Global governance of technology: meeting the needs of developing countries [1]

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Abstract: In 2000, world leaders adopted the United Nations Millennium Declaration in which they pledged to halve, by 2015, the proportion of the world's people earning less than a dollar a day, suffering from hunger and unable to obtain safe drinking water. This paper argues that meeting these targets will entail concerted efforts to raise economic productivity in the developing world and to redirect research and development (R&D) in the industrialized countries to address problems that affect the developing countries. Doing this will require approaches that place science and technology at the centre of development policy in a world that is marked by extreme disparities in the creation of scientific and technical knowledge. Mobilizing this knowledge to meet the agricultural, health, communication and environmental needs of developing countries will continue to be one of the most important issues in international relations in the years to come. The paper identifies ways of using the world's scientific and technological knowledge to meet the needs of developing countries. More specifically, it examines linkages among science, technology and development; emerging trends in innovation systems;

incentive measures for technological innovation; and how to make technology work for developing countries. The paper examines two categories of measures needed to promote the application of science and technology to development. The first includes measures adopted by developing countries themselves to promote scientific research and technological innovation as a key element in economic development policy. The second includes measures that can be adopted in the industrialized countries to contribute to solving problems in developing countries.

Keywords: Biotechnology; developing countries; energy; information technology; innovation; knowledge; pharmaceuticals; policy; science and technology.

Reference to this paper should be made as follows: Juma, C., Fang, K., Honca, D., Huete-Perez, J., Konde, V., Lee, S.H., Arenas, J., Ivinson, A., Robinson, H. and Singh, S. (2001) 'Global governance of technology: meeting the needs of developing countries', *Int. J. Technology Management*, Vol. 22, Nos. 7/8, pp.629–655.

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1 Introduction

Science and technology are widely recognized as important factors in the economic transformation of developing countries, as well as countries with economies in transition. However, this recognition is only beginning to feature in international development policy. In 2000, world leaders adopted the United Nations Millennium Declaration in which they pledged to "spare no effort to free our fellow men, women and children from the abject and dehumanizing conditions of extreme poverty, to which more than a billion of them are currently subjected" [2]. They resolved "to create an environment – at the national and global levels alike – which is conducive to development and to the elimination of poverty" [2]. The leaders also set out to "halve, by the year 2015, the proportion of the world's people whose income is less than one dollar a day and the proportion of people who suffer from hunger and, by the same date, to halve the proportion of people who are unable to reach or to afford safe drinking water." [2]

Meeting these targets will require concerted efforts to raise economic productivity in the developing world and to redirect research and development (R&D) in the industrialized countries in order to address problems that affect the developing countries. Doing this will require approaches that place science and technology at the centre of development policy in a world that is marked by extreme disparities in the creation of scientific and technical knowledge [3]. The majority of the world's scientific knowledge is generated and utilized in industrialized countries. Mobilizing this knowledge to meet the agricultural, health, communication and environmental needs of developing countries will continue to be one of the most important issues in international relations.

The aim of this report is to identify ways of using the world's scientific and technological knowledge to meet the needs of developing countries. More specifically, the report examines linkages between science, technology and development; emerging trends in innovation systems; incentive measures for technological innovation; and how to make technology work for developing countries. The report deals with two categories of measures needed to promote the application of science and technology to development. The first includes measures adopted by developing countries themselves to promote scientific research and technological innovation as a key element in economic development policy. The second includes measures that can be adopted in the industrialized countries to contribute to solving problems in developing countries. These two categories of measures are closely interrelated and are influenced by the wider forces of globalization [4]. Bringing technology to meet development challenges will require new technology governance systems that take into account the dynamics of globalization and local realities in developing countries.

There are two main messages in this report:

1. that S&T is crucial for development in all countries and must be used efficiently for the needs of developing countries; and
2. that for this purpose, cooperation with industrial countries is essential.

Reducing poverty and improving income distribution are closely linked to the ability of developing countries to master the use of knowledge in economic development. This process requires a combination of national leadership in the developing countries and commitment to international cooperation in the industrialized countries. Only a handful of countries currently provide the requisite political leadership needed to make a difference in developing countries. It is often the case that international technology cooperation is not a central agenda in industrialized country governments. Moreover, technology cooperation occupies a marginal place on the agenda of bilateral and multilateral agencies. We hope that this report will stimulate a process of inquiry and dialogue that seeks to place science and technology at the centre of development policy.

2 Trends in innovation systems

2.1 From invention to innovation: crossing the 'Darwinian sea' [5]

The process by which the results of scientific research or inventions are converted into products and services holds some similarities between industrialized countries and developing countries. Although developed countries benefit from a strong and mature industrial financial base, social capital, and a culture of invention that collectively create a positive innovation environment, those who attempt to convert scientific research and inventions into commercial products still face risks [6]. Many inventions emerging from the research community fail to materialize as a commercial product. The challenge is to create and to sustain a research environment that helps the inventor cross the 'Darwinian sea' separating the continent of invention from the continent of successful innovation and commercialization.

This transition from invention to commercialization presents challenges at multiple levels. Precise technical knowledge is required to commercialize a product. A gap between the realities of the technology and the profit demands of investors may arise. Furthermore, the different expectations and languages of researchers, business partners and venture capitalists may result in a communications gap that needs to be bridged through the creation of complementary institutions.

To better understand how to bridge these gaps, we need to focus on issues such as the separation of technical and market risks, the type of research needed to convert proof of concept to product, the communication styles of innovators and managers, as well as the kinds of enterprises best suited for high-risk technological innovations. While start-up companies suffer from a high degree of failure, they are one of the best sources of radical innovation. This is in contrast to medium-sized firms, which have a traditional approach to technical risk-taking. Even worse, large firms have little incentive to take any risks. Government has a role to play in bridging this divide. It can help foster collaboration between university research and corporations by building social capital, promoting venture capital through indirect incentives such as tax relief and a flexible regulatory structure, and by providing public venture capital.

In contrast to advanced developed nations, developing countries lack many of the ingredients needed for innovation. Opportunities are rare, prompting the analogy of an island of innovation opportunities that must be discovered in a large sea of risks. Most developing countries have only limited indigenous capacity to innovate. As a short-term measure, they can encourage foreign investment and local training. In the medium term, they may license foreign technology. This, however, will leave them paying substantial licensing fees for many years. In addition, heavy dependence on foreign technology will render a country less competitive in an unfavourable global economy.

To guard against such risks, long-term innovation capacity building is required. This can be achieved by a variety of measures, including local capacity building for innovation. Focusing on select local developments will decrease the risks associated with being spread too thinly across many sectors. As part of capacity building, investment can be placed into centres of excellence as a means of developing high-calibre national research capability. Innovation at the village level can be supported by nurturing local cottage industries, which are as important as large industrial initiatives. Networks can be developed to link these small enterprises. This will help toward the effort of building human resources and capital. This buildup will require investment in higher education as well as in universal schooling.

Preparing for success is the key for sustaining success. Pressing forward with success in mind creates the opportunity to build an infrastructure for further developing industry. Having such an infrastructure will increase the chances of future success.

2.2 Technological change as a learning process [7]

The gap between developing countries and developed countries in terms of real income and labour productivity has been widening since the Industrial Revolution. Differences in the accumulation of technology may account for much of this gap. Although globalization has contributed to the increased flow of goods and services, it has not resulted in a significant transfer of technology to developing countries. Technology in developed countries has now advanced to such a degree that developing countries are at a significant competitive disadvantage such that even a ready supply of cheap labour cannot make up the difference.

