science, innovation and society: shifting the possibility frontier

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The book you hold before you, published by BBVA, stands in tandem with the BBVA Foundation Frontiers of Knowledge Awards, whose first edition is about to be decided as these lines are being written. These awards, with a monetary amount among the highest in the world, are to be granted annually to teams of researchers and creators in eight categories—precisely the eight fields covered in this publication.

BBVA earns no immediate return from this initiative to foster the generation and dissemination of knowledge. Our group is not a part of the pharmaceuticals, information technology or telecommunications sector, or of any other industry that might obtain direct commercial benefits from the results of scientific research. Nevertheless, its purpose connects with two key vectors of BBVA's culture, strategy and activity: to work for a better future for people; and to do so by means of innovation, anchored in turn on the best available knowledge. We are convinced that, in this way, BBVA is fulfilling one of the functions that companies in general, and leading multinationals in particular, are called on to perform in the global society of the twenty-first century.

The BBVA knowledge agenda: innovation and corporate responsibility

There are currently over 70,000 multinational corporations in the world and they represent 25% of its economic production. In the last two decades, the combined foreign investment of these companies has exceeded the total amount of official development aid. They can thus be considered the main instruments for the construction of a global economy and society, facilitating the worldwide spread of technology, values and more modern and efficient commercial and management practices. Moreover, large corporations have an enormous social presence and impact through their employees, customers and suppliers, so can act as powerful catalysts for innovation and the transition to a sustainable world.

Companies cannot be a part of the world's problems; they have to be a part of their solution, and a vital one at that. In the twenty-first century, any responsible company attuned to the legitimate demands of its stakeholders has the duty to work for the improvement of the societies where it does business. And it has two very important reasons for doing so: conviction and interest. Conviction, because its actions must be guided by ethical considerations and the core values of corporate culture. Interest, because, in an increasingly informed and demanding society, companies need greater legitimacy if they are to successfully carry forward a long-term project, and because a prosperous and stable society is both a result and pre-condition of corporate development.

If that is the case for all companies, it is even more so for banks, because the financial industry stands at the heart of the economy and society. Its function is to help companies and individuals realize their projects, by offering them basic payment, savings and investment services, as well as a growing range of other, increasingly specialized solutions. For this reason, we can see banking as a fundamental motor for development. And for this reason too, it must serve as a repository of trust for social agents in not one but two senses: it must work for the interests of its stakeholders (in the strict meaning of the word "trust"); and it must also exhibit the prudence and professional competence associated with the term "confidence". Ethics and competence are two essential attributes that each institution, and the financial system in its entirety, must zealously protect. In recent months, events have revealed the grave effects on the global economy and society—and on finance entities themselves—of a breakdown of confidence in the financial sector.

In keeping with its central position in the economy and society, banking is fully exposed to technological and social change. Our customers change, in their needs, expectations and demands, as do the channels and procedures through which they choose to operate. Responding to these shifting demand patterns requires a profound technological, organizational and cultural transformation that parallels the transformation being undergone by global society, in order to harness the immense potential held out by technological and scientific advances. The goal of this transformation should be to sustain economic growth, improve the wellbeing of society and restore the environmental balance that has been lost in the recent past.

The financial industry works with two main raw materials: money and information. Money, at the beginning of the twenty-first century, has been largely dematerialized. It has turned into book entries, that is, information that can be transmitted instantly and at practically no cost. Technological advances have given banks exceptional opportunities to improve their services, and to take more and better products and services to an incomparably wider public, with a maximum of convenience and at much lower prices.

Unquestionably, the financial industry has changed in recent decades, adapting its systems and processes to new technological capabilities, but the breadth and depth of these changes have been of limited scope compared to other industries and services. Still, the weight of global events and social and economic realities means a more profound transformation is both urgent and inevitable.

BBVA seeks to occupy a leadership position in this transformation of the financial industry, following a strategy based on three pillars: principles, innovation, and people.

This strategy, and the corporate culture from which it flows—and which it nourishes—is encapsulated in our vision statement, "*BBVA, working towards a better future for people*". People in their multiple dimensions as customers, employees and shareholders, as well as citizens in the societies where we conduct our business.

We believe that we are contributing to a better future when we apply firm ethical principles of honesty and transparency, when we place people at the center of our activity, and when we work for the betterment of the societies where we operate, sharing in their aspirations. And, finally, when we foster innovation as a key enabler of more flexible, individualized customer solutions, affordably priced, as a means to give more people access to financial services, as a source of additional value for our shareholders and as an outlet for the creative talent of our professional teams.

This combination of innovation and corporate responsibility provides the framework for our commitment to promote and disseminate science and learning.

