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SCIENCE AND TECHNOLOGY: FUTURE APPLICATIONS, TRENDS AND IMPACT

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SCIENCE AND TECHNOLOGY FUTURE APPLICATIONS, TRENDS AND IMPACT

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As much as potential economic, environmental or social benefits of any scientific field can help foresee its future technology development, prevailing socio-economic factors, like demographic change, labor markets, ecological sustainability, or national security do have an impact on Research and Development (R&D) policies or the level of technological activities being carried on in any country. Similarly, while innovation performance is linked to the state of markets for innovative products and services, innovation strategies of technology-based businesses do not solely focus on furthering the technical potential of their technologies; they also consider long-term socio-economic – national and international – trends in the planning of such strategies and the development of their products. Such mutual influence of socio-economic factors and R&D and Innovation in Science and Technology (S&T) is traditionally well established in the economically and scientifically advanced countries. And it is also more and more visible globally through the R&D activities of multinational private companies (MNCs) exploring new markets. Hence, a majority of S&T foresight studies look from this perspective to examine trends in the possible future development and impact of S&T.

Introduction

The world is undergoing wide-ranging scientific and technological development that will significantly influence society and the global economy over the next decade. Technologies related to the field of renewable energy will advance considerably, and cheaper solar as well as wind power generation will come into large-scale use. The technical, social and business aspects of Information and Communication Technologies (ICT) will continue to shape our way of interacting, doing business and solving local as well as global challenges, but will ICT, as has been predicted, form the foundation upon which the global economic recovery will occur? A wide spectrum of biotechnology applications will continue to be refined and will affect the medical and food industries, transforming the health and agriculture sectors. Nanotechnologies will act as a catalyst across other technologies, for example to facilitate the engineering of new materials and new capabilities, including more energy efficient housing, improved water treatments and green manufacturing. The greatest technological advances, and hence the greatest potential impact on the global economy, will come in areas where nanotechnologies, biotechnologies and ICT are applied in an integrated and synergistic way.

Impacting Technologies

Various fields of research – including Biotechnology (Biotech), Information and Communication Technology (ICT), Clean Technologies (Clean tech) and Nanotechnology (Nano) – have been consistently identified, through surveys and foresight studies, to have the potential for significant global impact in the next 10 years. Indeed, many of their related technology applications reflect this potential for advancing science and technology, consolidating the industrial fabric, enhancing the quality of life, and/or favoring sustainable development and protecting the environment. According to a European report, the main evolution of science and technology that is most visibly common to diverse geographical studies and foresight exercises concerns the influential role of environmental issues as important accelerators of technology development.[2]

More generally, technology applications that will be most feasible and are likely to be implemented in the next 10 years, include cheap solar energy systems, filters and catalysts for water purification, green manufacturing, hybrid vehicles (Clean tech), targeted drug delivery, rapid bioassays, engineering of living tissue for implantation (biotech), ubiquitous information access, ubiquitous RFID tagging and quantum cryptography (ICT). These applications are likely to be implemented widely by 2020, because they serve at least a medium-sized market, affect two to 10 sectors at a minimum and raise little to no significant public policy issues.[3]

These technologies, by affecting the operation or characteristics of one sector, will significantly influence different sectors. For example, cheap solar energy systems, which are based on technical advances addressing the efficiency of collection and storage of solar energy, thus reducing its cost, will affect not only the energy and environment sectors, but also water, food and land through solar-powered water pumping and irrigation. Through rural economic development, such systems will also affect social structure and governance. Filtering and catalyst technologies that enable water purification and decontamination will enable access to clean water and help improve local hygiene, thus benefiting health. This technology application will also affect agriculture through increased food production. Green manufacturing processes will help reduce the volume of toxic materials in the environment and increase the productivity of resources (energy, water and land). By combining internal combustion with other power sources, such as electric motors and fuel cells, hybrid vehicles will curb air pollution especially in urban areas thus affecting the transportation sector. Furthermore, the cleaner environment resulting from these technologies would subsequently also have positive impacts on health.[4]

Previously described technology applications can be classified under the umbrella term "Clean Technology" and categorized as clean energy, clean water, clean materials and clean transportation, according to the Clean Edge classification.[5] Based on clean-technology proven markets, an emerging sustainable economy will further gain momentum thanks to scientific advances and the absence of related negative social impacts or public policy issues.

Other future technology applications, likely to be feasible by 2020, share comparable social acceptance or market potential as the previous ones. Among these, rapid bioassays, targeted drug delivery and engineering of living tissues for implantation will represent the biotech developments that could have the most impact in terms of the possibilities they offer to address various health and medical problems in both developing and/or developed countries. The capability to rapidly verify the presence or absence of specific biological substances by using bioassays would provide governments with new tools to limit the spread of diseases, eliminate threats to public health and ensure the safe movement of people and materials. Targeted drug delivery, which is the capability to design and implement drug therapies that attack specific tumors or pathogens without harming healthy tissues and cells, would enable treatment of many important tumors and pathogens. These two applications have a potential for global implementation. However, engineering of living tissue, i.e. the capability of addressing medical problems like treatment of wounds, disease, and injuries in a way that would minimize rejection and reoccurrence, will mainly benefit countries with required technical and medical expertise, but could also create public debate and raise ethical questions about sources of materials, bioengineering methods or access to and cost of treatment.[6]