Of the Latin American countries, Brazil and Mexico have been most successful in the process of industrialization. In East Asia, it is Korea and Taiwan that have been most successful. However these two sets of countries have gone about it in very different ways. Whereas the proportion of US patents (granted to residents of any country) held by Brazil and Mexico is 50 times less than their proportion of total world income, for Korea and Taiwan this relationship is reversed [8]. The processes of industrialization of all of them are essentially based on the absorption of innovations originally generated in industrialized countries, i.e., they are learners rather than innovators. However, those two sets of countries have very different patterns of technical change. The Latin Americans follow strategies of learning predominantly passively, whereas the East Asians follow active learning strategies.

The main objective of the technological strategy of a passive learner (corporation or country) is just to absorb the technological capabilities for production, using a kind of a 'black-box' approach. Usually the only improvements passive learners make to the absorbed technologies are incremental changes that are mainly the consequence of experience acquired in production. On the other hand, an active learner goes beyond that. Its technological strategy is mastery of the absorbed technology and its improvement through a deliberate effort.

Passive learners are doomed to depend on spurious competitiveness, such as low wages, natural resources depletion, and state subsidy or protection. They are, in the long run, doomed to remain underdeveloped. Active learning is a necessary, but not sufficient, condition for achieving development. A developed country relies on authentic competitiveness based on technology. However, as long as it is understood that technical change is not reduced just to innovation and simply technology transfer, it is realized that there is lots of room for domestic technological efforts in developing economies. Consequently, technology policy should be demystified. It does not need to be a business just for developed countries nor seen as a kind of unnecessary and wasteful luxury for poor countries.

To switch from a passive learner to an active learner, Brazil and similar countries should not immediately focus on innovation but should instead look towards improving the basic foundation of education and R&D capacity. Government can play an important role in defining the scope and parameters for industrial learning through specific policy measures, financial support, incentives and political leadership [9].

2.3 Institutional flexibility and innovation [10]

Scientific and technological innovations are associated with complementary institutional adjustments that facilitate the translation of inventions into products and services [11]. The first academic revolution started when universities began to regard themselves as agencies of research as opposed to purely teaching institutions. More recently, there has been a second academic revolution, which involves a shift toward entrepreneurship and the nurturing of new business opportunities. This 'incubator' approach, whereby universities train and develop young firms, as well as young people, and then send them out into the commercial world, is growing in popularity [12]. Along with the shift towards entrepreneurship, there has been a move away from discipline-based research toward multidisciplinary research. This has in a few cases led to the creation of new hybrid disciplines such as 'bioinformatics'.

Box 1 The Triple-Helix model

There is a change underway in the relationships among university industry and government in various countries, moving into a common configuration from different starting points. Under some conditions, organizational innovations, traditionally constrained by culture, transfer extremely rapidly. Various developments have coincided to influence change including: (1) the emergence, spread and convergence of technological and communications paradigms such as the computer, mobile telephony and the internet; (2) the interconnection between the laboratory and users of research, exemplified by the US 'land grant' model of county agents mediating between researchers and farmers and Pasteur's laboratorization of industrial production processes in France; and (3) the transition from vertical to lateral modes of coordination, represented by the emergence of networks, on the one hand, and the shrinking of bureaucratic layers, on the other.

In time, these forces lead to shifts in the political-economic relationship of university, industry and government, moving them closer in some societies and distancing them in others. For example, at US universities, industry and government are supposed to work more or less separately from each other. Government is not supposed to play a strong role with industry. Nevertheless, government increasingly plays an important role, not only in providing a regulatory environment but also in encouraging innovation through an indirect industrial policy. Academia is traditionally supposed to be apart from industry. Nevertheless, academia is increasingly involved with industry, not only in doing, consulting and contract research but also in forming companies from academic research.

Source: Etzkowitz, H. *et al*. [12]

A closer interaction among government, industry and academia, forming a triple helix model, is playing an increasingly important role in S&T capacity [13]. It is proving to be more successful than the previous bilateral relationships between academia and government, industry and government, and academia and industry. One example of this development of more complex hybrid relationships is the arrangement by which government provides research capital that is matched by private funding. Whereas public sector venture capital is essential to promoting the commercialization of new ideas, government must be careful to remain neutral. In supporting innovation, government should not attempt to differentiate winners from losers but instead should provide money in the shape of innovation grants rather than as investments. Collaboration in the commercial sector, albeit rare, is valuable and should be encouraged.

In developing countries private venture capital is not yet developed, leaving governments to take the lead. Direct support or matching funds, in collaboration with private investors, can be successful as can the involvement of academic institutions that often have good links to major institutions and the human capital of advanced countries.

3 Incentives for technological innovation

3.1 Technological divides [14]

Approximately one third of the world's population is technologically deprived, neither producing their own innovations and technological developments, nor having access to the technologies developed by other nations. Only 15% of the global population provides nearly all technological innovations. One approach to reducing this inequality is to foster collaboration. Collaboration is seen as a useful tool even in countries with advanced technology and a highly competitive market place in which companies are driving to outperform their competition [15].

Box 2 The visible hand: US government support for research

Government has played an important role in creating incentives for innovation. Through legislation such as the Bayh-Dole Act (which allows researchers to acquire property rights on inventions derived from government-funded research), the Orphan Drug Act, and the Small Business Innovation Research Program, the US government has provided incentives for both the private and public sectors to work on science and technology. Private sector incentives range from investment tax exemptions, property rights, market access, and market share protections. These legislative initiatives have had a major influence on the industrial structure of the countries and constitute major policy measures for promoting technological innovation. Some of them are deemed to have gone too far and created prospects for conflict of interest, especially in relation to the close linkages between industry, academia and government. Indeed, these measures are currently being emulated in other parts of the world where institutional rigidities have slowed down the flow of knowledge between the major industrial players and compromised international competitiveness. The government also uses other measures such as public procurement to facilitate technological innovation including research contracts for defence, space, environment, and public works, which have important lateral effects through promoting research in general and through results that find other applications.

Collaborative schemes to bring technology to developing countries, while still respecting intellectual property rights, are needed [16]. Some may disagree that although intellectual property represents a widely accepted practice, enforcement may not be the best way to help developing countries. Nevertheless, it is important to establish precise terms for sharing intellectual property before a collaborative project gets underway. What is being disputed is not whether intellectual property rights are essential or not, but their scope and the way they are enforced. Furthermore, it is also apparent that funding is not the only way to support collaboration. Some projects do not provide funds to developing countries but instead contribute other values such as expertise and human capital.

3.2 Technology and entrepreneurship [17]

Three assumptions provide a framework for understanding the relationship between technology and entrepreneurship. First, the world presents a closed economy within which people, products, ideas and capital flow relatively easily across borders. This is in part due to the decentralization of organizations. Secondly, entrepreneurship from small and medium size firms is thriving today, in stark contrast to the prediction that large industrial units would easily oust smaller counterparts. Finally, the phenomenon of increasing returns is become a more dominant feature of the economy.

Box 3 The contribution of new firms to economic growth in the USA

While it is true that small firms have been responsible for much of the job growth in the economy, only a few of these firms are responsible for the majority of the growth in the USA. For example, new firms are responsible for a third of the jobs created but upon closer inspection, 75% of the growth was generated by 10% of the group of new firms. Additionally, venture capital and public equity, while touted for their importance, do not play the dominant role in fostering technology-based entrepreneurship. Of the 500,000 new firms founded each year, only 500 received seed stage venture capital. At the same time, the average size of venture capital disbursements has tripled in the past five years and has increasingly focused on late term technologies. This trend suggests that those interested in promoting employment and income-generating activities in the developing world need to pay special attention to enterprise development. Policies that facilitate the creation of new enterprises will invariably place special emphasis on the use of technology. In many developing countries, enterprise development has been hampered by the absence of institutions that assist in international technology searches. Indeed, countries such as Chile have created institutions that focus on enterprise development through international identification of technologies of relevance to the Chilean economy. One such institution is the Chile Foundation (http://www.funpacifico.cl/), which was established in the 1970s as an endowed initiative of the government, and ITT. The Chile Foundation was responsible for introducing salmon farming and many other natural resource-based technologies in the country.

