicate the need of a strong policy for human resources in the EU, from education to research to the understanding of the culture of science. In our knowledge-based society, which generates innovative change from basic science, no societal issue can be dealt with excluding scientific practice: from the oceans to climate change, from public health to the environment, from transportation to communication, from welfare to social exclusion. If our education systems were invented as a means to support the development of industrial society, no doubt that they welcome a **re-invention** at the dawn of the knowledge-based era.

BOX 2.2

Perceptions of the future

At the beginning of the **1990's**, the OECD listed a series of issues arising from the perception of the situation in the area, read through the available indicators (OECD, 1992):

- the growth of R&D spending in the 1980's has been higher than GDP but there has been a recent slowdown. What will be the trend in the next decade?
- the role of enterprises in the performance of R&D has been growing. Has a limit been reached?
- we have witnessed a concentration of the R&D effort in the big countries, but also a dispersion of technological capacity (measured by hi-tech exports); what is the meaning of this tendency?
- the gap between industrialised countries and countries in other regions is continuing, and in cases even widening; how can we reduce the risk of potential conflicts?

Today, after a decade of full-blown globalisation, we can safely answer the first three questions; the fourth, unfortunately, is still looming over our societies. But new issues have arisen. Here is a list of, also, four:

- multinational corporations are the most efficient organisations in our economy; but can we rely on them for directing and structuring the knowledge-based economy?
- universities are essential cornerstones of modern systems of innovation; but are universities really innovative?
- the unimpeded circulation of knowledge needs to be regulated by intellectual property rights; but have these rights the capacity to organise the new world?
- The U.S. is today the indisputed superpower; but will the U.S. be able to maintain their leadership until and throughout the next structural crisis of adjustment?

By **2010**, changes to science and technology in Europe will hopefully allow us an easier response to the above questions. However, future-prone policy measures will have also to be implemented for that to happen.

3. SCIENCE AND TECHNOLOGY IN A CHANGING WORLD

The new enabling conditions and constraints that society impose on modern science practice evolve in conjunction with an escalation of uncertainties and instabilities in a context of demographic growth, urban sprawl, climate change and perturbing inequalities.

But maybe we should not have expected that the creation of a new knowledge-based society, involving strenuous cycles of change and adjustment, was a triumphal promenade towards the future. Rather, we should have been prepared to exert our sagacity in choosing between conflitual directions with severe and irreversible consequences. Contingency rules the world around us: only science, and the best available science, can enable humankind to see through the mists of complexity.

Knowledge-based society transformed the links between science and innovation, and also between science and education into such strong and essential bases of its operation that education, science and innovation appear now almost as a continuum, which must be treated in close articulation. Science is no longer at the end, or at the beginning, of specific societal processes. The level of science pervasiveness is a measure of achievement of a knowledge-based society.

New and emerging fields

Therefore we must expect a strong social-inducing effect in the development of science due to the need of supporting technological change. Globalisation has provided a strong impetus to this phenomenon: new fields of S&T have followed the initial advances in nuclear and solid state physics, materials science and biochemistry, molecular biology and neurosciences. We have thus been watching the emergence of new clusters of S&T areas which can possibly lay the pillars of a new techno-economic paradigm based on **molecularisation**: nanosciences and nanotechologies, biosciences and biomaterials, new communication and information processing technologies. On the other hand, basic science has been proceeding also by extending the space-time limits of our universe and by creating new states of matter, by attempting to create life anew and to understand consciousness. How can society be neutral with respect to the scientific effort?

The diversity and specialization of contemporary science is thus a measure of the **success** of science-based technology production, or S&T.

No big nation, or concert of nations, can afford to thwart the march of science. But the questions are: which directions to choose (because it is impossible to be excellent everywhere across the board); which impetus to allocate (as research structure and resources are interdependent); how much monitoring to exert (the level of autonomy) to assure expected returns?

The EU cannot afford to let science drift as time goes by, being directed solely by the geo-strategic objectives of big countries and the interests of big corporations and syndicates. The Lisbon strategy has the merit of clearly assuming such attitude.

Scientific performance

Preoccupations with the state of science performance, and with the relative strength of research across a wide range of countries, have induced attempts to assess the quality of scientific work (and maybe its efficiency): these are common at present. The scientific wealth of nations is an issue of today’s globalised world.

In a recent study published in Nature, David King analyses what different countries obtain in relation to their research spending, an indicator of its “scientific impact” (King, 2004). A key comparison is made between scientific wealth --- measured by the ratio between total citations and GDP: the citation intensity --- and economic wealth --- using GDP per capita as proxy. The results are displayed in Figure 3.1.

---- FIGURE 3.1 -----

From the data shown in the figure, we can associate strong performances to small nations, namely Switzerland, the Scandinavian countries, Israel and the Netherlands. On the other hand, big developing countries like India and China display very low citation intensities.

Another interesting analysis King attempts is on disciplinary strengths. Comparing namely the U.S. with EU (15), one finds the EU a little stronger in the physical sciences and engineering whereas the U.S. has the lead in life and medical sciences. But it is worth reflecting on the first sentences of the last paragraph of the study: «[a] strong science base need not lead directly to wealth generation. For instance, although the strength of the UK science base has long been acknowledged, it has only recently begun to translate into the development of high-tech clusters accompanying knowledge transfer between higher education and industry. However, strength in science has additional benefits for individual nations, and for the world as a whole».

But who benefits most? This is the question most policy-makers select as the main trigger of their present anguish.

Voices are being heard in the U.S. that they are loosing worldwide dominance in critical areas of science and innovation. Whatever their relevance, they reveal the outlines of a changing situation. These preocupations certainly originate because of matters regarding scientific output and institutions, and qualified human resources.

Let us examine first the trends of scientific production, as displayed in Fig. 3.2, concerning science and engineering papers published between 1988 and 2001.