In the field of ICT, communication devices for ubiquitous information access, ubiquitous Radio Frequency Identification (RFID) tagging and quantum cryptography are expected to be significantly beneficial applications. The first ICT application will have bearing on the governance, health, education and military sectors, as such communication devices will provide swift access to information sources anywhere and anytime and will have increasing local data storage cache capabilities for not only text but for meta-text with layered contextual information, images, voice, music, video, and movies. RFID tags to identify commercial products throughout the supply chain will influence the development of the retail sector through improved inventory control and more efficient marketing. This application, however, needs extensive infrastructure and raises privacy concerns when combined with cell phones for targeted it difficult to assign the technological applications to any specific field of research. For example, improved diagnostic and surgical methods – which are one of the future impacting technologies –, use advances in biotechnology and nanotechnologies to improve the precision of diagnoses and the efficacy of surgical procedures while reducing invasiveness and recovery time.[8] Such convergence of different fields of research points to some socio-technical trends in the development of science and technology. Convergence is becoming essential for maturing new products in order for them to achieve their full functionality and secure future markets.

Nanotechnologies – taken to mean R&D in nanometer scale science[9] – are by nature converging technologies; they build on the physical sciences, life sciences and engineering. This field of research based on the ability to understand and affect atomic and molecular interactions acts as an *enabler* across a variety of S&T fields like materials (e.g. carbon nanotubes, nanomaterials for solar cells and battery power and capacity), information and communication systems (semiconductor or metallic nanowires for increased computational speed) or designer drugs (e.g. functional nanostructures for controlled drug delivery and for improved performance of implants and prosthetic devices).[10] Hence, it is expected that nanotechnologies, with their transformative potential,[11] will stimulate a kind of industrial revolution in the 21st century, bringing important breakthroughs in various fields including materials, electronics, mechanics, biotechnology, pharmaceutical development, and medical treatment.

Defining the terms

Enabling technologies prepare the ground for a wide variety of technical solutions. Because they unlock vast potential and open the door to radically novel technological developments, they are also referred to as "key technologies." Nanotechnology is a prominent enabling technology. Biotechnology and information technology are also enabling, as is the knowledge base of cognitive, social, and other sciences.

Converging Technologies (CTs) refers to the convergence on a common goal by insights and techniques of basic science and technology: CTs are enabling technologies and scientific knowledge systems that enable each other for the achievement of a shared aim. Singly or together, NBIC-technologies (nano, bio, info, cogno) are likely to contribute to such convergence.

NBIC-convergence for Improving Human Performance is the name of a prominent agenda f or CT research in the US. "Bio-Systemics Synthesis" suggests another agenda for CT research that was developed in Canada.

Converging Technologies for the European Knowledge Society (CTEKS) designates the European approach to CTs. It prioritises the setting of a particular goal for CT research. This presents challenges and opportunities for research and governance alike, allowing for an integration of technological potential, recognition of limits, European needs, economic opportunities, and scientific interests.

Source: Converging Technologies – Shaping the Future of European Societies, 19 advertisement or used in ID cards for individual tracking. Another ICT application which can have much impact is the use of quantum mechanical methods to encode information for secure information transfer. Quantum cryptography – based on the use of quantum encoding devices – may well be feasible and implemented globally for it raises no significant public policy issues and satisfies a large market need in the banking and finance sector, thus influencing economic development.[7]

Converging Technologies

In general, when it comes to translating research results into technical applications, a multidisciplinary approach affects positively the development of scientific disciplines. These tend to be more integrated in order to answer certain challenges and in so doing they gain mutual insights, acquire similar methodologies and identify new possibilities. Particularly, when the sizes of the structures being dealt with in physics, chemistry and biology tend to converge to a common scale (order of magnitude) this allows for an integrated application of biological principles, physical laws and chemical properties to take place thus giving technological applications high scientific sophistication and significant impact. Furthermore, as technology increases in capability and sophistication, it will continue to integrate new developments, often from diverse areas of science.

This convergence – or multidisciplinary approach – is also observed in the integration of biotechnology, ICT and nanotechnology developments, making

Technical and Implementation Feasibility of Illustrative 2020 Technology Applications