Using the US innovation system as a point of reference for advanced technological development, it was shown how Israel had taken concrete and successful steps to improve its technological innovation. For example, government intervention and policies have made available matching grants to support projects attracting private investment. Furthermore, a magnet program and technology incubators had both been established. Collectively these efforts to jump-start the private venture capital industry were successful at creating realistic incentives for innovation and development.

It is important to recognize and to exploit national or cultural advantages when deciding which technologies to encourage. In addition, a country should start planning for the success that it hopes will follow the introduction of these programs. The foundation and infrastructure for sustained technological development cannot be put in place overnight but instead must be developed in anticipation of successful development strategies.

4 Science, technology and development

4.1 Technology and the development process [18]

The role of technology in development has not occupied its rightful place in international development policy. Today there is greater emphasis on science and technology as a tool for market competition than as a vehicle for improving the human condition. Indeed, many of the controversies surrounding technology deal with issues such as good nutrition, health and environmental management. These issues are at the core of the agenda for human welfare and highlight the central role that science and technology plays in human welfare.

Development goals that do not recognize the importance of science and technology in economic transformation are likely to fail, especially those aimed at reducing poverty and raising income levels. Much of the debate over the role of technology in developing countries focuses on the commercialization of products generated in industrialized countries. This is evident in debates over transgenic foods, AIDS drugs and what has been termed the digital divide between poor and rich nations. While this is an important theme, developing countries are unlikely to be major importers of these products unless their economies are able to grow. Such growth will not be possible without significant advances in the use of technologies for emerging countries.

Many obstacles stand in the way of improving the technological development capabilities in these countries. Resources that are needed include knowledge, financing, market opportunities and incentives. Financing of research – including in the field of agriculture – in developing countries has been in decline since the end of the Cold War. In addition to this decline in financing, research in industrialized countries aimed at solving developing country problems has also declined.

The conventional view of technology and development is that the former is a product of the latter. In fact, technological capacity is an essential component of development. Although there is plenty of evidence to show how over the past century technological breakthroughs have enabled social, physical, nutritional, and economic progress, less developed countries now have fewer opportunities to close the development gap. The main global policy challenge is therefore how to create and diffuse technology for development, especially so that people with low incomes can make use of it. Because these people do not constitute an immediate or traditional market, there is little incentive for industries of developed countries to consider their needs. Meeting this challenge will entail a combination of domestic effort as well as international response in order to provide incentives for private enterprises in the developed world to invest in research of relevance to developing countries.

4.2 Emerging knowledge markets [19]

The modern world is characterized by the emergence of the ‘knowledge economy’ or the ‘new economy’ that is dependent on the explicit recognition of knowledge as the motive force of economic growth [20]. This emergent knowledge market system depends on an integration of science and technology with policy in ways that do not presently exist in many developing countries. As a result, the productivity gains that are associated with this integration are not fully realized in these countries. In the absence of increases in productivity, policy measures for reducing poverty will be of little value. Furthermore, the full participation of the developing nations in the global economy will require them to improve their productive capacity and diversify their sources of economic income.

Many of the developing countries will have to move from natural resource extraction economies to knowledge-based ventures that add value to these resources. All these changes require a shift in public policy at the national and global level. Domestic innovation will not be possible without access to international markets; access to international markets will not be possible without domestic technological innovation. Local factors and global dynamics are thus intertwined in new ways requiring fresh approaches to domestic and international policy.

Reforms at the national level will require major adjustments in educational systems inherited from models that are antithetical to the demands of the knowledge economy. The classical model of knowledge creation was through specialized research institutions that operated independently from industry. Interactions between these institutions and the productive sectors were regulated by a set of norms that promoted separation and slow flow of information between the two. The separation between knowledge and production is even more dramatic in the developing world. The historical origins of the current educational systems in the developing world are not as important as their legacy.

The industrialized countries from which these models were copied have over the decades reformed their own systems but the many of the developing countries that adopted the models still continue the classical models now abandoned by their countries of origin.

Box 4 Reforming the research system in the UK

In the early 1970s, the UK's Rothschild Commission recommended a move away from the earlier models of science and technology, advocating instead the creation of systems that promote interactions between customers and contractors. Under the system, needs would be contracted out to accredited laboratories, universities, private consultants, or even overseas firms. The new model contributed to the recognition of knowledge as an essential part of the science and technology policy. It promoted competition in R&D contracts, facilitated the privatization of laboratories, and transformed relationships between government and industry. As part of this change, new institutions were created which forced scientists and engineers, for example, to collaborate on new research innovations. A process of social change encouraged cross-disciplinary efforts. A second example of this change was the Teaching Company Scheme (http://www.tcsonline.org.uk/) - an attempt to temporarily place students into companies as employees working on projects determined by the company, but evaluated by the university as well. Targeted research funding was introduced, where the government evaluated research projects for excellence. Variations on this theme around the world include teaching hospitals.

Such developments have not happened in many developing nations where still today much of the research community is isolated from the industrial sector and contributes very little to the country's innovation. In many cases, the research community is a drain on resources with few returns.

There are those who have recognized the importance of close cooperation between research and industry and have started to encourage the integration of science, technology and innovation as systems and the creation of knowledge markets. This approach suggests that special attention be placed on higher education, especially with a strong science and technology component.

A knowledge market consists of a network of nodes between which there must be a high level of connectivity. However, experience suggests that creating such institutional connectivity is still a long way off, partly because of the rigid structure of scientific investigation in developed countries. There are still many countries, especially in Africa, where national agricultural research and agriculture departments in universities have no formal links. Furthermore, these research activities are disconnected from private enterprises and as a result, the diffusion of research results is dependent on overstretched agricultural extension systems instead of commercial seed ventures. These models have been reinforced by international aid programs which are largely guided by the same approaches that the industrialized countries have abandoned. Indeed, donor agencies could play an important role helping to facilitate networking among research nodes through collaborative research programs.

4.3 Scientific and technological cooperation [21]

Collaboration among scientists is an integral part of research, playing an important role in the advancement of science and technology. Scientific collaboration between countries may be an important tool for building capacity in developing countries by transferring knowledge from developed countries. Capacity building is undergoing great change at the moment; there is a declining trend in traditional development assistance, which ha been re-channelled into capacity building and collaboration. Developing countries can be divided into four categories: scientifically advanced; proficient; promising; and lagging [22]. About 50 countries fall in the first two categories of ‘advanced or proficient’, 20 in the ‘promising’ category and the rest are ‘lagging’.

There is growing consensus that scientific cooperation is very valuable in building capacity in developing countries but is currently under-exploited. Other measures of technological capacity include the work of the United Nations Development Programme which has looked at: achievements; effective use of recent innovations for developing exports; progress in using old or otherwise well established technology, such as telecommunications, electricity infrastructure etc; and the level of investment in basic science and technology skill building.

Generally, developed countries spent very little on collaborative R&D projects. Almost all collaboration was ‘bottom up’ collaboration that might lead to peer reviewed research publication. Collaboration is seen to be stable and not dynamic. Most comes about as a result of face-to-face meetings, although information and communications technology can be important for sustaining collaboration. For the poorest countries, the donor-recipient paradigm does not work well because of the absence of true equal partnerships. Systems with greater local emphasis would address this problem of distance between the scientists and their ‘clients’. Indeed, efforts to bring the two closer together would also make the transfer of research findings to farms more effective and responsive.