---- FIGURE 3.2 ----

NSF recognises that the U.S. share of world output has declined, which indicates that cutting-edge research capabilities are being developed elsewhere (NSF, 2004). Europe has overtaken the U.S. in scientific output. Asian developing economies are also raising their scientific strength. What does this mean? However, we cannot attempt at figuring the whole by observing it solely through a partial perspective.

By looking at citations in science and engineering papers we can see that U.S. researchers continue to make important contributions to world's S&T knowledge, as evidenced by the high frequency with which they are cited by other researchers (NSF, 2004). Global citation data are depicted in Figure 3.3.

---- FIGURE 3.3 ----

The increase in citation of European scientific literature was led by some countries which exhibit dynamic scientific productivity, namely smaller members of the E.U. The overall meaning of these trends needs further consideration. Does this signify that European competitiveness is increasing? And, if yes, by how much? Is **enlargement** a competitive advantage? What are its limits?

Naturally these are issues worth considering when it is known that some 450,000 European-born researchers are working in the U.S. Let us turn our attention now to the second matter outlined above, namely that of institutions. Among the various types of scientific institutions we will choose the universities.

Learning and research

Universities were a European invention and they function as an essential element in scientific training, besides housing a large fraction of basic research performed in national S&T systems. In the strategy of Lisbon, universities are deemed to represent central nodes in knowledge production. We know that the older universities missed the scientific revolution, and only caught-up with science much later. Will the same fate be bestowed upon European universities now, when the surge of information technologies is revolutionising our behaviour?

On the other hand, U.S. academics are worrying about the capacity of their universities to withstand the pressure imposed by recent constraints. In a series of two recent editorials, appropriately entitled "Academic Health", Science's Editor-in-Chief warns against the increase in restrictions in public research awards (Kennedy, 2004). However, for the author, the deeper problem in higher education is «the steady erosion in the economic health of its great state-supported public universities», whose continued endeavour allowed the blooming of the new model --- the research university --- to flourish and impregnate the world. Apparently, apart from the U.S., the «powerful economic engine higher education represents» is not yet so cleary perceived. Even if aggregate comparison data have their limitations, as discussed before, the data represented in Figure 3.4. yield an interesting reflection.

---- FIGURE 3.4 ----

But are European universities as attractive as their U.S. counterparts? Taking as a measure of attractiveness a series of high-visibility science indicators such as numbers of Nobel laureates, Fields medals, highly-cited researchers, articles in Nature and Science, and articles in SCI and SSCI, as in the study of the Shangai Jiao Tong University, we get: (i) in the top-10 world universities --- two European ones (Cambridge, #3; and Oxford, #8); (ii) in the top-20 --- the same two universities, plus seventeen U.S. universities and one Japanese (Tokyo, #14), (Liu et al., 2004).

However, if we take a different measure of attractiveness, namely research expenditure, we get a different picture. NSF provides data on R&D expenditure of U.S. universities (NSF, 2004). In the EU no such comprehensive survey exists. Considering therefore just data for the research income of UK universities (total research grants plus contract income plus funding council recurrent grant) we can get somewhat comparable figures (Evidence, 2003). The top UK performer in 2001/2002 was the University of Oxford with a research income of 214.704 M£, which converts into some 365 million dollars. This ranks the University of Oxford just below Harvard University, and at the level of the Universities of Arizona and of Colorado. The data are presented in Table 3.1.

---- TABLE 3.1 ----

There may be reasons for such a situation. National education policies do not favour competition among universities and academic staff salaries are usually indexed to national pay scales. Signs of change are appearing though: a recent statement by the German federal research minister announced that «from 2006 to 2010, up to ten [German] universities were to receive an extra €50 million each year for hiring top scientists, modernizing labs, and improving research and education (…) [to] help a few elite institutions to compete internationally» (Schiermeier, 2004). Only the future will tell us how much momentum this seed of change is able to gather.

It is here that concerns about the conduction of the Bologna process must be expressed. Shouldn't Bologna be reframed in terms of its **contribution** to the Barcelona target? And shouldn't the European budget be **redirected** to concentrate also in creating the conditions for the emergence of ten research universities in the EU, capable of being listed in the top-20 universities of the world?

Qualified human resources

Let us now consider the issue of human resources for S&T. «People are Europe's main asset and should be the focal point of the Union's policies» stated the European Council at Lisbon in 2000. In fact, the performance of a knowledge-based economy is critically dependent upon the quality of human resources, on their knowledge competences, on their abilities to learn. And advanced societies have, in the last two decades, been implementing science-based innovation systems, which require a highly qualified labour force.
Employment in research and technological development in the U.S. has been growing faster than overall employment in the last decades. The data displayed in Figure 3.5 shows this trend, which reflects also a result of the ability to attract foreign-born scientists and engineers.

----- FIGURE 3.5 -----

The training of human resources for S&T can be sketched as a diagram depicting successive stages of qualification with a main path of progression and, for each stage, a possibility of feed-back loops, as in Figure 3.6 (EUR, 2003).

----- FIGURE 3.6 -----

From the diagram it is easy to understand that, in each nation, the level of research employment is primarily determined by the rate of S&T doctoral production combined with the intervention of two regulators: (i) that of the exit to a non-research job and, eventually, emigration --- in this case, the **brain-drain** effect; and (ii) the entry of immigrant researchers – the **brain-gain**. It is no wonder that, in a globalising world, the mobility of research workers is increasing; this is reason why the **attractiveness** of S&T human resources is becoming an important issue in human resources policy.

The U.S. recognizes that "[as] nations have turned to the task of developing a broader base of knowledge – intensive industries [and services], they face the necessity of rethinking their workforce needs. Many are further expanding their education systems, placing emphasis on S&T training. Japan and the mature industrial nations of Europe, which have ageing and declining or stagnating populations, are seeking an inflow of scientists and engineers from abroad as well as the return of their own researchers from other countries." (NSF, 2004).