	Implementation Feasibility			
	Niche market only	May satisfy a need for a medium or large market, but raises significant public policy issues	Satisfies a strong need for a medium market and raises no significant public policy issues	Satisfies a strong need for a large market and raises no significant public policy issues
Technical Feasibility	(– –)	(–)	(+)	(+ +)
Highly Feasible (+ +)	• CBRN Sensors on ERT (2,G)	• Genetic Screening (2,G) • GM Crops (8,M) • Pervasive Sensors (4,G)	• Targeted Drug Delivery (5,M) • Ubiquitous Information Access (6,M) • Ubiquitous RFID Tagging (4,G)	• Hybrid Vehicles (2,G) • Internet [for purposes of comparison] (7,G) • Rapid Bioassays (4,G) • Rural Wireless Comms (7,G)
Feasible (+)	• GM Animals for R&D (2,M) • Unconventional Transport (5,M)	• Implants for Tracking and ID (3,M) • Xenotransplantation (1,M)	• Cheap Solar Energy (10,M) • Drug Development from Screening (2,M) • Filters and Catalysts (7,M) • Green Manufacturing (6,M) • Monitoring and Control for Disease Management (2,M) • Smart Systems (1,M) • Tissue Engineering (4,M)	• Improved Diagnostic and Surgical Methods (2,G) • Quantum Cryptography (2,G)
Uncertain (U)	• Commercial UAVs (6,M) • High-Tech Terrorism (3,M) • Military Nanotechnologies (2,G) • Military Robotics (2,G)	• Biometrics as sole ID (3,M) • CBRN Sensor Network in Cities (4,M) • Gene Therapy (2,G) • GM Insects (5,M) • Hospital Robotics (2,M) • Secure Video Monitoring (3,M) • Therapies based on Stem Cell R&D (5,M)	• Enhanced Medical Recovery (3,M) • Immunotherapy (2,M) • Improved Treatments from Data Analysis (2,M) • Smart Textiles (4,M) • Wearable Computers (5,M)	• Electronic Transactions (2,G) • Hands-free Computer Interface (2,G) • In-silico drug R&D (2,G) • Resistant Textiles (2,G) • Secure Data Transfer (2,M)
Unlikely (–)	• Memory-Enhancing Drugs (3,M) • Robotic Scientist (1,M) • Super Soldiers (2,M)	• Chip Implants for Brain (4,M)	• Drugs Tailored to Genetics (2,M)	• Cheap Autonomous Housing (6,G) • Print-to-Order-Books (2,G)
Highly Unlikely (– –)	• Proxy-bot (3,M) • Quantum Computers (3,M)	• Genetic Selection of Offspring (2,M)	• Artificial Muscles and Tissue (2,M)	• Hydrogen Vehicles (2,G)

For each technology, the parenthetical information indicates the number out of 12 societal sectors (water, food, land, population, governance, social structure, energy, health, economic development, education, defense and conflict, and environment and pollution) that can be impacted by the technology, and if the diffusion will be *global* (G) or *moderated* (M). For example, Hybrid Vehicles affect two sectors and will have global diffusion.
Source: The Global Technology Revolution 2020, In-Depth Analyses (RAND, 2006). Table S.1-Reprinted with permission.

ICT are also horizontal and *enabling* technologies, finding use in a large number of applications across several scientific fields. For this reason, some foresight studies concerning ICT look at the integrated development of semiconductor materials processing and fabrication, mathematical algorithms, Micro-Electro-Mechanical systems (MEMS), Nano-Electro-Mechanical systems (NEMS), smart materials, and biomaterials and biomedical devices.[12]

Clean technologies encompass technological innovations that cut through most of the industrial economy – from energy and water to agriculture and transportation to software and advanced algorithms. They build on innovations from other technology sectors such as materials science and nanotechnology as well as, increasingly, more mature wireless technologies.[13] Previously mentioned technology applications such as cheap solar systems and filters and catalysts reflect this convergence trend in the Clean Technology field.

The issue of convergence at the scientific field level is of utmost importance for current and future R&D performance. As a matter of fact, one of the key challenges facing scientifically advanced countries in the years to come will be how to successfully exploit the full potential to be realized through the many links between nanotechnologies and computing (nano-computers), neurology and nanosensors, mobile communications technologies and technologies for health, and between nanotechnologies and photovoltaics. From this perspective, economic competition is no longer based on technological supremacy, but on scientific convergence capacity. Beyond the attempts to safeguard the technological leadership it has in "traditional fields" like ICT, the US is now focusing on completely new, potentially highly rewarding economic activities that result from scientific convergence which, in turn, could become a key challenge for economic development in the future. More generally, it is important to underline that this new focus comes with an increased emphasis on applied technologies rather than fundamental R&D and attributes increasing priority to converging technologies in an attempt to foster economic development. This is particularly true for the scientific fields of nanotechnology, biotechnology and ICT.[14]

Increasingly, countries are considering various ways to promote potential links between different scientific fields and public policies. Lending support to the creation of multidisciplinary institutes, paying the necessary attention to projects featuring scientific links, targeting project applications requiring scientific cooperation, supporting the setting up of forums for debate and a variety of networking tools, creating specific multidisciplinary budget lines all have an important role to play in furthering convergence.[15]

To the extent that converging technologies are a part of the continuing trend towards miniaturization and interaction, they will blend into the environment, become pervasive and eventually form an invisible technical infrastructure for human action – analogous to the visible infrastructure provided by buildings and cities. Such an artificial environment holds the promise for greater and more equal access to knowledge and information, new therapeutic interventions, improved environmental monitoring, greater safety and security, and expanded communication capacities. However, the potential benefits of this convergence come with a variety of risks. These could include adverse health effects from novel materials and devices, invasions of privacy, or damage to human integrity and autonomy.[16]

Impact of Socio-economic Factors on S&T Strategies

National concerns like job creation, education or health, as well as global challenges such as energy security and climate change, are shaping policies for research in different countries. The promotion of economic development and the strengthening of the competitiveness of specific sectors constitute the main driving rationales for public R&D support in Europe, Japan and the US. For example, since the 1990s, a key driver of Japanese S&T policies is the need to overcome the economic malaise by the creation of new knowledge and the generation of new industries. However, R&D support also finds an important part of its justifications in social factors in Japan as well as in some European countries. Social demands in terms of environmental and quality of life objectives are present in most scientifically advanced countries. Among these demands, the most important ones seem to be the promotion of health and well-being and the increasing awareness of resource depletion with a specific focus on energy resources availability and rational use.