In a similar vein, incentive systems must be closely matched to development goals. Scientists are necessarily preoccupied with their own career development, which is often based on their publication record. The need for publication shapes the direction of research because journals may be biased towards questions dictated by a scientific community based in the USA and Europe. Thus, the incentive for the researcher is often at odds with development goals. Individual credit as a means of recognition, success and promotion may in fact hinder international collaboration efforts.

Box 5 International agricultural research: contrasting approaches

Numerous approaches are used to promote international cooperation in agricultural research. Take, for example, the Consultative Group on International Agricultural Research (CGIAR, http://www.cgiar.org/) system, which is a network of scientists in a loose governance structure. As the dominant international cooperation model in agricultural research, its advantages are the production of global public goods and a transnational sharing of research results. While the results of this cooperation have been beneficial for farmers producing agricultural varieties on high potential irrigated lands, the CGIAR system has had less success in addressing the problems of low resource farmers on the drylands of South Asia, or the problems faced by farmers in Sub-Saharan Africa growing a mix of local crops on lands with poor soil and unreliable rainfall. The CGIAR system tends to work at a distance from highly variable local conditions, and it lacks strong contacts with farmers. A system with a greater local presence would address this problem of distance between the scientists and their 'clients'. Indeed, efforts to bring the two closer together would also make the transfer of research findings to farms more effective.

In addition to local links with farmers, agricultural research now demands greater international cooperation with strong direct links between scientists in donor and recipient countries. Other models have sought to forge closer links between developing and developed country researchers. An example of such a model is the USAID Collaborative Research Support Project (CRSP, http://crsps.unl.edu/). This program finances research collaboration between agricultural scientists working inside US universities and counterpart scientists working within national agricultural research systems in the developing world. Under the terms of the CRSP, a significant share of all research funds must be spent by partner scientists within the developing country. This allows young scientists from the developing world to train in the United States and then return to their home and build a local research program without losing contact with their international research university network. Unfortunately, funding for this program is also dropping.

5 Making technology work for developing countries

5.1 Energy technology [23]

Why should the focus be on energy technology as part of energy use? Simply put, because in many fields, technology has played a central role in expanding the services available to local people. There is good reason to see technological advances as a mainstay of societal evolution. The current evolution of the energy sector is characterized by fluctuating prices, deregulation of the energy market, privatization in many countries, a shift toward using natural gas, and a global wave of mergers and acquisitions. In this climate, the future trajectory of technological innovation is uncertain. Nonetheless, increased energy demands of both developed and low-income countries as well as pressing health and environmental concerns make energy technology development absolutely essential.

Energy consumption per capita is very different between developed and developing regions of the world. Broadly speaking, one could say that in developing countries there are two kinds of energy needs. The first pertains to urban populations that use electricity, petrol, LPG, etc. Availability of, and access to, energy are better for this group than for those beyond city limits who represent the second group of energy users. In many parts of the world, this rural population largely relies on energy sources such as wood, other biomass energy sources, and kerosene. Unfortunately, these more basic energy forms receive far less attention in the policy domain.

Different kinds of energy technologies are subject to differing levels of governance. An obvious example is nuclear energy – internationally agreed safety standards and verification of peaceful use are generally enforced in countries that make use of nuclear energy. On the other hand, the need to avoid Chernobyl-type accidents means that local governance of technology is also essential. A second example involves the kind of governance that emerges from international agreements such as the Climate Convention aimed at stabilizing greenhouse gas emissions. It is important to understand that for many energy issues there are often separate local and global concerns/needs and hence a need to pay attention to both local and global voices while constructing any governance regime [24].

Thus in making energy technology work for developing countries, it is critical to understand the nuances of both local and global needs, and accordingly develop local and global governance mechanisms. Receiving scant attention internationally is the need to tackle small and local problems. For example, indoor air pollution, caused by burning biomass fuels for heat and cooking, is a major public health problem worldwide. However, it is rarely discussed within the global climate change arena. Those exposed to the hazard have relatively climate-friendly lifestyles, even though these same lifestyles are eventually detrimental to their health.

Most energy technology innovation takes place in industrialized countries. In other words, most energy technologies are developed and first deployed in industrialized countries. Energy technologies are generally available internationally through purchase or licensing, although firms sometimes restrict licensing on their highest value-added technologies. A key question for the global governance of technology is to consider the roles that developing countries and industrialized countries can play in the process of the development and adoption of the new energy systems that are necessary to meet environment, development and security needs. This is a big question that lies at the heart of sustainable development, and which does not have a simple answer. Examples of past practice can begin to shed light on some of the challenges and opportunities facing both developing and industrialized countries.

With technology available from industrialized countries, developing countries could, and often do, play only the role of purchaser. However, for many developing countries this is neither affordable nor desirable. Rather, they would like to develop further technological capabilities to undertake manufacturing, systems integration, and energy R&D. But how and under what circumstances should developing country governments decide to invest in or in other ways facilitate the development of indigenous technological capabilities?

Two examples highlight some of the factors involved in successful development of indigenous technological capability. The first is geothermal power generation in Mexico, where the state utility has been a leader in the development of this technology, including exporting their skills to other countries [25]. Several factors contributed to this successful investment by the Mexican government, including the existence of the indigenous geothermal resource, prior technological capabilities in oil exploration that were transferable to geothermal exploration, and effective partnerships with industrialized countries for training and joint R&D. A second example is the development of biogassifier systems in India for silk drying. This development went forward with the support and involvement of an Indian energy NGO, the Indian government, and international organizations. The project focus was to become a systems developer for an intermediate technology that was applicable in India but had no market in industrialized countries.

Turning next to industrialized countries, we need to examine their role as financiers and technology development partners, both through the private sector and through bilateral and multilateral governmental institutions. A question not too different from one above is whether these organizations will finance only the purchase of technology or also finance activities that can lead to increased technological capabilities. For increasing technological capabilities, experience thus far shows that demonstration alone is useless; the landscape in some developing countries is littered with abandoned demonstrations. The World Bank and others have taken this lesson to heart, and their new renewable energy programs combine subsidies with domestic policy reform, the development of domestic financial institutions, support for retailers, and support to consumers. These programs are too new to judge whether they have resulted in ongoing private markets for new energy technologies. Some concerns are whether they provide support for an adequate time period for the learning process to take place, resulting in price decreases and reduced transaction costs that make it possible for the private market to function without the subsidies provided in these programs.

Another important issue relates to what types of additional funds are provided for developing countries to address global environmental issues. The international community understands that industrialized countries need to provide funding for the additional cost of adopting technologies that reduce global environmental impacts, such as climate change. Using the multilateral fund of the Montreal protocol as an example, the international community seems better at subsidizing the purchase of technology than at supporting R&D or manufacturing capabilities in developing countries. In the energy sector, this could prove to be a severe limitation, as developing countries have valid concerns about energy security and the affordability of imported foreign technology.

Making technology work for developing countries involves understanding local human needs and concerns, as well as technological innovation processes. Once local and global aspirations are added in, the scene becomes even more complicated. Global aspirations involve selling technology, thereby fostering technological dependence. These thoughts lead to the observation that wants, needs, and aspirations are all rolled into the conventional use of the term ‘rights’. Any efforts at global governance of energy technology have to ensure that it differentiates between the wants and needs of different groups and gives primacy to the latter.