In the 1990's the U.S. were able to integrate some two million highly qualified immigrants in professional S&T jobs. But fears are being raised now about the possibility of a slowdown of the growth of the S&T workforce. In Europe we face the challenge of meeting the Barcelona target. A simple calculation shows that without a massive inflow of some 600,000 researchers the EU objective will be ranked as an illusion.

The rate of production of doctoral degrees in Europe is, also, incompatible with the achievement of the objective in the next decade, indicated in Figure 3.7 (in the diagram, Europe includes only France, Germany and the UK). Or, else, a courageous policy of attraction of non-European researchers must be implemented.

---- FIGURE 3.7 ----

New policies and actions are thus needed, and the fears of a declining interest in science studies among the younger generations derive from real problems that have to be dealt with at a much global level than the sectoral or the national levels. We have to understand the shifting patterns of change of a globalised society in search of its identity.

We must not confuse “interest in science” with “scientific occupation”. If better job opportunities are being offered in law, medicine, architecture, finance, the media, etc. than in science, why should the brightest youngsters choose scientific careers?

Scientific productivity is being used as a prime determinant of researchers careers and of the level of science financing. But can we identify with ease the entities who overall control science?

The scientific condition

This reveals the dysfunctions of the scientific condition today, and why we must not envisage this issue as a temporary one. Science has fallen victim of its own success: the teaching of science, the deepening and enlargement of the scientific culture of citizens, the furthering of experimentation and of critical attitude, are at the center of our well-being and welfare. But science is being engulfed by “technoscience”, a swift change from “S&T” to “T&S”.

BOX 3.1

Science and technoscience

Only the most naïve may envisage the unfolding of technoscience as being neutral in social terms. In fact, the scientific enterprise is changing from an **exploitation of nature** to a **production of life**. The culture of technoscience is more and more aiming towards the direct control of the human beings by centering its weight on the knowledge of physiological and psychological behaviour rather than through the intermediate effect of understanding and coping with the forces of nature.

By acting on procreation, on embryo development, on birth, on sexuality, on aging, and on death, biological technoscience influences directly the emotions of the individuals. Ethics thus erupts for the wrong reasons: rather than a stimulus to the improvement of new modes of conduct, ethics is being applied essentially to formulate interdictions.

The social image globally projected by science is no longer that of the researcher who doubts, who questions the limits of knowledge, but rather that of the engineer who is certain about the measures to be implemented to obtain the most efficient responses, or that of the specialist who presents practical solutions to resolve the problems of development and quality of life in a community.

The social impact of science is therefore associated with the usefulness or with the problematic effects of the products that are based in science and its principles. The current relationship between science and power, in the political, economic and military spheres, does not favour the understanding of the essential civic role of contemporary scientific practice – on the contrary, it conceals it.

We now watch a wide proliferation and renovation of pseudo-knowledge in all the media. The strategy followed by the practitioners of pseudo-knowledge is that of “certainty” versus the methodological “doubt”, that of escaping confrontation between subject and object, that of finding refuge in unknown powers. It is based on the detection of flaws in the public system concerning scientific culture, in conjunction with the dysfunctions that exist in teaching the practice of active citizenship. That is, the space of occultation in contemporary society thrives on superstition, and feeds on intolerance.

We have to stimulate in the younger generations the pleasure of discovery, the love of learning, the joy of imagination. New generations must feel the need to change, to take risks, to transform things. The experimental teaching of science is a considerable contribution to this objective, encouraging and stimulating a systematic attitude of **openness** towards the world and the other human beings.

Favouring scientific practices is the best guarantee that there will be a strong sense of participation in society, that the desire to know and to learn will be fostered. Citizens need to understand the major questions involving science in our contemporary world -— because it is in the present that decisions are made, even though the action will necessarily take place in the future. Solidarity between the present and the future therefore depends on how freely we embrace the scientific adventure.

4. ACKNOWLEDGEMENTS

In the course of the analysis, several choices had to be made with regard to conciseness and intelligibility, probably not the most adroit ones. These faults rest entirely upon the author. The careful reading of the manuscript and the suggestions of Manuel Mira Godinho greatly improved the text, a contribution that is gratefully acknowledged. The assistance of Neville Reeve during all phases of the preparation of the paper is also acknowledged. And thanks are due to Deborah Mota, Alcina Mota, Inês Mascarenhas, Rita Rebelo de Andrade and Francisca Moura for all the help and encouragement provided.

REFERENCES

Commission of the European Commities, “Science and Technology, the key to Europe’s future” COM (2004) 353 final.

Delanghe H., Duchêne V. and Muldur U., “À l’aube d’une nouvelle vague de croissance”, Futuribles nº 300 (2004) p. 19-49.

EUR (20025) “Third European Report on Science & Technology indicators”, EC, Luxembourg 2003.

Evidence Ltd, “UK High Education Research Yearbook”, 2003.

Freeman C. and Louçã F., “As time goes by”, Oxford University Press, Oxford 2001.

Gibbons M., Limoges C., Nowotny H., Schwartzman S., Scott P. and Trow M., “The new production of knowledge”, Sage Publications, London 1994.

Kennedy D., “Academic Health” (2 editorials), Science vol. 305 (2004) p. 1077 and p. 1213.

King D.A., “The scientific impact of nations”, Nature vol. 430 (2004) p. 311-316.

Liu N.C., Cheng Y. and Liu L., “Academic Ranking of World Universities 2004”, Shangai Jiao Tong University, Shangai 2004.

Malerba F. (ed.), “Sectoral Systems of Innovation”, Cambrigde University Press, Cambridge 2004.

NSF “Science and Engineering Indicators 2004”, National Science Foundation, Arlington 2004.

OECD “Science and Technology – Review and Outlook”, Paris 1992.

OECD “Main Science and Technology Indicators” vol. 2004/1, Paris 2004.

Polanyi K., “The great transformation”, Beacon Press, Boston 1957.

Schiermeier Q., “Political wrangling derails German university reforms”, Nature vol. 430 (2004) p. 283.