Innovation is a mainstay of the BBVA strategy and culture, as reflected in our current innovation and transformation plan. This perspective sets us apart from more conventional competitors, while leveraging our capacity to generate recurrent value on a sustained basis. We are aware that science, research and the creative climate they both draw on and enrich are essential aspects of process and product innovation, and the search for new, more efficient solutions to the demands and challenges of contemporary societies.

Responsibility towards the societies in which we do business—currently over thirty countries and growing in various continents—is also an integral part of BBVA's strategy and culture.

We believe our primary responsibility is to do our work well, and that striving day by day to improve the quality, reliability and price of the services we offer is the best way we have of contributing to economic development and social stability.

But our commitment is more far-reaching: we want to help make that growth sustainable over time. That is why we have implemented pioneering policies in our sector with regard to the environment. And why we have developed a social strategy and policy with three basic lines of action, in which education and knowledge play a central role.

The first line is articulated through our "Financial Inclusion" program, to favor access to the basic financial services of payments, savings and loans.

Banking accessibility is a key means to prevent economic and social exclusion and to further the personal development of low-income sectors of society who tend to be let down by the mainstream finance industry. In some areas where BBVA operates, such as Latin America, this group represents a majority of the population.

Many of these initiatives are being carried out by the bank itself by means of innovative models whose intensive use of technology makes it possible to drastically reduce the cost of producing and distributing basic financial services. Moreover, our Group is strongly committed to the development of microfinances, and has set up the BBVA Microfinance Foundation, a non-profit organization funded with 200 million euros.

"Aid to Education", especially among the least-favored segments of the population, is another priority action line. BBVA's Social Action Plan for Latin America is funded with 1% of the profits of each Group bank in the region, with more than 80% of those resources earmarked for educational initiatives.

The third line of action, as stated at the start of these pages, is "Knowledge Promotion". This is carried out fundamentally by the BBVA Foundation through programs supporting scientific research and publications, with special emphasis on social sciences, biomedicine, the environment and basic sciences, and arts and humanities (particularly Spanish and Latin American literature and contemporary music).

The present book, *Frontiers of Knowledge,* and the awards of the same name, are a part of this endeavor. They seek to address the lack of visibility and explicit recognition —especially notable in Spanish and Latin American society—of the multiple achievements of the scientific community. The idea is to improve social awareness of the latest developments in science, technology and contemporary artistic creation, and their significance as a source of new opportunities and choices for individuals and groups. They will also cast a spotlight on those whose research and creative work have enlarged the space of knowledge and enriched the realm of culture.

It is a paradox that society's high esteem for scientists and researchers in the abstract—evidenced by multiple surveys since the decade of the 1950s—finds little expression in the public recognition, and far less acclaim, of individuals who have contributed decisively to the advancement of knowledge. This contrasts with the high-profile treatment of other professions far less central to society's wellbeing. Only a few international prizes—the best known being the Nobel Prize—bring a select group of researchers and creators to the attention of the wider public. The Frontiers of Knowledge Awards want to make their own contribution to raising the social visibility of modern scientific culture.

These new awards, funded by BBVA through its Foundation, differ in important respects from other major international honors. They seek to recognize and encourage research and artistic creation, prizing contributions of lasting impact for their originality, theoretical and conceptual implications and, where appropriate, their translation to innovative practices of a salient nature. The name of the scheme is intended to encapsulate both research work that successfully enlarges the scope of our current knowledge—continually pushing forward the frontiers of the known world—and the meeting and overlap of different disciplinary areas. Specifically, honors are given in eight categories coinciding with the eight chapters in this book: Basic Sciences (Physics, Chemistry, Mathematics); Biomedicine; Ecology and Conservation Biology; Climate Change; Information and Communication Technologies; Economics, Finance and Management; Development Cooperation; and Art (Music, Painting, Sculpture, Architecture).

Besides the number of categories and their respective contents, there are other elements that give these awards their unique profile. Firstly, they recognize the increasingly interdisciplinary nature of knowledge through the closing decades of the last century and up to the present day. Secondly, they acknowledge the fact that many seminal contributions to our current stock of knowledge are the result of collaborative working between large research teams. This is why, unlike others, these awards may be shared by any number of any size teams, provided the achievement being recognized is the result of collaborative or parallel working. Thirdly, honors in science and technology are joined by a category recognizing creative work of excellence in four fields decisive in shaping the culture and identity of this or any other era, namely contemporary music, painting, sculpture and architecture. And fourthly, recognition is extended to diverse endeavors (from research through to practical actions and initiatives) in the areas of climate change and development cooperation, two central and interlocking issues of the global society of the 21st century that are vital to the fight against the poverty and exclusion affecting large areas of our planet.