5.2 Information technology [26]

Bridging the digital divide has become a major theme on the international agenda. This is partly because the digital gap between poor and rich nations is both real and symbolic. Real because as electronic communication expands, a large section of humanity is left out of the global system. Symbolic because the gap represents a deeper challenge related to technological disparities. However, unlike other technologies, connectivity either can build on existing infrastructure or can bypass traditional methods by relying on new wireless technologies. Technical responses are therefore within reach. Institutional responses such as relaxation of intellectual property rights on key aspects of software technology could also result in major expansion in the acquisition of skills in the developing world. Although the long-term impact of communications technology is uncertain, increasing global connectivity offers new opportunities for participation in the global economy for a large section of humanity.

Box 6 E-development in India

Of the recent unprecedented technological developments that have created many new ‘spaces’, cyberspace is the most powerful, being most widely accessible around the planet. An example is the SARI (Sustainable Access in Rural India, http://edevelopment.media.mit.edu/sari.html) project, an information communication technology (ICT) project in southern India, which is being undertaken with the collaboration of the Indian Institute of Technology, MIT Media Lab, the Indian government, and local non-governmental organizations. This project aims to connect 100 villages, which are off the telecom grid, to the Internet in the next three months, 1000 villages and hamlets outside the cities in Madurai District in the next 18 months and finally two million connections within three years. ICT can help humanistic development by using the tele-kiosk model to organize communities and businesses. From core communication services, which will solve network problems and bring in multi-literate users, to business and cyber café services, financial products and services, entertainment, SARI will generate an aggregate demand. The project hopes to prove that the benefit of networking grows exponentially when the number of people connected to it grows in the same way. Instead of cherry-picking villages and hamlets, SARI intends to move beyond the pilot mentality and connect all villages in the region.

The free software and open source ware movement is becoming a major global force in the IT sector. Because of the licensing properties of free software and proprietary software, free software is emerging as a political movement. While the source can be downloaded free, proprietary extensions cannot be made, nor can the patented information be included. With respect to software, freedom is the right to examine the software that we use and to freely access the software to alter it as well as the inability to reduce the fee of others. Open source allows open software to be bundled with closed software.

Open source and free software have growing followings in developing countries. Open code has no licensing cost, allows developing nations to train innovators and can be made culturally appropriate. For example, GNU Linux is available in Tamil, Icelandic, and Chinese.

Free software has a dangerous side as well. Laws on liability and ownership must be carefully written and strong copyright laws must underlie free software. However, culture implies a unique balance between the market and public space and a careful selection of licence can reflect this balance. Developing countries like China, India, Mexico and developed ones like Germany have built several uses and homegrown businesses around open source ware Linux. ICT leaders such as IBM, Sun and Compaq are now investing in Linux.

Intellectual property is not homogenous. Information products may be covered by patents, copyrights, trade secrets, or laws governing the sale of professional services. The relative advantages for each mechanism should be examined for new information products.

5.3 Agricultural biotechnology [27]

While the debate over the safety of transgenic crops rages on, a few developing countries are consolidating their advances in this field. China was the first to practice widespread use of a transgenic crop when, in 1990, it planted virus-resistant tobacco. It was also quick to follow the US introduction of transgenic cotton. These early developments and its significant contributions of basic research and scientific breakthroughs in this field make China a leading player in transgenic crops. This position of strength did not come about by accident. For many years, China has invested in biotechnology research and had a multi-level pro-technology policy, including the general goal to take advantage of the developed world's slow-down in biotechnology. This may enable China to become a worldwide producer of agricultural biotechnology products.

If China continues these policies, which are applied across many different technology sectors, it is likely that over the next decade it will develop into a major exporter of biotechnology. This could include the large medical biotechnology sector. A number of circumstances and policies have contributed to China's current state of having a strong biotechnology sector. This includes being well positioned to move in this sector thanks to its large internal seed and pesticide production industries that pre-existed the biotechnology industry, large numbers of trained scientists in residence, and a large public sector investment in biotechnology and in human capital, as well as its earlier success in exporting agricultural chemicals.

Unlike China, many developing countries have rejected the widespread adoption of transgenic crops. By examining in detail the experiences of Brazil, India and Kenya, each of which has so far not allowed the production of transgenic crops, and comparing them to the experience of China, it is surprising to see that anti-GM policies did not stem from principled objections on the grounds of safety or environment [28].

Box 7 Technological leapfrogging: biotechnology in China
From 1995 to 1999 China's biotechnology investment grew by 30% each year. Notable long-term plant projects include a huge plant breeding program and its rice genome project (http://www.ncgr.ac.cn/). This research investment was matched by significant economic incentives to encourage development and exports. The Biosafety Committee is located within the Ministry of Agriculture (http://www.agri.gov.cn/english/) as opposed to within an environmental agency which may mean that biotechnology regulation is more pro-technology than in other countries. Crucially, many of the benefits of these central policies, such as better yields and reduced use of expensive pesticides, have been passed on directly to small farmers as opposed to the big seed companies. For example, Monsanto's Bt cotton now planted extensively in China has yielded significant financial savings, 87% of which have gone to the farmers, 8% to the Chinese seed company collaborator and just 5% of which have gone to Monsanto. Strikingly, Monsanto is the only multi-national company now selling transgenic seed within China's agricultural biotechnology sector.

Although Kenya has adopted a regulatory framework developed by other countries, it is simply unable to process applications through this regulatory process. Rather than risk public scrutiny following any approval of transgenic development and use, it has instead adopted a policy of moving very slowly such that no approvals are likely to be forthcoming in the near future. It is this regulatory capacity problem that is blocking the introduction of transgenic crops.

Brazil has a government agency that is aggressively implementing its biosafety laws in its efforts to approve the use of transgenic crops. Despite this willingness and ability, it has been stalled by a court injunction brought by a Brazilian non-governmental organization (NGO). The crux of the NGOs argument is that although the agency has jurisdiction over approval, approval should in fact lie with the Environmental Agency. In effect, Brazil's inability to develop transgenic crop use lies in legal/constitutional issues.

India has two committees overseeing transgenic crop policies; one controlling small-scale experiments housed in a technology agency and the other, controlling commercial release, based in an environmental agency. However anti-biotechnology NGOs have side stepped this regulatory process by arguing that there is a risk that foreign multinationals will dominate Indian food production if India adopts foreign transgenic practices and products. NGOs destroyed small scale trials and exerted sufficient pressure on the environmental agency to effectively halt their approval process.

The experience of these three countries contrasts with that of China. Although China's biosafety regulations are similar to those of India and Brazil, it is insulated from the attention and actions of NGOs, media attention and opposition political parties. Those Chinese authorities that are eager to move forward are therefore able to influence the appropriate regulatory authorities without much opposition.

5.4 Pharmaceutical research [29,30]

A number of international controversies involving drugs have drawn attention to the global pharmaceutical industry, highlighting the role of science and technology in the welfare of developing countries. Pharmaceutical research and development is now governed by the Agreement on Trade-Related Intellectual Property Rights (TRIPS) under the World Trade Organization (WTO). In the past, the issue of intellectual property was not managed by the global trade regime.

Instead, the global intellectual property rights (IPRs) regime was comprised of several treaties and conventions that have been administered by the World Intellectual Property Organization (WIPO) since 1970. Because this system tended to be flexible (with limited substantive standards), with voluntary state membership in the various intellectual property agreement, and no effective dispute settlement or enforcement mechanism, countries adopted various approaches to drug patents. Thus, some countries provided pharmaceutical product and process patents, others provided just process patents, and still others provided nothing at all. Process patents were the most popular form of protection afforded to drugs by the developing countries (when protection was granted) since it permitted firms with limited resources to work around a patent by developing identical drugs using new processes. In addition, it was common to find wide discrepancies in the terms of patent protection between countries.

Some important highlights of the TRIPS Agreement with regard to pharmaceutical products include:

1. protection for a minimum term of 20 years from the date of filing;
2. the right to supply the market with imports of the patented product;
3. the availability of compulsory licences subject to conditions detailed in the Agreement.