TABLE 2.1

Top-20 "regional" R&D performers (2000/2001)

Country or State (U.S.)	GERD / GDP (*) (%)
New Mexico	5.87
Michigan	5.84
Washington	4.82
Maryland	4.67
Massachusetts	4.59
Sweden	4.27
Rhode Island	4.16
California	4.14
Delaware	4.11
Idaho	3.90
District of Columbia	3.83
New Jersey	3.67
Finland	3.41
Japan	3.07
Iceland	3.06
Connecticut	3.02
Korea	2.92
Ilinois	2.74
Switzerland	2.57
Vermont	2.57
(Germany)	(2.51)

Note: (*) GSP for U.S. States

Sources: Main Science and Technology Indicators vol. 2004/1, OECD

Science and Engineering Indicators 2004, National Science Foundation

TABLE 3.1

Top-20 academic R&D performers (2001/2002)

University	R&D expendidure (U.S. M$)
Johns Hopkins Univ. (*)	999
U. of California – L.A. (public)	694
U. of Wisconsin – Madison (public)	604
U. of Michigan (public)	601
U. of Washington-Seattle (public)	590
U. of California – S. Diego (public)	557
U. of California – S. Francisco (public)	525
Stanford Univ.	483
U. of Pennsylvania	470
U. of Minnesota (public)	462
Penn.State Univ. (public)	458
U. of California (Berkeley) (public)	446
Cornell Univ.	444
M.I.T.	435
U. of California – Davis (public)	432
Texas A&M Univ. (public)	407
Washington Univ.	407
U. of Illinois (public)	391
Ohio State Univ. (public)	391
Baylor Coll. of Medicine	381
(Duke Univ.)	(375)
(Harvard Univ.)	(372)
(U. of Oxford)	(365+)

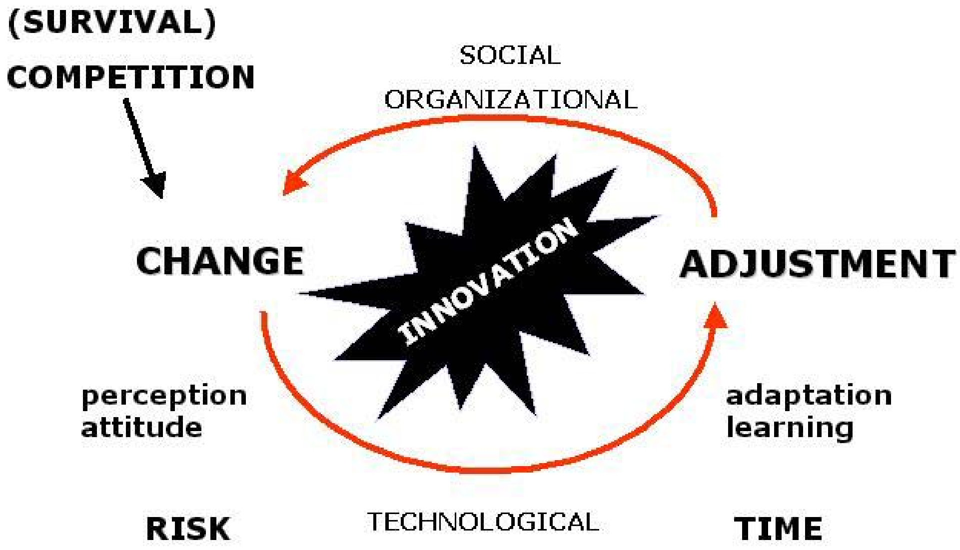
Notes: (*) including the Johns Hopkins Applied Physics Laboratory

(public) refers to institutional control

Sources: Science and Engineering Indicators 2004, National Science Foundation

UK High Education Research Yearbook 2003, Evidence Ltd

TRANSFORMATIONS IN SOCIETY

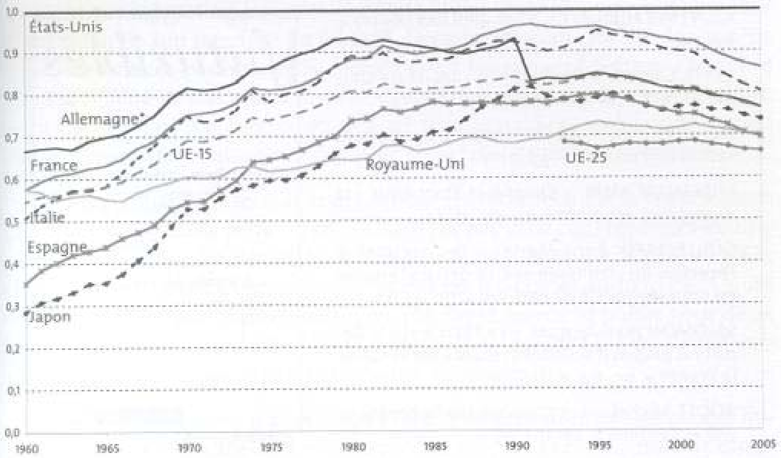


Source: Polanyi 1944

FIG. 1.1

Graphique 2 — Productivité dans les grandes économies de l'Union européenne (UE) relativement aux États-unis (base = 1), 1960-2005

(mesurée à partir du PIB par personne employée en standards de pouvoir d'achat, en euros 1995)

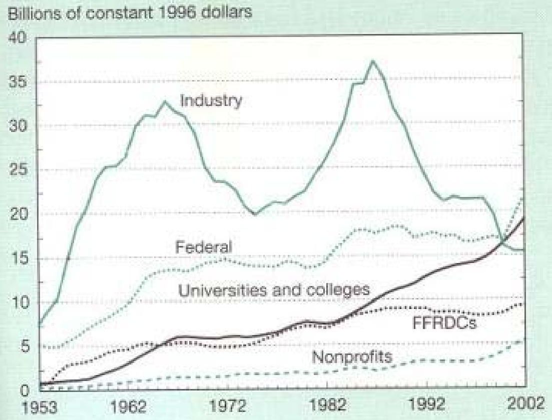


Source : services de la Commission européenne, banque de données AMECO (Annual Macro-Economic Database).