These awards respond to BBVA's vision of knowledge and innovation in our global society; a vision which we outline here by way of introduction to the central chapters of this book.

Knowledge society and global society

The term "knowledge society" and related terms like "information society" or "the knowledge economy" made their first appearance in the 1960s. They all refer to the one phenomenon or facets of the same: namely, the emergence of a society (an economy) in which scientific-technological advances—especially in information and telecommunications—and their rapid transfer to society become central planks of economic activity, as well as deeply transforming culture and lifestyles.

The first author to use the concept of "information society" may have been the economist Fritz Machlup 1962. As early as 1962, he noted that the number of employees engaged in handling information was greater that those carrying out physical or manual labor.

The expression "knowledge society" was first used by Peter Drucker in his 1968 book *The Age of Discontinuity.* In it, he postulates that the basic resource for the production of wealth in our time lies in knowledge and its productivity. Later, the same influential author emphasized the profound social transformation this would imply and the close links between "knowledge" and "globalization". In Drucker's view, the rise of information and communication technologies allows companies, products and consumers to transcend national borders, furthering the emergence of a global market (Drucker 1994).

In the decades since Machlup and Drucker's initial contributions, the trends they detected have gained more force than they could possibly have foreseen. It is no surprise, then, that a series of sociological and economic models have been proposed in recent decades to explain the transition from Industrial Society to what is known as Postindustrial Society, incorporating the main attributes of the Information Society. Two of the best-known authors of such models are A. Touraine and, especially, Daniel Bell.[1] The societies of the last third of the twentieth century have received many other similar labels, the most characteristic of which have been compiled by Beninger (1986). These labels emphasize the importance of the *technological* base—especially "*information* technologies"—in modeling the structure of advanced societies: *Computer Society, The Information Era, Compunications, Postindustrial Society, Electronic Revolution, The Wired Society, The Micromillennium* and *The Third Wave.* And the list could be further enlarged to include other expressions, such as Beninger's own *Control Revolution,* or, in the final decade of the twentieth century, *Network Nation, Virtual Community, The Network Society* and *Cybersociety 2.0.*

Technological advances, cultural change and innovation

The interaction of electronic technologies, new materials, computers and telecommunications, as well as developments underway in the fields of nanotechnology and biotechnology, have made it possible to replace the technological base that sustained various decades of uninterrupted growth from the end of the Second World War almost until the close of the twentieth century. One of the essential components of the current techno-scientific push—the association of computing and telecommunications—has the peculiarity of affecting processes and products in all economic sectors without exception. It also spans the entire economic cycle, from design to marketing, and everything in between, including engineering and production. Besides the direct economic impact of information technologies, over at least the last two decades, their fundamental effects are also measurable in a long series of areas such as scientific work itself, education, healthcare, leisure, associative practices (the emergence of interest groups, electronic associations and "virtual" communities) and the field of culture.

In the last half century, information technology has made formidable progress. "Moore's Law" (actually an empirical observation that storage and information-processing capacity will double every 18 months), has proved true ever since Gordon Moore formulated it in the 1960s. But that is not all. The universal spread of computers and the development of the Internet have been of fundamental importance. The Internet is a platform whose enormous power lies in its combination of both the information it stores and continuously updates, and its status as a *network.* In fact, "Metcalfe's Law" establishes that the value of a network can be expressed as the square of the number of persons connected to it.

It is clear that one of the factors explaining the rapid spread of information lies in scientific-technological advances that allow the sustained improvement of features at the same time that costs drop. But the computer's trajectory from the mid-1940s to the present day has also been affected by social dimensions, some as intangible as the *way of seeing* the computer: what possibilities it offers and how we conceive of the "cohabitation" of human processors and electronic ones, to quote the stimulating image of Nobel prizewinner Herbert Simon (1985). It is worth briefly considering those two aspects—technology and society—as a way of shedding light on the complexity of innovatory processes.

Today, we take it for granted that the computer is an "all-purpose" technology ("The Universal Machine"), which puts it at a very different level than the emblematic machines of the industrial revolution, which were designed to do one, or at

1
In the 1976 prolog to the second edition of *The Coming of the Postindustrial Society,* Daniel Bell expressed his discomfort with the labels, "Information Society," "Knowledge Society" and "Service Society," which only refer to partial aspects of the model of emerging society. But the analytical focus and literal tenor of Bell's argument so clearly address the techno-intellectual dimension of new society, that he clearly merits inclusion in the group of authors of information society models.

most a very few previously-determined tasks. We see, and use, the computer as technology that can support and expand an ever greater variety of mental functions and specialized tasks. This versatility goes far beyond the function its name refers to ("computing" or "calculation"), leading to such varied functions as integral treatment of quantitative or categorical (qualitative) information and the creating of images, or even "virtual worlds", and much more, including interaction with telecommunications, a flexible and robust communications platform that accepts all formats from voice to text, images and video, and so on. Moreover, it spans the entire planet, thus shaping "Global Networks" (Harasim 1993).