Full compliance with the Agreement for developing countries that had previously not protected pharmaceutical products is not due until 2005.

The new global IPRs regime underscores the importance of strengthening innovation systems in developing countries. This includes: improving industrial innovative capacity (particularly research and development); addressing weaknesses in scientific and technological infrastructures including university research and public laboratories and the linkages between these institutions and industry; and ensuring the coherence of government policies affecting innovation including finance, technology, trade, investment and competition policies. In the absence of a holistic approach to improving innovative performance in developing countries, it is unlikely that they will be able to benefit from an enhanced IPRs regime.

Research in diseases of relevance to developing countries has historically been negligible worldwide. According to the World Health Organization (WHO) only 11 out of 1223 new chemical entities developed between 1975-1996 were for the treatment of tropical diseases. Almost all of this research has been performed either by international organizations or by the military in industrial countries. Pharmaceutical firms in developing countries are discouraged from researching and developing new drugs because of the prohibitive costs of such a strategy. Inadequate international support and local financing mechanisms have often meant that the majority of research proposals never reach the implementation phase.

Moreover, it is unlikely that multinational firms will increase R&D in tropical diseases because of patent reform alone. The main reason for this reluctance has been the prevalence of poverty in developing and least developed countries which restricts market profits. It is important to recognize, however, that although most drugs are developed for diseases prevalent in the industrial countries they can be of benefit to the developing countries provided that they are accessible. This is particularly true for treatments of HIV/AIDS and of drug resistant strains including diseases such as pneumonia, diarrhoea, malaria and gonorrhoea. There is a serious concern, however, that most of these treatments will be out of reach for most of the world's poor people.

Several national and international efforts are underway in response to this concern. At the national level developing country governments have been working to formulate national patent legislation that conforms to the TRIPS Agreement but that also takes into account socio-economic conditions. In addition, several countries (including Argentina, Brazil, India and Egypt) with local manufacturing capabilities have been actively producing generic copies of expensive patented drugs for domestic markets and for export. This has demonstrated that generic production in developing countries offers a feasible alternative for the supply of cheap good-quality drugs. It also heightens the need to improve the generic production capacity in the developing countries. These efforts, however, in addition to attempts to incorporate compulsory licences, parallel imports and generic substitution provisions in national laws have met with intense resistance from the global pharmaceutical industry.

Box 8 South Africa vs. the global pharmaceutical industry

In March 2001, a lawsuit involving South Africa's Pharmaceutical Manufacturers Association (PMA) and the South African government began in the Pretoria High Court. The case concerned South Africa's 1997 Medicines and Related Substances Control Amendment Act, which contained provisions regarding the authorization of parallel imports of branded pharmaceutical products and the implementation of generic substitution laws. The PMA's main arguments were that these provisions granted excessive powers to the health minister, discriminated against the industry and violated the TRIPS Agreement. In reality the aim of these provisions was to enable the minister to "prescribe conditions for the supply of more affordable medicines in certain circumstances so as to protect the health of the public..."

Following escalating protests from HIV activists worldwide, intensifying competition from generic drug producers, demands for compulsory licenses from around the world, and the reaffirmation of President Clinton's Executive Order (March 2000) by President Bush that the US would not pressure developing countries that allow the production of cheaper drugs provided that they adhered to the TRIPS, the PMA announced on April 18, 2001 that they were withdrawing the application for suit against the South African government. The Government subsequently announced its intention to move quickly to implement the controversial 1997 law. Although this was perceived as victory, particularly for people living with HIV/AIDS, it is not yet clear what impact this will have on the HIV-infected population in South Africa. *Source*: Abdelgar, B. [30]

At the international level there have also been various attempts to deal with the inaccessibility of medicines for the poor. To date these efforts have largely concentrated on the HIV/AIDS pandemic. For instance, in 1998 UNAIDS began urging multinational drug firms to make steep price reductions on their AIDS drugs. As a result several multinational corporations have agreed to slash the prices of HIV/AIDS drugs by as much as 85% leaving them still out of reach for most for the world's poor, their governments and donor agencies. As a result UN Secretary General, Kofi Annan, has called for a $7-10 billion global fund dedicated to the battle against HIV/AIDS and other infectious diseases. In addition, the European Commission has developed a program that supports the mobilization of resources, tiered pricing, and increased support for research and development for vaccines. In June the TRIPS Council will hold a special session to discuss IPRs and access to drugs. In the meantime discussions are continuing among donors and multilateral organizations regarding the specifics of an international fund for infectious diseases.

5.5 Building on local knowledge systems [31]

In discussing technology development in developing countries, we must recognize several often overlooked issues. First, developing countries must not be viewed simply as a source of pathology and problem but must also be seen as sources of new knowledge and understanding. Second, almost by definition, technology transfer is limiting for developing countries since invariably it only offers to transfer technologies that developed countries have already developed. The challenge for most countries is how to build on their traditional knowledge systems [32].

Box 9 Blending local knowledge with modern science in South Africa

One example of such a biotechnology-based initiative is a South African bioprospecting consortium's ten-year program to identify the 20,000-plus indigenous species of plants, to investigate biodiversity and to develop entrepreneurial possibilities based on that knowledge. In a larger sense, the project will attempt to identify a market niche and help develop South Africa's national innovation system. The project involves a team of biochemists at the Council for Scientific and Industrial Research (http://www.csir.co.za/), indigenous healers and plant experts, the National Botanical Institute (http://www.nbi.ac.za/), the Medical and Agricultural Research Councils (http://www.mrc.ac.za/, and http://www.mrc.ac.za/), three local universities, the National Research Foundation (http://www.nrf.ac.za/), as well as some foreign research partners such as the National Cancer Institute. These organizations are mainly sponsored by the government, and are located either within the public sector or within larger academic institutions. The role of private industry, venture capital, and user group involvement in South African biotechnology initiatives is still small.

Governmental oversight for biotechnology programming is exercised mainly by the South African Department of Arts, Science, Culture and Technology (http://www.dacst.gov.za/) and a corresponding Parliamentary Portfolio Committee. The bridging of knowledge systems, and the mix of people, ideas, cultures and interests involved in the project, have led inevitably to questions concerning not just technological development, but also benefit and risk sharing, the relationship between power and knowledge, and how to build trust which facilitates the flow of ideas and information among partners. The social innovation of creating a viable learning network may be as important as any innovative biotechnology outputs. Additionally, licensing models from open code software may be useful for biotechnology. They allow traditional knowledge of appropriate interface design to be built into software.

As indigenous and local knowledge systems do exist in the developing world, it should be possible for such countries to develop their indigenous knowledge systems, while building up national science and technology capability and interactive local learning networks which make them more viable participants in an international system of collaboration. Indeed, these indigenous knowledge systems are currently being used as a basis for screening the pharmaceutical potential of a wider range of plants, animals and microorganisms. They may provide part of the foundation for agricultural and industrial development and should be recognized as vital for future development.

6 Conclusions and outlook

International debates on the role of science and technology in international development have previously been confined to inter-governmental forums. Recent global controversies surrounding access to essential medicines, transgenic crops and environmentally sound technologies have changed the content and nature of the debate. They highlight the significant role that technology plays in globalization. Indeed, the on-going controversies over globalization are essentially arguments about different facets of technology. Industrialized countries that underwrite the initial investments needed to bring new technologies to the market place demand respect for intellectual property rights as outlined under the World Trade Organization (WTO). But developing countries that face pressing challenges in the fields of agriculture, human health and the environment demand access to emerging technologies to solve these problems. These tensions will increase as global health, agricultural and environmental challenges intensify.