Exposure to particular diseases and demographic change are major challenges in the US and Japan as well as in Austria, France, Germany, Spain, and Switzerland. Taking into account the importance of social and environmental factors, the field of biotechnology is potentially the most important research area in Europe giving the continent the possibility of taking a leading role in the future.[17] The same is true of the biotechnology field in the US, as demand for a healthy and long life is an important social issue there. The US pharmaceutical industry is very important and research on infectious diseases also targets plants and animals, thus benefiting both agriculture and agro-food sectors and thereby impacting economic development.[18]

Biotechnology for health is central for Japanese society. An aging population is an important factor in the development of health related biotechnologies that focus on preventing and treating diseases.

Food technology is also a key topic in Japan, as it contributes to food security, promotes a healthy diet and secures a sustainable food production. Since it contributes to secure food, Japan is highly interested in agricultural biotechnological issues.

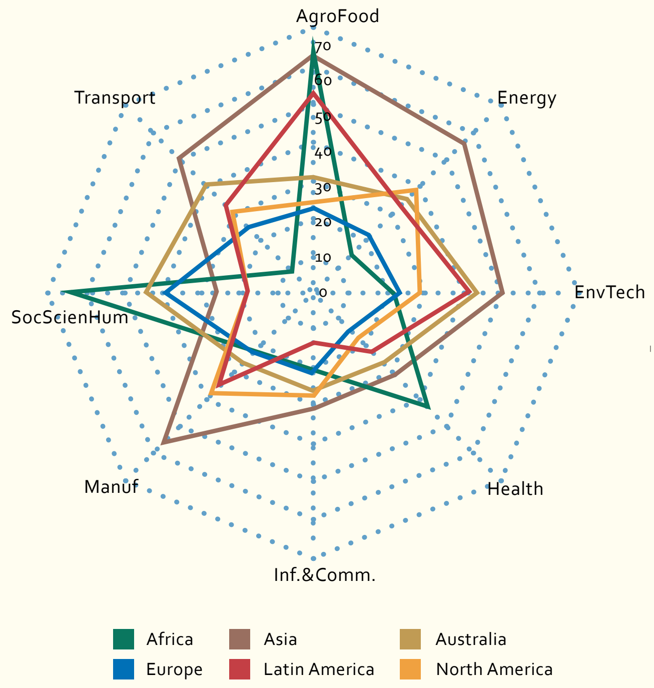
Nanotechnology is supported at the highest political level in the US and described by the Office of Science and Technology Policy as key "to maintaining US competitiveness." This field of research is organized through the National Nanotechnology Initiative (NNI). It groups 11 Federal agencies such as the Department of Defense (DOD), the Department of Energy (DOE), the Department of Homeland Security (DHS), NASA, the National Institutes of Health (NIH), National Science Foundation (NSF) and other participating agencies. Nanotechnology is also one of the four priority areas for Japanese scientific and technologic expansion. Nanotechnologies are considered strategic because they strengthen Japanese industrial competitiveness and help improve the lives of the population by helping to respond to socio-environmental problems. Japan has been successively increasing its R&D investment in this field in order to take a leading position with respect to Europe and the US.[19] Thus, nanotechnology provides an important example of R&D being supported for economic reasons and leading to a complete reorganization of the scientific field by means of a common political initiative.

ICT produces changes in socio-economic activities that impact the daily lives of the population: for example, electronic commerce, remote medical treatments, distance education programs, home offices, electronic governance, etc. The Ministries of Education, Culture, Sports, and Science and Technology in Japan consider that research in this field is essential for expansion of knowledge industries like IT or high-tech industries, as well as for improving existing manufacturing technologies.[20] So, social, economic and political factors are largely used to support this R&D field in Japan.

But if we take into consideration that ICT can benefit every industrial sector and so could easily be linked to competitiveness in general terms, advanced and less advanced countries should be close to this model of S&T development, where support to ICT is primarily due to economic factors.

In addition to the economic factor, which is the main driver for nanotechnology and ICT in west European countries, the political factor is also a key driver for biotechnology on the one hand and clean tech on the other. Both these areas are always driven by their own specific issues (social for biotechnology and energy security/environment for clean tech). But rather than emphasize the potential market or economic development issues these fields could represent, the focus is put at the government level on the use of R&D as key means to provide significant answers. As an example, low cost solar cells technology benefits from a strong policy support which, in turn, is mainly due to the presence of "green" parties at government level and/or a strong awareness of the population regarding the importance of energy issues.[21]

Future Societal Demand for Science in Foresight Exercises in Several Regions of the World



Source: Europe in the Global Research Landscape

Capacity of Acquiring Technological Applications

Socio-economic development is increasingly based on the capacities of a given country to implement and benefit from science and technology applications. Such capacities are also influenced by social, economic and/or political drivers or barriers capable of fostering or hindering the technology acquisition process, thus accounting for capacity differentiation between countries.