Our perception of the breach with the recent past brought about by the universal spread of computers and the web it has woven is so strong that we must turn to historians of technology to realize that the dominant conception of early electronic computers, even among most of their creators, was that of a highly specialized technology destined to occupy a limited place in just a few large organizations: corporations, the military and scientific institutions. Paul Ceruzzi, who collaborates in the present book, points out that, as late as 1951, experts thought the United States' computer needs would be satisfied with four or five computers (Ceruzzi 1986). Such a narrow view of the computer's possible uses and destiny can be explained by technological and cultural factors.

Beginning with the technological questions, analysis of the history and processes of scientific-technological innovations has shown that the maximization of the potentialities of a specific technology requires the confluence of various technological developments (clusters of different advances) (Freeman and Soete 1997). For Rosenberg (1976), the length of time between an "invention" and its spread as an "innovation" is largely dependent on the time it takes to carry out *additional* inventive activities to refine the original design in order to meet the needs of the final users.

In the case of the computer, without the microelectronic revolution it would be impossible to explain the mass production of computers and their spread from large companies to private homes. Nor would we be able to explain what the late Michael Dertouzos, a computer scientist at MIT, called "hidden computers"—microprocessors built into a broad range of products and technologies (advanced machine tools, automobiles, household appliances, sound and image devices, clocks and watches, and many, many others) to improve their features, increase their reliability, considerably save materials and even allow remote diagnosis (Dertouzos 1984) and repair.

From a cultural standpoint, the early conception of the computer is similar to what happened with other radical technologies when they first appeared: the new technology was harnessed with the image of the tool or technology it "replaced". Thus, the car was seen as a "horseless carriage" rather than as the beginning of "the era of auto-mobility". And for a short period of time, even Alexander Graham Bell considered the telephone as a means of sending messages from a central point (like a radio), rather than as a conversation tool. In that sense, there is nothing strange about the initial conception of the electronic computer as a powerful tool intended to advantageously replace the only existing "computers" of the time: dedicated individuals with paper and pencil—or mechanical "tabulators"—who calculated tables used in different areas (navigation, insurance, etc.).

Indeed, the very possibility of a *personal* computer required a multitude of advances in programming languages, interfaces, operating systems and applications, all of which have practically eliminated the initial barriers to its use. But cultural factors—how the computer is viewed and how final users relate to it—have also been fundamental to its massive spread. Visionaries such as Vannevar Bush, Douglas Engelbart, the Stanford Research Institute's (SRI) "Augmented Human Intellect" project, the community of Artificial Intelligence researchers, the legendary Xerox research center in Palo Alto, the Computer Supported Cooperative Work (CSCW) research program, and the implementation of some of those communities' guidelines at the beginning of the Apple company, shaped a view of the computer as technology to "expand" (rather than replace) the capacity of human beings, broadening the possibilities of communication and cooperation in working groups and even among social groups and individuals.

The jump from a dozen or so large computers in the 1940s, each carrying out a few specialized tasks for a tiny segment of scientists and engineers, to the millions of all-purpose microcomputers accessible even to children in the 1990s represents a fundamental milestone in the history of technology and its social impact. But more recently, the closeness and merging of telecommunications and computing, characterized by the exponential growth of networks and the Internet, have marked a decisive before and after in the development of technology, as well as an unprecedented space for social experimentation.

This entire complex process shows how radical innovation can only be successful when accompanied by the interaction of numerous advances, from strictly technological ones to those of a social or cultural nature. And each of these advances develops at its own pace, making it difficult to foresee when or even how an innovation with significant effects will emerge.

Toward a true knowledge society?

Among the social effects of computer and telecommunications innovations, the most important may be that citizens now live in an information society. We have access to a universe of information in perpetual expansion. We have ever more powerful and widely accessible technology for creating and accessing that information, as well as transmitting, treating, analyzing, relating, and, eventually, converting it into knowledge for use in problem solving. Thus, in a little over three decades, we have reversed a centuries-old pattern characterized, first, by an absolute paucity of information, and second, but no less important, by the concentration of information in the hands of a tiny proportion of society.