The mounting political activism surrounding these issues is an indicator of the need to find ways of promoting technological cooperation without undermining the incentive systems that make it possible for the global science community to generate new innovations. This search should start with a re-examination of existing policies, especially those that shape national, regional and global systems of innovation. Many developing countries have so far paid little attention to the importance of science and technology in economic development. Industrialized countries have in turn not considered international technology cooperation as an essential feature of a viable global economy. Much of the public debate on science and technology is influenced by concerns about its negative impacts and as a result there is little systematic inquiry into how to shape technology to address development challenges.

The first step might be efforts aimed at improving our understanding of the role of technology in economic growth, especially in the poor nations. Benefits might also flow from greater attention to the social dynamics of knowledge creation and innovation in those countries. It is through such examination that we are likely to get a better understanding of how some countries have overcome abject poverty and others have not [33]. The answer lies in the active generation, distribution and utilization of knowledge as a development resource as well as the institutional innovations associated with this process. Meaningful governance systems at the local, national regional and global levels will need to take this into account. Ultimately, this new thinking should be reflected in reforms in public policy to bring science and technology to the centre of the development process.

Equally important is the role of contemporary forces in shaping the way knowledge is used in the productive process. Most of the policies and institutional arrangements affecting technology were shaped in the pre-globalization era. There is an urgent need to rethink these approaches and come up with alternatives that reflect the modern world through the systematic integration of science and technology into development thinking. In other words, science and technology policy is no longer an optional activity for developing countries, it has become a necessity in addressing the challenges of sustainable development. As the world leaders asserted in the United Nations Millennium Declaration, “only through broad and sustained efforts to create a shared future, based upon our common humanity in all its diversity, can globalization be made fully inclusive and equitable.” [2]

Acknowledgements

We would like to thank the participants of the workshop on ‘Global Governance of Technology: Meeting the Needs of Developing Countries’ held at Harvard University on 20-21 April 2001, many of whom made written contributions to this synthesis. These include Basma Abdelgafar (Canadian International Development Agency), Pnina Abir-Am (Harvard University), Zuhre Aksoy (University of Massachusetts, Amherst), Alberto Araoz (College of Management, University of Massachusetts, Boston), Mona Ashiya (Harvard Business School), Phillip Auerswald (Belfer Center for Science & Intl. Affairs, Harvard University), Geri Augusto (Kennedy School of Government, Harvard University), Michael Best (Massachusetts Institute of Technology Media Lab), Lewis Branscomb (Belfer Center for Science and Intl. Affairs, Harvard University), Jean Camp (Kennedy School of Government, Harvard University), Clarissa Ceruti (Harvard Business School), Connie Chang (Advanced Technology Program), Adolfo Chiri (Kennedy School of Government, Harvard University), Nazli Choucri (Department of Political Science, Massachusetts Institute of Technology), Norman Clark (Graduate School on Environmental Studies, University of Strathclyde), Maria Denslow (Harvard Medical School), Chris Dresser (Funders Working Group Emerging Technologies), Mohammed Elzeir (Civil Engineering Department, Brown University), Henry Etzkowitz (Science Policy Institute, State University of New York), Darryl Farber (Belfer Center for Science and Intl. Affairs, Harvard University), Craig Farkos (Kennedy School of Government, Harvard University), Matthew Feldmann (Harvard College), Michael Fischer (Massachusetts Institute of Technology), Anne Fitzgerald (The Des Moines Register), Patricia Freeland (Rutgers University), Sakiko Fukuda-Parr (United Nations Development Programme), Marianne Gieseke (Suffolk University), Adi Gopalakrishnan (Belfer Center for Science & Intl. Affairs, Harvard University), Wendy Hollingsworth (Inter-American Institute for Cooperation on Agriculture (IICA)), Henry Jimenez-Escobar (Universidad Ded Valle - Sede Zarzal), Sanjeev Khagram (Kennedy School of Government, Harvard University), Mikael Klintman (Dept. of Political Science, Massachusetts Institute of Technology), Edson Kondo (United Nations University Institute of Advanced Studies), Magda Kowalczykowski (Harvard College), Myanna Lahsen (Belfer Center for Science and Intl. Affairs, Harvard University), Luis E. Loria (Harvard Business School), Daniel Lustyan (Decision Direct Institute), Travis Lybbert (Cornell University), Barbara Mack (Massachusetts Institute of Technology), Felipe Maintego (USAID), Michael Malinowski (Widener University School of Law), Diego

Malpede (Ministry of Foreign Affairs - Argentina), Jenny Mandell (Harvard College), Maximilian Martin (Kennedy School of Government, Harvard University), Hugo Martinez (Kennedy School of Government, Harvard University), Janet Maughan (Rockefeller Foundation), Robert Maybury (International Organization for Chemical Sciences in Development (IOCD)), John McCracken (Harvard School of Public Health), Parker Mitchell (Engineers Without Borders), Brian Martin Murphy (Niagara University), Sainath Nagarajan (Carnegie Mellon University), Yen Thi Nguyen (Brown University), William Nickerson (Massachusetts Institute of Technology), Vicki Norberg-Bohm (Belfer Center for Science and Intl. Affairs, Harvard University), Dieudonne Nusibono (Brown University and the University of Kinshasa), Robert Paarlberg (Weatherhead Center for International Affairs, Harvard University), Elena Patino (Kennedy School of Government, Harvard University), Carl Pray (Department of Agricultural, Food, and Resource Economics, Rutgers University), Fernando Quezada (Biotechnology Center of Excellence Corporation), Kelly Quinn (Winrock International), Patricia Ramirez Romero (Universidad Autonoma Metropolitana, Depto. de Hidrobiologia), Kate Raworth (United Nations Development Programme), John Reppert (Belfer Center for Science and International Affairs, Kennedy School of Government, Harvard University), David Rice (Kennedy School of Government, Harvard University), Mikael Román (Center for International Studies, Massachusetts Institute of Technology), Ian Roustan-Espinosa (New England Biolabs, Inc.), Mary Rundle (Kennedy School of Government, Harvard University), Ambuj Sagar (Belfer Center for Science & Intl. Affairs, Harvard University), Tiago Santos Pereira (Belfer Center for Science and Intl. Affairs, Harvard University), James Seward (Kennedy School of Government, Harvard University), Kate Showers (Boston University), Sara Sievers (Center for International Development, Harvard University), Candice Stevens (Directorate for Science and Technology, OECD), Nicole Szuminski (Harvard School of Public Health, Environmental Health Dept.), Akiko Takano (The Gene Media Forum), Mariachiara Tallachini (Belfer Center for Science and Intl. Affairs, Harvard University), Halla Thorsteinsdottir (Joint Centre for Bioethics, Univeristy of Toronto), Brian Torpy (Belfer Center for Science and Intl. Affairs, Harvard University), Emy Tseng (Massachusetts Institute of Technology), Jonhatan Vestrud (Kennedy School of Government, Harvard University), Victor Vinas-Nicolas (Universidad Nacional Pedro Henriquez Urena), Eduardo Viotti (New School University), Caroline Wagner (Science & Technology Policy Institute, RAND), Judi Wakhungu (Science, Technology, and Society Program and the Women in Science and Engineering Institute, Penn State), Richard Wetzler (Watson Institute for International Studies, Brown University), Shernan Wissinger (), Kifle Woldesilassie (Brown University, Watson Institute of International Studies), Deok Yim (Science and Technology Policy Institute, Seoul, Korea), Jimin Zhao (Belfer Center for Science and Intl. Affairs, Harvard University).