Comparison between countries' S&T capacities can be made in terms of public budget, country-level particularities or socioeconomic factors motivating particular public policy strategies. However, each scientific field has its particular differentiating characteristics at the socio-economic level. These particularities address four main subject areas:

- Economic: the existence of strong industrial base, the level of competitiveness, the market potential
- Societal: the existence of a collective-societal issue, ethical issues, awareness and public/scientific acceptance
- Scientific and technological: the history of the field, resources in R&D and education systems, technology transfer issues
- Politics: legislation issues, coherence of R&D organization and funding schemes, fiscal environment.[22]

For example, supporting the development of nanotechnology, and by extension of all converging technologies, entails adapted R&D organization that covers different scientific domains at a time. To do so, it has been emphasized that the creation of multidisciplinary laboratories capable of developing their own research programs is paramount. These should be backed by specific and efficient public funding and new ways of financing multidisciplinary research, such as specific guidelines or incentive programs to foster cooperation between different scientific fields. Admittedly though, the private sector/ investment based on a solid industrial position will continue to play the main role for the relative development of nanotechnology.[23]

This is also true for the ICT field which is linked to the industrial basis available in a country. So development of this sector will mainly depend on the support given to industries, industrial R&D and to the reinforcement of the links between public and private R&D in the field.

As for biotechnology, besides the fact that a vigorous technology-based industry can lead to good global scientific positioning (e.g. pharmaceutical industry), public strategies and investment can be effective in reaching scientific excellence or leadership in specific technological niches (converging applications targeted at specific societal needs). The evolution of clean technologies, especially for the energy domain, seems to present the same (economic and societal) challenges for global scientific leadership (biofuels and fuel cells R&D). At a country level though, public and policy support based on environmental awareness (societal factor) is judged to stimulate strong national R&D in this field.[24]

ICT and biotechnology account for 77 percent and 73 percent of the total public R&D budgets in the US and Japan, respectively, thus reflecting the relative priority levels attributed to the different S&T fields. Europe's support to R&D is more multi-targeted with 80 percent of European R&D funding being focused on ICT, biotechnologies and clean technologies, which includes environment and energy.[25]

It is important to note that a strong R&D financial contribution must necessarily be supported by a strong political involvement at a governmental level and is thus not merely a reflection of specific financial or investment tools. In other words, public support to R&D is not solely a technical but rather a political matter. For small sized countries with limited financial means or those wanting to make a specific effort, international cooperation and R&D networks are clearly useful national strategies to catch up with other countries in terms of R&D competencies.[26] This highlights the fact that the political factor is important for advancing S&T performance and can often account for the differentiation between countries.

The growing technology-based industry is increasing the need for highly skilled personnel in many countries, driving demand for human resources in science and technology. This in turn has made the market for the highly skilled more competitive. The capacity of attracting the best and most promising student with research potential is a highly important factor in support of a dynamic R&D landscape.[27] Hence, countries offering an environment where people engaged in S&T research have the opportunity to acquire the skills required in their fields, gain practical experience, and be rewarded for their efforts, will definitely benefit from future trends in S&T.

More generally, it is thought that the most economically and scientifically advanced countries will have the best capacity to acquire and implement a full range of future technology applications to address a diversity of problems and issues. For the less economically and scientifically advanced nations, however, substantial disparities between their capacity to acquire and implement technology applications exist. Thus, introducing structural reforms to improve the S&T environment and strengthen the country's R&D capability through enhanced institutional, human, and physical capacities will help narrow the gap in technology acquisition and implementation between them and the scientifically advanced countries. However, for those countries that have less dynamic economies and less scientific growth, and also suffer from political and social instability, implementation of technology applications will be very difficult, even when they have the capacity to acquire the relevant technology applications.

In terms of capacities to implement technology applications, the following points are worth noting:[28]

- The technological preeminence of the scientifically advanced countries of North America, Western Europe, and Japan.[29]
- The emergence of China and India as rising technological powers, with the scientifically proficient countries of Eastern Europe, as represented by Poland, not far behind.[30]
- The large scientific and technological gap between most of the countries of Africa, the Middle East, and Oceania and the rest of the world. Notable exceptions to these regional trends are South Africa, Israel, and Turkey.