Of course our society is by far the one that has generated and accumulated the largest amount of knowledge in the history of humanity. In 1990, David Linowes affirmed that the amount of knowledge existing at the time of Christ did not double until the mid-eighteenth century. It doubled again in the following 150 years—around the beginning of the twentieth century—and again in just fifty years, around 1950. Nowadays, the volume of knowledge doubles every four or five years.

Nevertheless, a true knowledge society is still no more than an aspiration, a goal towards which we are advancing, though it still escapes us. There are two fundamental reasons for this: first, a large portion of humanity continues to be excluded from this development. As Janet Abbate points out in her article in this book, over half the population of developed countries was using the Internet by 2005, compared to 1% of the population in the 50 least-developed countries. Today there is an immense digital divide that slows the collective possibilities offered by computers and the web (Norris 2001). This urgently requires the attention of public and private agents if we are to bridge the gap between advanced societies and those that have not managed to enter the path of sustainable growth.

The second reason why a knowledge society is still more of a goal than an empirically observable reality is that the immense majority of available information is an enormous and undifferentiated mass of quantitative data and categorical or qualitative information. The structure of most of this information remains hidden (we do not know what internal relations exist between the multiple pieces that constitute such a mass), and we do not have articulate explanations to make it globally coherent. In short, we have not mastered an essential technology: how to convert that data into knowledge and how to convert a significant part of knowledge into innovation, i.e. into new applications that are useful in people's lives and in solving the planet's main problems. A clear example of this situation is the recent explosion of genetic information (the decoding of the human genome) and the difficulty of interpreting it and applying it to new and more efficient therapies. But intense work is being done today to develop statistical algorithms and methodologies capable of helping us discover the meaning of gigantic volumes of information of diverse nature. The success of this effort will largely determine our capacity to transform information into knowledge, which we can use to generate innovations that satisfy needs and demands in a multitude of areas (Hastie, Tibshirani and Friedman 2003).

The technological revolution and the rapid growth of knowledge have undoubtedly led to a highly expansive phase of global economic growth. Nevertheless, the benefits of that growth are very unequally distributed. The planet's current productive capacity allows it to support a population three times as large as in the mid-twentieth century. The quality of life has also improved in much of the world, and extreme poverty is shrinking, not only in relation to the total population, but also in absolute terms (United Nations 2007).

And yet inequalities have increased in almost every country in the world, as well as between the most and least advanced areas (World Bank 2008). Not surprisingly, there has been a proliferation of reflections on the difficulties and problems of globalization, as well as a greater focus on the problems than on the opportunities of globalization and scientific-technological change.[2]

Moreover, accelerated population growth and productive activity bring very serious problems of environmental sustainability linked to the overexploitation of natural resources on land and sea, scarcity of fresh water, the accelerated loss of biodiversity (species and habitats) and climate change. Each of them will have its own impact on populations and their economies in the coming decades, and these fundamental questions are being addressed in the present book with contributions by outstanding specialists.

Still, there are reasons for optimism. The basic sciences continue to delve ever deeper into physical, chemical, and biological processes and structures, with consequences of all kinds, from strictly cognitive ones (improved knowledge) to technological ones (new instruments to cover necessities). We are at the beginning of the evolution of extremely powerful and

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In 1998, the sociologist from the University of Chicago, Saskia Sassen published *Globalization and Its Discontents* (New York: The New Press, 1998) and four years later, the Nobel Prize-winning economist, Joseph E. Stiglitz published his own work with the same title (*Globalization and Its Discontents*. New York-London: W. W.Norton & Company, 2002).

highly versatile technologies, including the Internet, whose third generation will offer much greater possibilities for cooperation and the active inclusion of everyone in electronic space. We are barely scratching the surface of a gigantic vein of wealth and wellbeing for humanity. And this is certainly the most "democratic" technological revolution ever. Not only for the obvious reason that democracy is the reigning political regime in most of the world right now—though this undoubtedly reinforces its positive effects—but also because this is the revolution that has most rapidly spread around the world, despite the barriers and limitations mentioned above. This is the one that has proved most accessible to people in all parts of the world.

How can the generation of knowledge be accelerated?

This context, in which serious and ever-more-pressing problems coexist with enormous potential for scientific and technological growth, poses questions as to the most appropriate mechanisms and procedures for empowering the generation and spread of knowledge. And those questions are key to the future of humanity.

Traditionally, there were two main catalysts to the generation of knowledge: economic advantage, which drove private agents; and war, which drove government initiatives and programs.

War requirements attained unprecedented efficiency as catalysts for scientific and technological advance in the context of the Second World War. Subatomic science and technologies, microelectronics and the computer were fostered by the war effort, and there were also fundamental advances in other areas, especially medicine, pharmacology, psychology, and operative research.[3]

The Second World War's impetus to scientific and technological research was reinforced in the last decades of the twentieth century by a growing participation of the private sector. This was a response to growing opportunities for commercial exploitation of advances in research.