In addition, we would like to thank those who have participated as speakers at our various events and generously contributed their thoughts and ideas. These include Klaus Amman (University of Bern, Switzerland), Andrew Appel (AgBiotech), Alberto Araoz (University of Massachusetts at Boston), Amir Attaran (Center for International Development, Harvard University), John Barton (Stanford School of Law), Richard Bax (Biosyn, Inc.), David Bell (Center for Disease Control and Prevention), Philip Bereano (Department of Technical Communication, University of Washington, Seattle), Carl Bergstrom (Emory University), Gardner Brown (University of Washington), Victor

Buxton (Environment Canada, Ottawa), Luiz Antonio Barreto de Castro (The Brazilian Enterprise of Agriculture Research, Brazil), Cesar Caviedes (Department of Geography, University of Florida), Michelle Chauvet (Universidad Autonoma Metropolitana), William Clark (Belfer Center for Science and Intl. Affairs, Harvard University), Gary Comstock (Iowa State University), Ralph Cordell (Center for Disease Control and Prevention), Michael Crow (School of International and Public Affairs, Columbia University), Lola Dare (University of Ibadan), Joseph DiMasi (Sackler School at Tufts University), Jim Dratwa (Fonds National de la Recherche Scientifique Bruxelles, Belgium), Johnson Ekpere (Scientific, Technical and Research Commission, Organization of African Unity), Juan Enriquez (David Rockefeller Center for Latin American Studies, Harvard University), Elliot Entis (A/F Protein, Inc.), Thomas Epprecht (Swiss Reinsurance Company, Zurich, Switzerland), Janine Ferretti (North American Commission for Environmental Cooperation), David Fidler (Indiana University), Michael Fischer (Program in Science, Technology and Society, MIT), Terry Fisher (Harvard Law School), Susanne Freidberg (Radcliffe Institute for Advanced Study), John Gallop (Center for International Development, Harvard University), Amanda Galvez (Universidad Nacional Autonoma de Mexico), Terry Gips (Sustainability Associates), Timo Goeschl (Cambridge University), Rebecca Goldburg (Environmental Defense), Alexander Golikov (Inter-Agency Commission on Genetic Engineering Activity, Russian Academy of Sciences, Moscow), Aarti Gupta (Belfer Center for Science and Intl. Affairs, Harvard University), Anil Gupta (Indian Institute of Management, Ahmedabad, India), Edward Hammond (Genetic Resources), Mohamed Hassan (Third World Academy of Sciences, Trieste, Italy), Richard Hayes (Exploratory Initiative on the New Human Genetic Technologies), Rebecca Henderson (MIT Sloan School), Robert Herdt (Rockefeller Foundation, New York), Robert Herdt (Rockefeller Foundation, New York), Hans Herren (International Center of Insect Physiology and Ecology, Nairobi), John Holdren (Belfer Center for Science and Intl. Affairs, Harvard University), Thomas Hooton (Harborview Medical Center and the University of Washington), Deborah Hurley (Harvard University), Sheila Jasanoff (Belfer Center for Science and Intl. Affairs, Harvard University), Daniel Jernigan (Center for Disease Control and Prevention), Daniel Johnson (Wellesley College), Jaakko Kangasniemi (World Bank), Manfred Kern (AgrEvo GmbH, Frankfurt, Germany), Julian Kinderlerer (Department of Molecular Biology and Biotechnology, Sheffield University, UK), Michael Kremer (Center for International Development, Harvard University), Sheldon Krimsky (Department of Urban and Environmental Policy, Tufts University, Medford, USA), Tony La Vina (World Resources Institute, Washington, DC), Patrice Laget (Delegation of European Communities, Washington, DC), Richard Laing (Boston University School of Public Health), Ramanan Laxminarayan (Resources for the Future), Klaus M. Leisinger (Novartis Foundation for Sustainable Development, Basel, Switzerland), William Leiss (Royal Society, Canada), Les Levidow (Center for Technology Strategy, Open University, Milton Keynes, UK), Richard Lewontin (Museum of Comparative Zoology, Harvard University), Marc Lipsitch (Harvard School of Public Health), Ragnar Lofstedt (Harvard School of Public Health), Richard Manning (), Gary Marchant (College of Law, Arizona State University), Will Masters (Center for International Development, Harvard University), Alan McHughen (University of Saskachewan, Canada), Katy Moran (The Healing Forest Conservancy, Washington, DC), Stefan Moravek (United Nations Commission on Science and Technology for Development, Geneva), Julian Morris (Institute of Economic Affairs), John Mugabe (African Centre for Technology Studies, Nairobi, Kenya), Lynn Mytelka (United Nations Conference on Trade and Development, Geneva), Sudha Nair (M.S. Swaminathan Research Foundation, Chunnai, India), Horacio Navarrete (Monsanto Corporation), Michael Oborne (OECD), Thomas O'Brien (Brigham and Women's Hospital, Boston), Theodore Panayaotou (Center for International Development, Harvard University), Peter Pauker (Department of Foreign Affairs and International Trade, Ottawa), Tomas Philipson (University of Chicago), Per Pinstrup-Andersen (International Food Policy Research Institute, Washington, DC), Fernando Quezada (Biotechnology Center of Excellence Corporation, Boston), Carolyn Raffensperger (Science and Environmental Health Network, Windsor, North Dakota), Alex Rakowsky (Food and Drug Administration), Peter Raven (Missouri Botanical Garden, St. Louis), Ortwin Renn (Center of Technology Assessment, Baden-Württemberg, Germany), Frank Rijsberman (International Water Management Institute, Colombo, Sri Lanka), Mario Rodriguez (Agrobio Mexico), Elettra Ronchi (OECD), Bob Rowthorn (University of Cambridge), Vernon W. Ruttan (University of Minnesota), Jeffrey Sachs (Center for International Development, Harvard University), Cristian Samper (The Humboldt Institute, Bogota, Colombia), David Sandalow (White House Council on Environmental Quality/National Security Council, Washington, DC), Marc Saner (Ethics and Policy Issues Centre, Carleton University, Canada), F.M. Scherer (Center for Business and Government, Kennedy School of Government, Harvard University), David Simpson (Resources for the Future), Ed Soule (McDonough School of Business, Georgetown University), Andrew Spiegelman (Harvard School of Public Health), Scott Stern (Sloan School of Management, Massachusetts Institute of Technology), Harriet Strimpel (Bromberg and Sunstein, Attorneys at Law, Boston), Timothy Swanson (University of Chicago), Wallace Tyner (Purdue University), Luther Val Giddings (Biotechnology Industry Organization, Washington, DC), Piet Van der Meer (Netherlands Ministry of Environment, The Hague, The Netherlands), Konrad Von Moltke (International Institute for Sustainable Development, Winnipeg, Manitoba, Canada), Rene von Schomberg (European Commission, Brussels), Kim Waddell (National Research Council), Jayashree Watal (Institute for International Economics, Washington, D.C.), Timothy Weiskel (Environmental Ethics and Public Policy Program, Harvard Divinity School), David Wheat (The Bowditch Group), Jim Wilen (University of California, Davis), Rosamund Williams (World Health Organization), and Peter Young (AlphaVax, USA).

References and Notes

1 This paper is a synthesis of a series of seminars, workshops and conferences organized by the Belfer Center for Science and International Affairs at Harvard University and the Center for International Development at Harvard University over the last two years. The events outlined the key research and policy aspects of the role of science and technology in economic growth in developing countries. The activities were funded by the Rockefeller Foundation, the Belfer Center for Science and International Affairs, the Center for International Development at Harvard University and the Kennedy School of Government, Harvard University. The last event in this series was the workshop on 'Global Governance of Technology: Meeting the Needs of Developing Countries' held at Harvard University, 20-21 April 2001. It is a contribution to the ongoing international search for solutions to persistent economic development challenges in developing nations.

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