An increasing share of R&D is sourced from abroad, through private business, public institutions or international organizations based in advanced countries. In most industrialized countries, the share of foreign affiliates in business R&D is growing, as foreign firms acquire local R&D-performing firms, or establish new subsidiaries.[31]

Globalization is spreading to an increasing number of countries as trade and financial flows increase and technological progress facilitates the exchange of ideas and the development of new markets for goods and services. One of the main drivers of the globalization process are multinational companies

(MNCs) which structure sales, production, and R&D efforts in transnational and dynamic contexts. Cross-border flows of R&D, which had mainly been confined to the United States (US), Japan and Europe, seem to be changing in favor of emerging economies, such as China, India and Brazil.[32] The quality of R&D and the resulting externalities for local firms and institutions, in terms of absorption and learning, depend on the host country's local capabilities. A large part of development performance in the emerging economies has been based on using existing technologies, especially platform technologies that have broad applications in the economy. Developments and products achieved in ICT, biotechnology, nanotechnology and new materials have strong implications for long-term economic transformation.[33]

However, the digital divide excludes many populations both within the developing countries and in the least developed countries.[34] In the R&D area of public health, the global divide is also dramatically apparent, linked partly to a market failure. While people in high-income countries have benefited greatly from progress in technologies driven by biotechnology, this has not been the case for most part of the world's population.[35] Research intensity is relatively high for diseases that hit both developed and developing countries, but very limited for diseases that occur exclusively in low- and middle-income countries. At the same time, the direct transferability of research findings from high-income to low-income countries is limited. Public purposeful efforts, investments and further research are needed to optimize the impact and societal benefits of technologies. Indeed, a country needs a certain level of scientific and technological capability to adapt and fully use existing technologies. Accumulated investments in education and learning are essential, in particular for least developed countries to enable them to benefit from technologies and utilize them. Technologies can also be transferred through joint projects and technological cooperation.

Globalization of Technology R&D

Global Market Needs Vs Local Socio-economic Factors

Private and public R&D sectors face different dynamics, and businesses' R&D expenditure – in particular that of multinational enterprises – is increasingly mobile as new markets open up, different economies compete with each other to host R&D facilities, and a supportive global financial system is in place. Public R&D expenditure is more dependent on government funding and is therefore more rooted in the local national context. Furthermore, the relative influence of public authorities is changing. Since the 1980s and 1990s, the share of public R&D financing in the total Gross Expenditure on Research and Development (GERD) has diminished in most of OECD countries, although it has remained constant in the last seven years.[36]

In the industrialized countries, the private sector accounts for the majority of R&D that is performed. However, businesses' R&D expenditure (BERD) growth has slowed down in the US and EU27 since 2001. Some emerging economies are becoming important R&D spenders, hence changing the global distribution of R&D expenditures. For example, China's Gross Expenditure on R&D grew to reach 19 percent annually from 2001 to 2006 and its BERD-to-GDP ratio has increased rapidly to catch up the EU27's, with 1.02 of GDP by 2006.[37]

As global providers of S&T innovations, MNCs increasingly look around the globe for opportunities in terms of markets, technology and cost efficiency. This has led to the internationalization of their R&D activities and made them responsible for half of global R&D expenditures. Even in the gloom of the present recession, it has been found that more than two-thirds of MNCs maintained or increased their R&D spending. For years, this has been considered as a competitive necessity.[38]

MNCs now organize their research activities towards more globally distributed research networks, and no longer tend to polarize research in the home location. As the world demand is inexorably spreading to the newly emerging economies, it is self evident that those economies host a growing part of R&D units. Hence, local demand and social trends in host countries are driving the production of new knowledge outside the MNCs home locations in units located abroad. Beyond the simple adaptation of technology to local conditions, these R&D units tend to be highly concentrated in a limited number of economic sectors.[39] However, the distinction between adaptive and innovative R&D units is not entirely clear. There are indications that both demand and supply motivate the location of R&D activities in host countries.[40]

Statistics show that the increased budget spent on R&D outside the MNC's home country is directed more and more towards developing countries. No less than half of the Foreign Direct Investment (FDI) projects involving R&D worldwide during the period 2002-2004 were undertaken in developing countries, or in south east Europe and the Commonwealth of Independent States. China, Singapore and South Korea are especially attractive locations for US-owned MNCs foreign affiliates and their R&D expenditures. Japan-based manufacturing companies are increasingly basing their foreign R&D centers in China. Furthermore, EU and North American based firms are much more inclined to generate technological knowledge abroad and to engage in international R&D activities.[41]

In fact, some MNCs spend more on R&D than many countries. For instance, the top 15 MNCs have budgets equivalent to the overall R&D spending in countries like Belgium, Argentina, Finland, Denmark, Israel, Brazil, India, Mexico and Singapore.[42] Computing and electronics, health care and auto sectors continue to account for the bulk of global R&D spending – more than two thirds of the total in 2008. Health –care companies spent the most on R&D as a percent of sales, followed closely by software and internet companies. Companies headquartered in North America, Europe and Japan continue to dominate global R&D spending, accounting for 94 percent of the total. The fastest-growing companies, by far, continue to be those headquartered in India, China and the rest of the world.[43]