In the last fifty years, there have been profound changes in how knowledge is generated and used. In the light of the unprecedented growth of scientific knowledge, governments, companies and scientific institutions have been debating the most efficient ways to apply scientific advances to make companies and countries more competitive, thus improving collective possibilities.

For decades, the dominant approach was for public powers and a few large corporations to unreservedly support basic research on the supposition that sooner or later the knowledge it generated would lead to practical but highly unforeseeable applications of the most radical sort: applications that competing countries and companies would have great difficulty imitating. This model was more or less related to the doctrine of Vannevar Bush and the experiences of the Second World War.[4]

Since at least the 1980s, though, conceptual and practical dissatisfaction with this inherited approach became patent. For example, MIT's Commission on Industrial Productivity, whose members included the Nobel Prize-winning economist, Robert Solow, published the influential interdisciplinary report, *Made in America* (Dertouzos, Lester, and Solow 1989), which sought to explain the paradox that the United States had the most advanced basic science and the best-trained scientists and technologists, yet its capacity to turn that cognitive gap into innovation had dropped in comparison to the decades immediately following the end of the Second World War. Yet Japan, where the focus was more on applied research, seemed capable of capturing markets for unmistakably American products (such as consumer electronics), brought new products onto the market in far less time in sectors traditionally associated with US industry (automobiles), and reached far higher levels of quality.

Such difficulties were hardly limited to the United States, as the authors of the mentioned report seemed to believe. Almost a decade later, the European Commission (re)discovered the same problem and did not hesitate to label it "the European paradox" in *The Green Book of Innovation* (1995) and the related *Made in Europe* project.

This type of analysis has led—not without criticism from some sectors of the scientific community—to a change of perspective in the drawing up of scientific policy. Support for research directed at the advancement of knowledge (known as "pure" or "basic" research) with no direct practical applications has lessened. This "type" of science has had to cede, or at least share, financial and human resources with so-called "strategic research", subject to external planning (by public agencies or institutions), that seeks to satisfy socioeconomic objectives—especially the competitiveness of national economies, defense, and health policies.

This focus has also taken root in large companies, leading to a strict alignment of research programs with economic objectives. In many cases, companies have reduced or even eliminated their own industrial laboratories, turning to the market instead. In other cases, R&D departments are replaced by contracts with public centers or private institutes dedicated exclusively to research. Uncertainty about the possible results and the difficulty of exclusive control of the

3
The interaction between military needs and technological development is analyzed in the William H. McNeil's classic *The Pursuit of Power. Technology, Armed Force, and Society since A.D. 1000.* Chicago: Chicago University Press, 1982. The specific and emblematic case of the USA is addressed in the work edited by Merrit Roe Smith, *Military Enterprise and Technological Change. Perspectives on the American Experience.* London: MIT Press,1987.

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For a critical analysis of the strengths and limitation of the model of support for the sciences linked to this engineer from MIT, see: Claude E. Barfield,ed., *Science for the 21st Century. The Bush Report Revisited.* Washington: The American Enterprise Institute Press, 1997.

fruits of such research—especially in the case of pure research—have been important factors in this reconsideration of the scale and role of Research and Development and its financial support.

Since the 1980s, public administrations in advanced societies have considered the postwar model of pure science development exhausted.

But the underlying suppositions of models for the strategic direction of science are far from solid. The history of technology and innovation reveals the winding path that leads from purely theoretical progress to the improvement and introduction of new processes and products, and vice versa.

It is certainly difficult to predict and manage the transformation of theoretical advances into new applications. On the other hand, the links between theory and practical application have multiplied, and their roots have grown deeper, making it necessary to discard simplified notions of what is useful and what, theoretically, "only" contributes to greater knowledge of reality. In countries and regions culturally and institutionally committed to excellence and innovation, public and private agents share the view that economy and society are increasingly dependent on an infrastructure of intangibles—theories, information, and scientific knowledge—in which scientific activity and corporate strategies broadly overlap and continuously redefine themselves.

Europe, which is generally slow to incorporate concepts and experience from the other side of the Atlantic, needs to pay more attention to what is really going on in the United States. Literature and empirical evidence show that scientific research financed with public funds has played a leading role in the United States' industrial innovation.