*République fédérale d'Allemagne de 1960 à 1990, Allemagne réunifiée à partir de 1991.

FIG. 2.1

Figure 4-13
Federal R&D support, by performing sector: 1953–2002



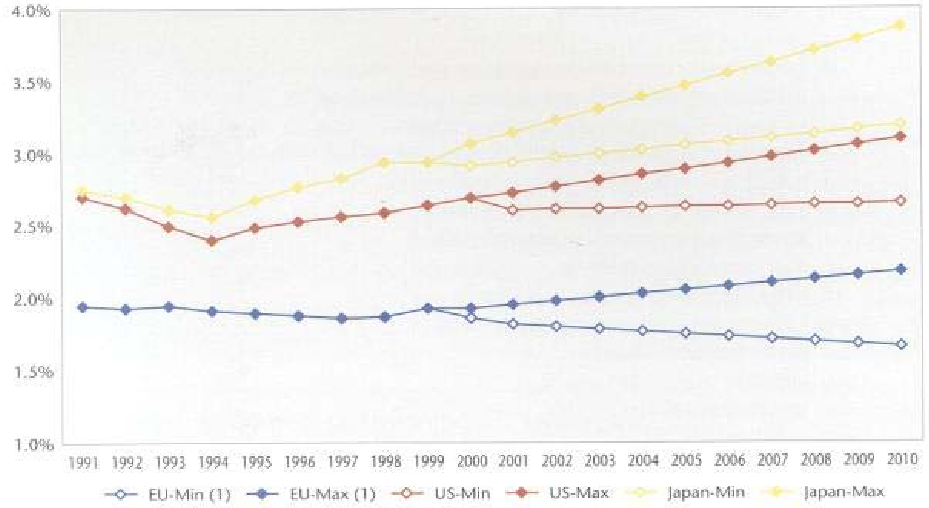
FFRDC federally funded research and development center

SOURCE: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources*, annual series. See appendix table 4-6.

Science & Engineering Indicators – 2004

FIG.2.2

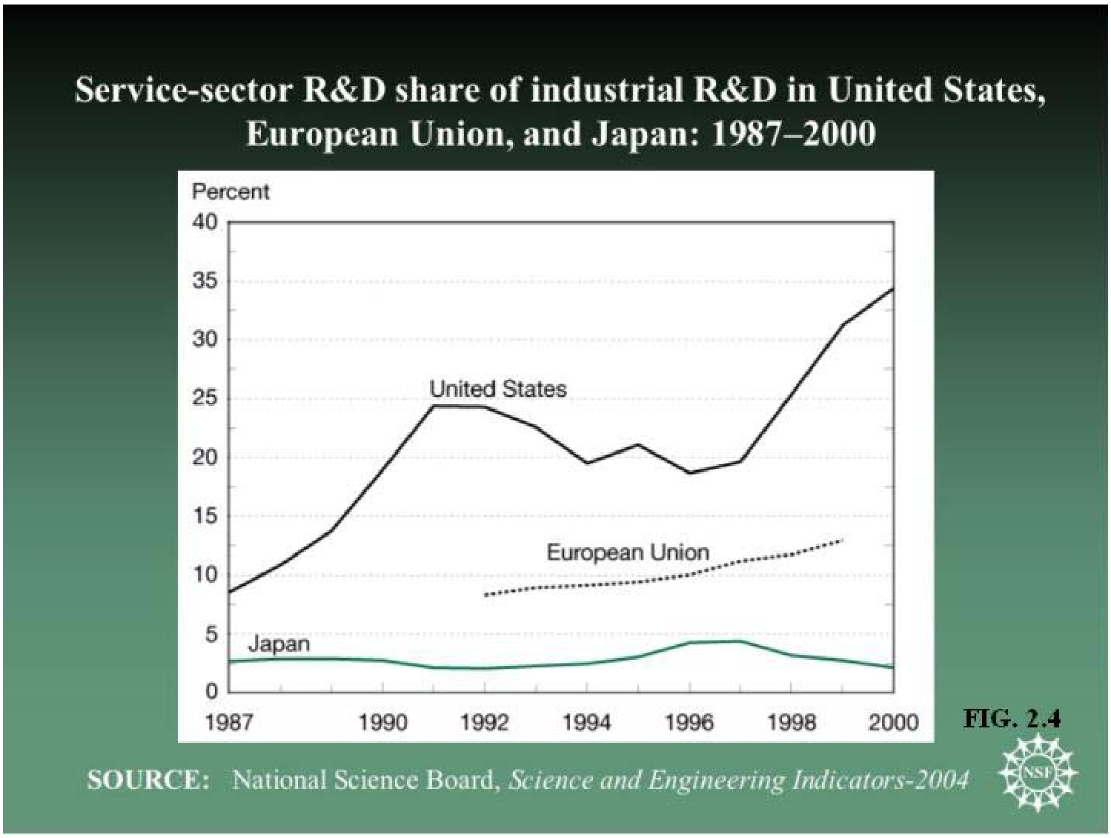
Figure 2.1.6 R&D intensity (%) – forecast to 2010 with minimum and maximum projections, and with the presumption that no major changes in policy or in the R&D environment as a whole will occur



Source: DG Research
Data: Basic data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates. Projections: DG Research
Note: (1) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