Not only MNCs are important R&D actors, they are also important for the overall innovation process. Innovation has become more expensive, more complex and interdisciplinary and as such requires more collaboration between scientists, engineers and end-users as well as between design, manufacturing, supply and marketing. Reduced geographical barriers together with the development of communication technologies and the creation of knowledge in centers of excellence all around the world speed up the process and make it more global. This increasingly turns MNCs into integrators of globally distributed R&D, forcing them to manage their global innovation networks resourcefully with the right balance between local in-house R&D, external R&D, and R&D performed at foreign affiliates or by foreign partners. The role of MNCs in the international exploitation of research and technology is a second important way in which MNCs contribute to the process of internationalization. At present, MNCs seek not only to exploit knowledge generated at home and in other countries, but also to source technology internationally and tap into centers of increasingly multidisciplinary knowledge worldwide. Indeed, firms are embracing "open" innovation approaches and actively cooperate with actors outside the firm to gain access to knowledge and commercialize their own knowledge.[44]

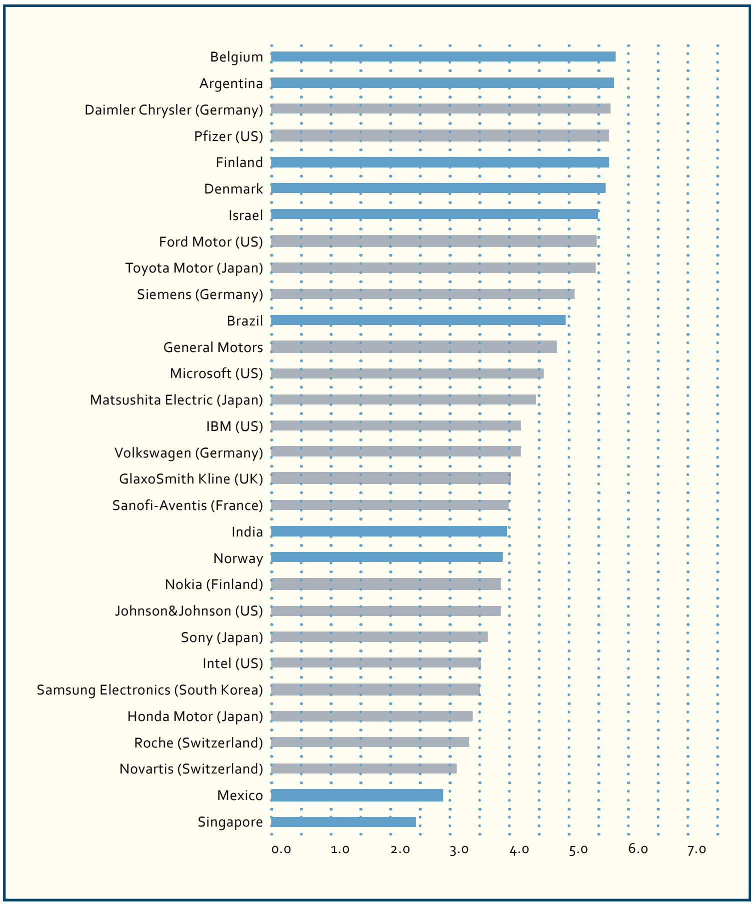
To the extent that MNCs are attracted by large supplies of researchers, top level universities and research institutes, high quality infrastructure and the like, more and more emerging countries are focusing to build their national research and innovation capacity to attract foreign investment in R& D and Innovation.

Increasing investment is being made in research, and more knowledge is being produced outside the triad (US, Japan and Europe).[45] Developing countries capable of benefiting from the internationalization of R&D will see the growth of their markets for innovation and technologies, on both supply and demand sides, which will benefit the local knowledge system.

Conclusion

In the new global landscape of knowledge production, future societal challenges generate emerging global demands for science and technology, which go beyond any specific country. Moreover, there is evidence of a global market divide namely in sustainable development (Clean technologies), public health (Biotechnologies) or global inclusion (ICT). Prospects in the manufacturing sector and the new global competition, world population growth, age structure and spread of infectious diseases, the growing global divide with large populations falling outside the international economy, and the unsustainable demand on energy and natural resources, constitute big challenges for science and technology.[46] These challenges, however, also present

R&D Expenditure by World Top 15 R&D Spending MNEs and Selected Economies, 2004 (Euros Billion)



Source: Europe in the Global Research Landscape p. 71.

potential new markets and further opportunities for transfer of technology. For the economically and scientifically advanced countries, transformative technology applications will respond to the need of competitiveness. Emerging economies will continue to encourage production and consumption of technologies that enhance accessibility to services and products. Poor countries will mainly benefit from technology applications designed to provide affordable solutions.

Increased globalization of R&D activities and more open and networked forms of innovation are also challenging national S&T policies. Increasingly, developed and developing countries are taking into account these recent trends when formulating their national strategies. In order to strengthen their S&T research and innovation capacities and to foster their participation in the global value chain, they are using tax credits to enhance their attractiveness for R&D-related FDI, supporting innovation eco-systems with a view to creating world class clusters, opening their national programs to cooperation with research entities worldwide, setting mobility programs to attract talented foreign scientists, fostering cooperation with developing countries in education, or using their innovation potential to contribute to the solution of global challenges. Policies to encourage demand for innovation, such as the development of lead markets, innovation-friendly procurement and the development of standards, are also receiving greater emphasis.[47]