Patterns of innovation in the United States indicate the need to increase public and private support for Research and Development on this side of the Atlantic, promoting science and technology of excellence, and, most of all, introducing a "market" culture of open competition and sustained effort to excel, with universities and research centers ranked according to their capacity to contribute to knowledge and innovation. There must be mobility and interaction among researchers and the private sector, and new interfaces for efficient communication between institutions dedicated to the creation and transmission of knowledge and the corporate world. This is a program whose development requires vigorous support and coordination by public administrations on every scale, from European to national to regional.

It is time to renegotiate the previous "implicit contract" between universities, industry and the administration, redefining what each can expect from, and give to, the others. As two outstanding experts on innovation—professors Rosenberg and Nelson—have pointed out, we must modify the *status quo.* But these changes must be based on a careful consideration of the functional specialization of each institution, seeking a better division of labor among all participants in the innovation system.

What seems clear, at any rate, is the need to establish a tight network of relations between industry and universities. This can take various forms, from fluid access by corporate R&D personnel to their university colleagues (and vice versa) to the development of specialized institutions halfway between corporations and public research centers, along with public financing of research areas whose goal is to improve competitiveness, supervised by composite advisory committees with representation of academia, corporations and the public administration. No matter what formulas are applied, what really matters is to create dynamic networks that transmit information and signals, and to generate trust and the exchange of tacit knowledge (which is difficult to codify) among the different participants, breaking down barriers still visible in much of Europe, which, succinctly put, separate academia and corporate enterprise.

Interactions between science and technology

The results of scientific research and technological innovation are increasingly present in all aspects of human life and activity. As Peter Drucker points out, "much more than a social transformation, [they are generating] a change in the human condition" (Drucker 1994). This creates growing interpenetration and cross-pollination between scientific research, innovation, and human productive activities and lifestyles. It also leads to a drastic reduction of the lag time between scientific discovery and the commercial exploitation of its results (Mowery 1989).

Increasingly, science and technology are advancing driven by their overlap and cross-fertilization, and also through the interaction of classic disciplines and the emergence of new ones, illustrating the obsolescence of the classical argument as to whether technology depends on previous scientific knowledge, whether the latter benefits from the former, or whether the two are completely independent of each other. During the twentieth century, especially the second half, relations between science and technology, and between both of them and society, changed in fundamental ways. Corporate and industrial sectors, as well as social demands in areas such as health, energy, agriculture and food, transportation, the environment, inequality and poverty are sources and signals for science. They call for the analytic power that can only be provided by scientific research, and the efficacious and efficient solutions offered by technology—an area that Nobel laureate Herbert Simon labeled "the sciences of the artificial" (1996).

The present complex framework also helps to explain the growing importance of multidisciplinary cooperation in contemporary scientific research, as well as the fact that most scientific research is carried out by large teams made up of researchers from different institutions, based in different parts of the world. Telecommunications and Internet innovations allow active and simultaneous participation in a specific project by researchers all over the world, including—and this is a motive for optimism—those from the least rich and advanced regions of the world.

Science's institutional architecture and cultural setting

Nowadays, science is a markedly social and highly institutionalized activity. It continues to require individual creativity and risk, but it is developed cooperatively in specialized organizational frameworks and a social setting from which it obtains not only the adequate human and material resources, but also signals (appreciation of science, research priorities) and conceptual and cultural influences. These can come from nearby fields, or from those of the Humanities, and from overall culture (the "worldviews" active in a society).

The alignment and positive interaction of all these elements has become critically important in recent decades. As Nathan Rosenberg explains in his excellent article in this book, a crucial challenge is the adaptation of science and research's institutional setting to our global society.

In that sense, we now face new organizational challenges for the development of research that is increasingly interdisciplinary, multipolar—even delocalized—and strongly cooperative, as well as increasingly interactive with its social medium.

How can we develop interdisciplinary research in universities divided into departments defined by specific disciplines, with researchers and scientists who—at least in the academic world—place great importance on the fact that they work in a recognized field? How can we combine the frameworks and disciplinary structures of knowledge, which are well defined and based on theoretical traditions and reasoning, with interdisciplinary institutions and centers that are closer to dealing with practical challenges? How can we reconcile the interests of governments and national public agencies—they are, after all, an integral part of the scientific world—with the configuration of multinational, highly flexible and changing research teams? How can we protect the incentive for companies to assign resources to research when projects have multiple participants and vital information can be divulged instantly *urbi et orbe*? And lastly, how can we ensure that this entire institutional structure focuses on the solving of problems of general interest, effectively contributing to the wellbeing of people, so that scientific and technological advances do not lead to increasing inequality and greater problems of global sustainability?

The mere enumeration of these challenges indicates that many of the answers must come from the field of the social and behavioral sciences, especially the "soft" technologies of organization and incentives, as well as the study of culture and attitudes.