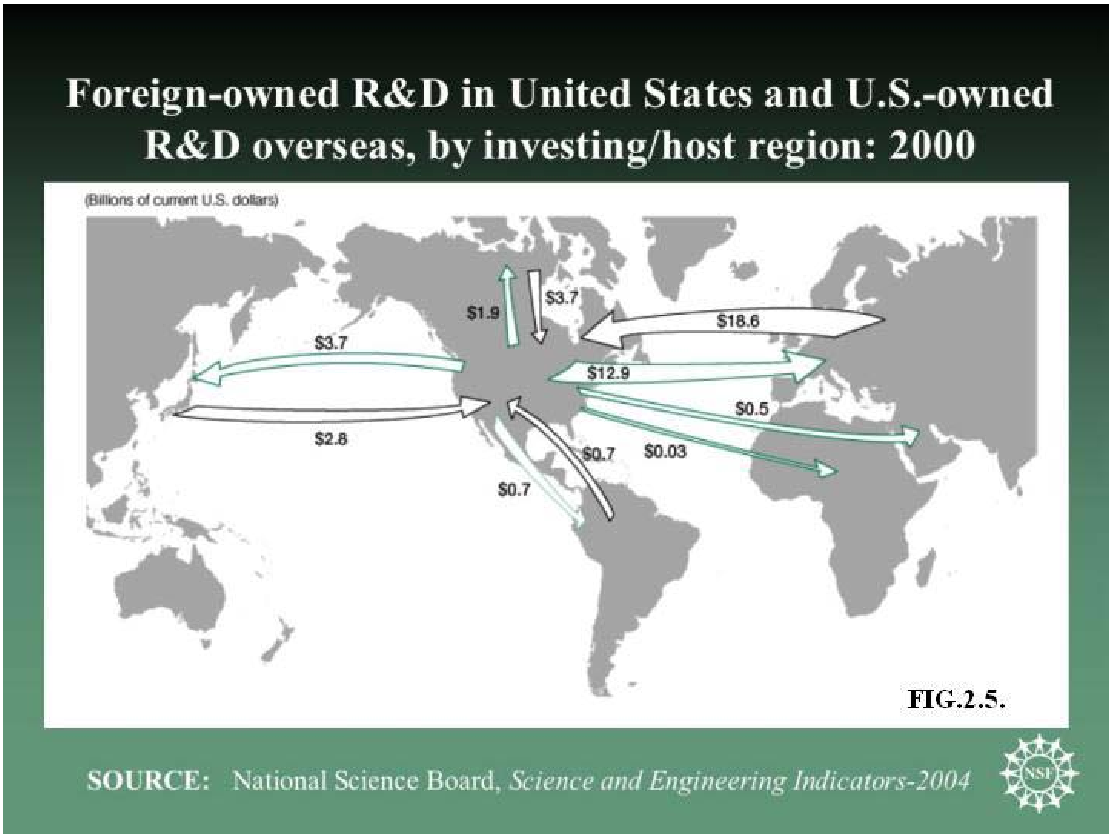
FIG. 2.3



Service-sector R&D share of industrial R&D in United States, European Union, and Japan: 1987–2000

FIG. 2.4

SOURCE: National Science Board, *Science and Engineering Indicators-2004*



Foreign-owned R&D in United States and U.S.-owned R&D overseas, by investing/host region: 2000

FIG.2.5.

SOURCE: National Science Board, *Science and Engineering Indicators-2004*

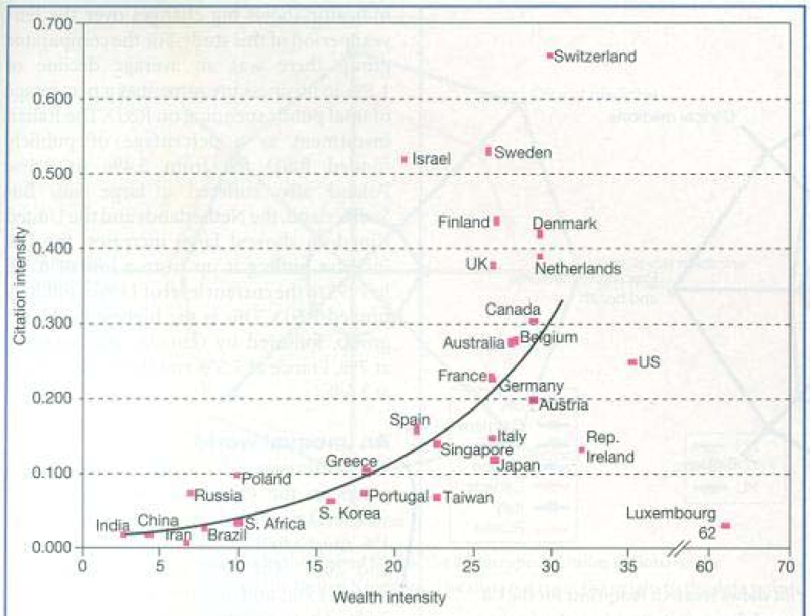
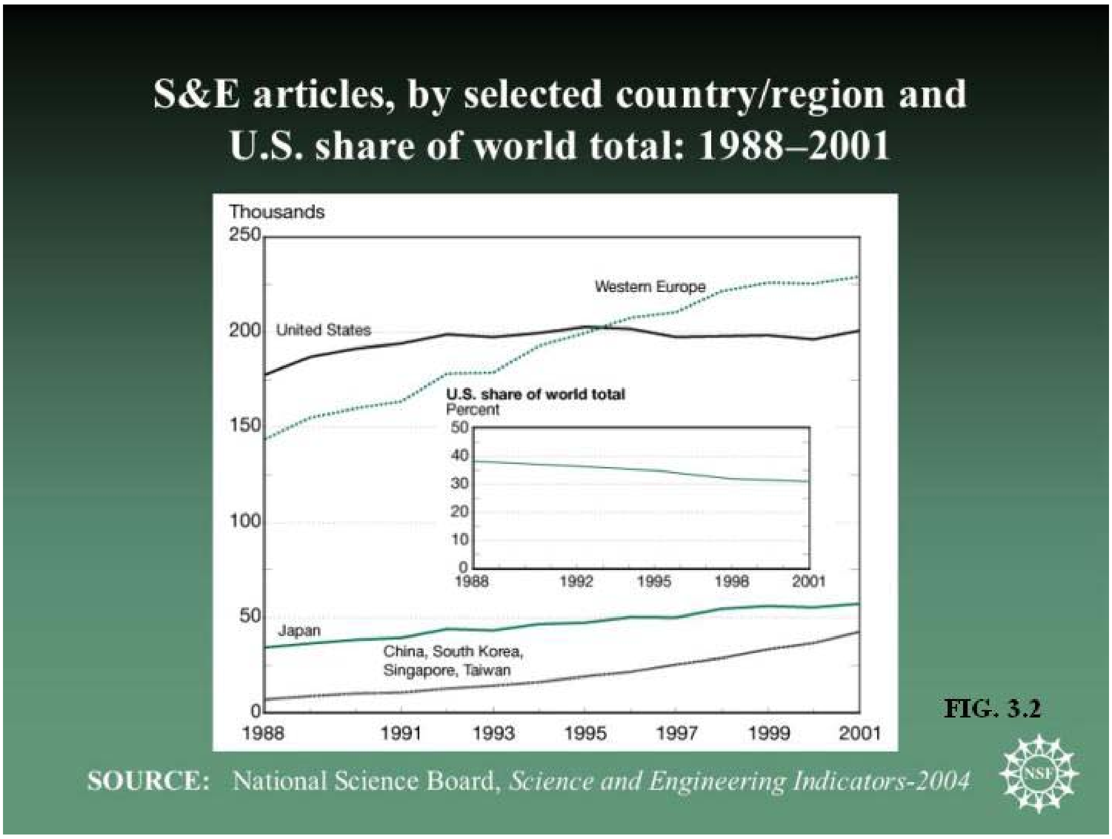