Endnotes

1. This paper is mainly based on US and European Foresight studies.
2. Directorate-General for Research - Foresight Unit K2 – Scientific and Technological Foresight, "Emerging Science and Technology Priorities in Public Research Policies in the EU, the US and Japan", (March 2006), 5, 15-16 and 18.
3. Richard Silberglitt, Philip S. Anton, David R. Howell, Anny Wong, ,"The Global Technology Revolution 2020, In-Depth Analyses" (RAND Corporation, 2006), 19
4. Ibid., 15, 19, 23, 25 and 27.
5. Stefan Den Doelder, "Investing in Clean Tech Private Equity Funds" (Robeco Rivate Equity, 2009), 8.
6. "The Global Technology Revolution 2020", op. cit., 23-24 and 28.
7. Ibid., 26 and 30
8. Axel Zweck, "Technologies and the Future", in T*echnology Guide: Principles, Applications, Trends*, Ed. Hans-Jorg Bullinger (Springer, 2009), 3. "The Global Technology Revolution", op. cit., 15 and 29
9. A nanometer is a billionth of a meter, approximately 10 times the atomic size scale, thus nanotechnology opens the door to engineering at the molecular level.
10. "The Global Technology Revolution", op. cit., 10, 12
11. I borrow this denomination from A high Level Expert Group Report on

Fore-sighting the New Technology Wave, by Alfred Nordmann Rapporteur, "Converging Technologies – Shaping the Future of European Societies" (Luxembourg 2004), 6.

12. "The Global Technology Revolution 2020", op. cit., 14
13. "Investing in Clean Tech Private Equity Fund", op. cit., 9
14. "Emerging Science and Technology Priorities", op. cit., 37
15. Ibid., 21-22
16. "Converging Technologies: Shaping the Future of European Societies", op. cit., 10
17. "Emerging Science and Technology Priorities", op. cit., 6
18. Ibid., 29-30.
19. Ibid., 37 and 41.
20. Ibid., 42-43.
21. Ibid., 52, 71 and 88
22. Ibid., 21-22.
23. The 21st Century Nanotechnology Research and Development Act of 2004 provides for approximately $1 billion annually in U.S. government nanotechnology funding through 2008, and global funding for nanotechnology – in 2006- was several times larger, with every major economic power and many developing economies investing substantial resources, in "The Global Technology Revolution 2020", op. cit.,10.
24. "Emerging Science and Technology Priorities", op. cit., 79 and 96-99.
25. Ibid., 27-28.
26. Ibid., 35
27. Organisation for Economic Co-operation and Development, "OECD Science, Technology and Industry Outlook", (OECD, 2008), 13
28. "The Global Technology Revolution 2020", op. cit., xxiv-xxvi.
29. R&D in Japan is at the same level or slightly higher than that in European countries and in the USA. The Japanese government has been successively increasing its R&D investment in S&T fields in order to take the leading position. For more information see the case of Japan in "Emerging Science and Technology Priorities", op. cit., 33.
30. In fact, some of the countries outside the triad (USA Japan and Europe) are developing scientific capabilities for research and development of key technologies. This is the case in ICT and nanotechnologies in China and India Europe in "The Global Technology Revolution 2020", op. cit., 47 and 52.
31. "OECD Science, Technology and Industry Outlook", op. cit., 12.
32. Directorate-General for Research Unit C4 — Economic and prospective analysis, "Europe in the Global Research Landscape", (Luxembourg, 2007), 67-69
33. Ibid., 65
34. While the total population in the OECD countries amounts to less than 20 per cent of the world population, more than 80 per cent of ICT broadband and almost 70 per cent of Internet subscribers in the world live in these OECD

countries. "Europe in the Global Research Landscape", op.cit., 65

35. At the end of the 1990s, more than 50 per cent of the total global funding for health research was provided from public sources (the pharmaceutical industry accounted for 42 per cent and private, non-profit and university funds for the rest). "Europe in the Global Research Landscape", op.cit., 66
36. Ibid., 12 and 67
37. "OECD Science, Technology and Industry Outlook", op. cit., 11
38. "Europe in the Global Research Landscape", op.cit., 69-70 and Barry Jaruzelski, Kevin Dehoff, "Profits Down, Spending Steady: The Global Innovation 1000", (Booz&co 2009),.3-4
39. "Europe in the Global Research Landscape", op.cit.,.95 and 101
40. "OECD Science, Technology and Industry Outlook", op.cit., 32
41. "Europe in the Global Research Landscape", op.cit., 73
42. Moreover, the 1,000 MNCs that spent the most on R&D, spent just over half the money invested worldwide in 2008, 34% more than governments and 81% of the total spent by all corporations worldwide in" Profits Down, Spending Steady: The Global Innovation 1000", op.cit. 5; and "Europe in the Global Research Landscape", op.cit., 70
43. "Profits Down, Spending Steady: The Global Innovation 1000", op. cit., 7.
44. "OECD Science, Technology and Industry Outlook", op. cit., 31, and "Europe in the Global Research Landscape", op. cit., 69-70
45. "Europe in the Global Research Landscape", op. cit., 101
46. Ibid., 67
47. "OECD Science, Technology and Industry Outlook", op. cit., 13-14 and 90.