Moreover, the redesign of science and technology's institutional architecture, of public policy for the promotion and strategic management of R&D and innovation by corporations, requires intangibles, values and perceptions—that is, science's cultural setting—to be sensitive to this, operating to foster and orient it.

Reconciling science, technology, and society

A positive social view of science is crucial in at least three fundamental ways. First, so that the citizenry, with its opinions, votes and even its buying power, can push public policy-makers and private industry decision-makers to support and invest in education and research. Rewarding innovation (the "high road") and discouraging competition based merely on low costs rather than on added value. Second, it attracts human capital to the sciences, so that talented youths feel motivated to undertake a demanding but thrilling career in research that is rewarding both economically and symbolically. Finally, the intellectual and cultural "appropriation" of science by society is crucial for both scientific creativity and for the efficient use and integration of new developments into the social tissue. In sum, the attitude that, in the case of the United States, was labeled by technology historian Thomas Hughes as "technological enthusiasm" is decisive for the advance of knowledge and of the society that fosters and welcomes it (Hughes 2004).

We might be tempted to think that, after various decades in which science and technology have made stunning contributions to humanity's economic progress and wellbeing, the general consideration of science as an unmistakably positive factor must be firmly established. But, as Gerald Holton points out in his excellent essay in the present volume, social attitudes towards science have historically been subject to strong oscillations. And the social status most desirable for science is not guaranteed. Following the optimistic sense of progress that reemerged after the Second World War—exemplified by Vannevar Bush's famous report, *Science, the Endless Frontier,* commissioned by President Franklin Roosevelt and published in 1945—voices and critical movements spoke out in the final part of the twentieth century against science's role in our society, recalling motives of Romantic resistance to science and modernization (Marx 1988). Such criticism attributes negative effects to scientific and technological progress, relating them to the development of weapons of mass destruction, the deterioration of the environment, inequalities within each society and between different parts of the world, and even the configuration of a uniform, dehumanized and excessively materialistic global culture lacking moral values.

Of course, concern for these questions, especially the serious worldwide deterioration of the environment, is not only legitimate, it is shared by many, many citizens. Leo Marx, the historian of American culture at MIT, has indicated that the belief in progress that characterizes modern Euro-American culture was eroded during the last decades of the twentieth century, mostly by pessimism about the human role in nature and the perception that the system of industrial production based on science and technology is having strong, unwanted effects on the global ecosystem (Marx 1998).

More-or-less systematic criticism of science seems to have lessened at the end of the first decade of the twenty-first century. Nevertheless, underlying concern about some of science's unwanted, though indirect, effects, as well as the complexity of global society, make it fundamentally necessary to promote and consolidate a favorable attitude towards science—a view based on the assumption that scientific and technological advances are, in fact, key elements in helping humanity deal with its largest challenges, and a recognition that scientific and humanistic aspects of our culture are not only fully compatible, but that together they can and must contribute to a sustainable improvement of the conditions of human existence. Three quarters of a century ago, the US philosopher and educator, John Dewey, made a recommendation that we would do well in recalling and applying today: use science to "cure the wounds caused by applied science" and, in particular, to foster the development of scientific culture and the transmission to general society of mental habits and attitudes that are characteristic of researchers: curiosity, objectivity, innovation, rational debate and a willingness to change one's mind on the basis of discussion and empirical evidence (Dewey 1934). This, in short, is the tradition of enlightened rationalism tirelessly defended by Karl R. Popper, undoubtedly one of the greatest philosophers and thinkers of the second half of the twentieth century.

To contribute, even in a modest manner, to this great task is the fundamental purpose of the present book, in which outstanding figures in science and the arts of our time—researchers on the frontiers of knowledge—review the state of the art and perspectives for our century's most characteristic scientific and artistic disciplines. These are the disciplines most responsible for advances visible to the overall citizenry, and these are the ones addressing the challenges most relevant to our future and that of our children: health, information and communications technologies, natural resources, the environment and climate change, the generation and fairer distribution of wealth, and of course, the arts, which are the expression of our culture and the sensors of social concerns in our time.

At BBVA, we are proud to contribute to the fostering of knowledge and creativity with the publication of this book and, in a more permanent way, through the BBVA Foundation Frontiers of Knowledge Awards. Our very sincere thanks to each and every one of the outstanding researchers and creators who responded to our request for first-hand reporting—with the intimate and authoritative experience conferred by their illustrious careers—on a selection of questions fundamental to their respective fields. It is our wish and desire that the readers of this book enjoy it as much as we have enjoyed publishing it, and that they join us in saluting the thousands of researchers who strive daily to advance our knowledge of the natural and social worlds, thus expanding our freedom to make decisions and our individual and collective possibilities.