Figure 2 **Comparing economic and scientific wealth. National science citation intensity, measured as the ratio of the citations to all papers to the national GDP, shown as a function of the national wealth intensity, or GDP per person, for the 31 nations in the comparator group. GDP and wealth intensity are given in thousands of US dollars at 1995 purchasing-power parity. Sources: Thomson ISI, OECD and the World Bank.**

FIG.3.1.



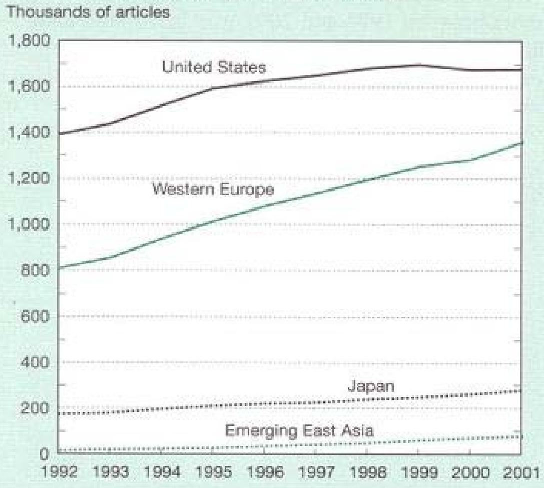
S&E articles, by selected country/region and U.S. share of world total: 1988–2001

FIG. 3.2

SOURCE: National Science Board, *Science and Engineering Indicators-2004*

Figure 5-41

Scientific research cited in S&E articles, by selected countries/regions: 1992–2001



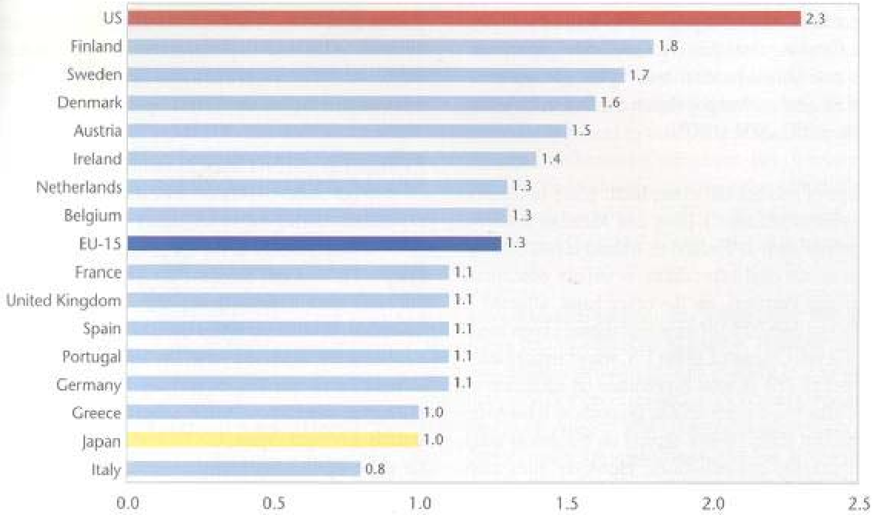
NOTE: Emerging East Asia consists of China, Singapore, South Korea, and Taiwan.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-48.

Science & Engineering Indicators – 2004

FIG. 3.3

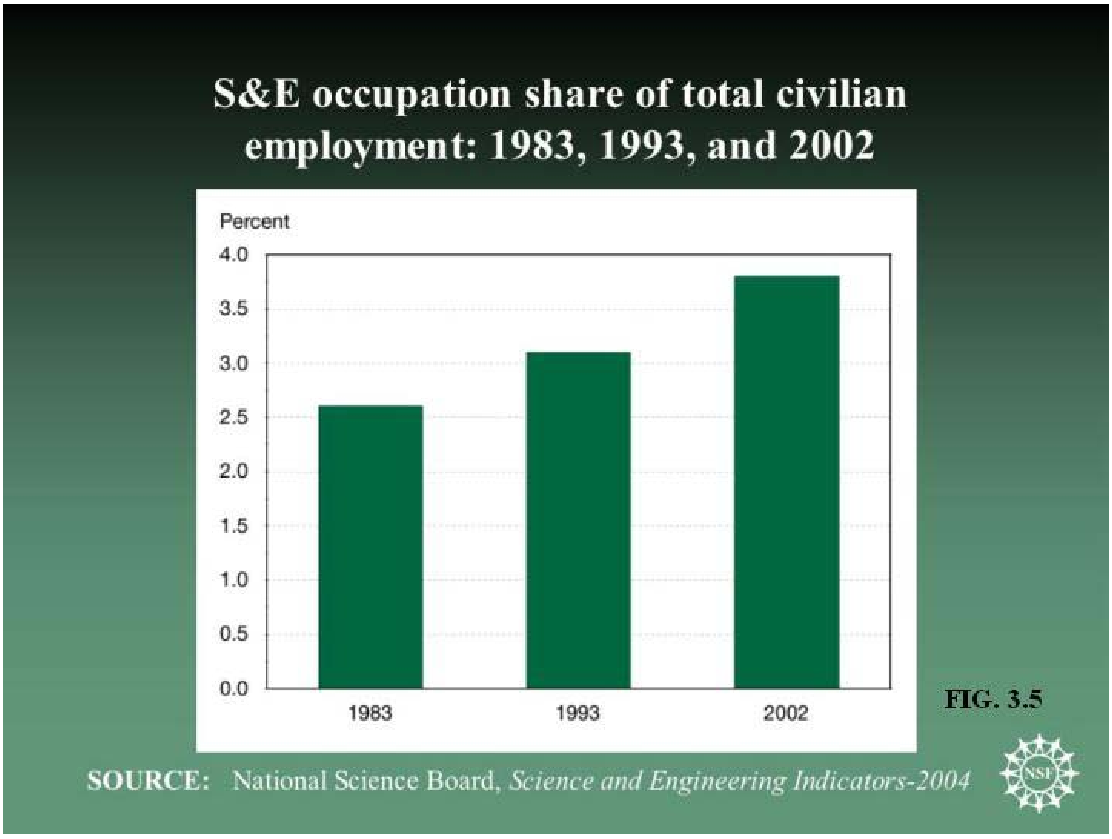
Figure 4.3.4 Expenditure on tertiary education as percentage of GDP 1999



Source:	DG Research
Data:	OECD 2001 and 2002
Note:	No data available for L. B: public expenditure only. EU-15 figure is a simple country average calculated across all countries for which data are available. Estimates: DG Research.

FIG. 3.4

Third European Report on S&T Indicators, 2003



S&E occupation share of total civilian employment: 1983, 1993, and 2002

FIG. 3.5

SOURCE: National Science Board, *Science and Engineering Indicators-2004*

Figure 4.0.1 The education pipeline for human resources in S&T

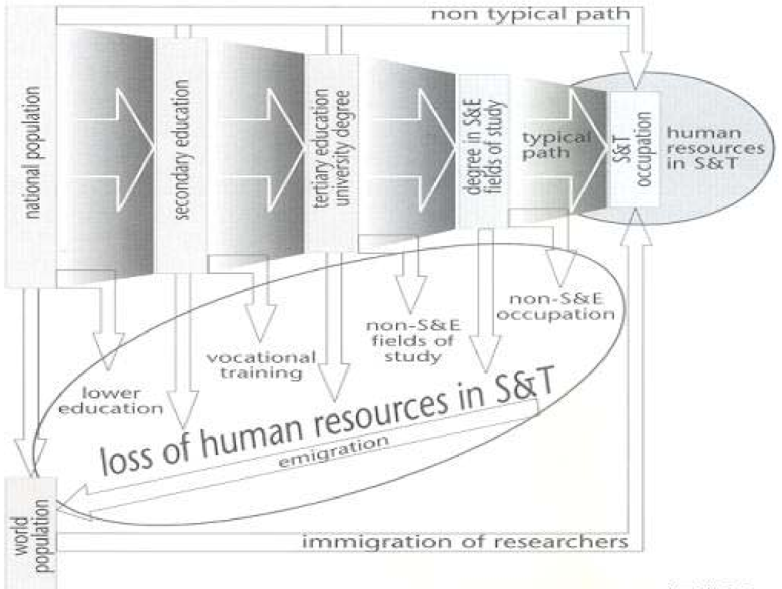
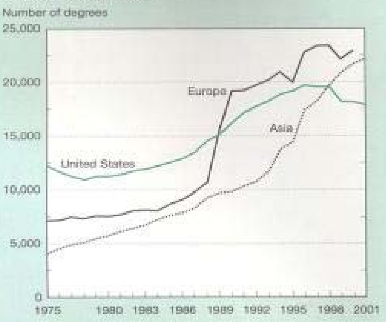


FIG. 3.6

Source: DG Research
Third European Report on S&T Indicators, 2003

Figure 2-38
NS&E doctoral degrees in United States, Europe, and Asia: 1975–2001



NS&E natural sciences and engineering

NOTES: NS&E includes natural (physical, biological, earth, atmospheric, and ocean sciences), agricultural, and computer sciences; mathematics; and engineering. Europe includes only France, Germany, and the United Kingdom. Asia includes only China, India, Japan, South Korea, and Taiwan. The jump in the European data in 1989 is due to the inclusion of French data, which were unavailable in this data series before 1989. French data are estimated for 2000.

SOURCES: France—National Ministry of Education and Research, *Rapport sur les Études Doctorales;* Germany— Federal Statistical Office, *Prüfungen an Hochschulen;* United Kingdom—Higher Education Statistics Agency, special tabulations; China—National Research Center for Science and Technology for Development; India—Department of Science and Technology, *Research and Development Statistics;* Japan—Government of Japan, Monbusho Survey of Education; South Korea—Ministry of Education, *Statistical Yearbook of Education;* and Organisation for Economic Co-operation and Development, *Education at a Glance 2002;* Taiwan—Ministry of Education, *Educational Statistics of the Republic of China;* and United States—National Science Foundation, Division of Science Resources Statistics, *Science and Engineering Doctorate Awards.* See appendix tables 2-26, 2-38, and 2-39.

Science & Engineering Indicators – 2004

FIG. 3.7