MillenniumProject

Commissioned by the UN Secretary General and supported by the UN Development Group

Interim Report of Task Force 10 on Science, Technology and Innovation

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Note to the reader
This Interim Report is a preliminary output of the Millennium Project Task Force on Science, Technology and Innovation. The recommendations presented herein are preliminary and circulated for public discussion. Comments are welcome and should be sent to the e-mail address indicated above. The Task Force will be revising the contents of this document in preparation of its Final Task Force report, due December 2004. The Final Task Force report will feed into the Millennium Project's Final Synthesis Report, due to the Secretary-General by June 30, 2005

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The Millennium Project is the independent advisory body to United Nations Secretary-General Kofi Annan that is commissioned with recommending, by June 2005, operational strategies for meeting the Millennium Development Goals (MDGs). This includes reviewing current innovative practices, prioritizing policy reforms, identifying frameworks for policy implementation, and evaluating financing options. The Project's ultimate objective is to help ensure that all developing countries meet the MDGs.

As a United Nations-sponsored initiative, the Millennium Project proceeds under the overall guidance of the Secretary-General and United Nations Development Programme (UNDP) Administrator Mark Malloch Brown in his capacity as chair of the United Nations Development Group (UNDG). Professor Jeffrey Sachs directs the Project, which brings together the expertise of world-class scholars in both developed and developing countries, United Nations agencies, and public, non-governmental, and private-sector institutions. Ten Task Forces carry out the bulk of the Millennium Project's analytical work with support from a small secretariat based at UNDP headquarters in New York. The Task Forces and their Coordinators are listed below.

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2 - Hunger	• Pedro Sanchez • M.S. Swaminathan
3 - Education and Gender Equality	• Nancy Birdsall • Amina Ibrahim • Geeta Rao Gupta
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5 - HIV/AIDS, Malaria, TB, Other Major Diseases and Access to Essential Medicines	• Agnes Binagwaho • Jaap Broekmans • Paula Munderi • Josh Ruxin • Burton Singer
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9 - Open, Rule-Based Trading Systems	• Patrick Messerlin • Ernesto Zedillo
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TASK FORCE ON SCIENCE, TECHNOLOGY AND INNOVATION
Millennium Project commissioned by the United Nations Secretary-General and Supported by the United Nations Development Group

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CONTENTS

BOXES

EXECUTIVE SUMMARY

INTRODUCTION

The aim of this Report of the Millennium Project Task Force on Science, Technology and Innovation is to outline approaches for the effective application of science, technology and innovation (STI) to achieving the Millennium Development Goals (MDGs) adopted by the 2000 United Nations Millennium Summit. The MDGs have become the international standard of reference for measuring and tracking improvements in the human condition in developing countries. The welfare of these countries is also intricately intertwined with the security of the industrialized countries, making development a truly global venture.

Indeed, countries such as the United States have started to classify human development challenges that are prevalent in developing countries, such as HIV/AIDS, as national security issues. This step is the beginning of a process that recognizes the emergence of a globalized world that requires collective action to deal with issues that would otherwise be considered as strictly national. The MDGs have the advantage of (1) a political mandate agreed by the leaders of all United Nations member states, (2) offering a comprehensive and multidimensional development framework, and (3) setting clear quantifiable targets to be achieved in all countries by 2015.

This report builds on the view that meeting the MDGs will require a substantial reorientation of development policies to focus on key sources of economic growth, especially those associated with the use of new scientific and technological knowledge, and related institutional adjustments. The MDGs cover almost every field of human endeavor and include targets on issues such as poverty, hunger, primary education, gender equality, child and maternal mortality, HIV/AIDS, malaria, tuberculosis (TB), and other major diseases, as well as access to essential medicines. In addition, the goals stress sustainable development, safe water, upgrading slums, open rule-based trading systems, and global partnerships (including technology transfers).

The Task Force has identified a number of options for action, suggesting ways in which science, technology and innovation could contribute to the implementation of the MDGs. The following sections outline a summary of these options.

1. SCIENCE, TECHNOLOGY AND INNOVATION

Economic systems evolve over time through changes in knowledge and institutions. Economic transformation is a learning process that involves the use of new knowledge in productive activities and the complementary adjustment of social institutions. In this learning process, governments play important roles as facilitators of the generation, use, and diffusion of knowledge in the economic system. In conjunction with other sectors of society, governments also play a key role in building up the requisite scientific and technical skills in the population. Enterprises (private or public), however, are the mechanisms through which scientific and technological knowledge is transformed into goods and services, leading to economic transformation.

There are three sources of accelerated technological innovation:

Governments can play an important role as facilitators of technological learning. However, most governments do so in an implicit way. Promoting technological change will require governments to serve as active promoters of technological learning. This can be done through the creation of science and technology advice institutions that support decision-making in executive and other branches of government.

Science, technology, and engineering education institutions should create indigenous capacity by training scientists, technologists, and engineers in relevant fields. Such a strategy will help address local concerns (such as health, food security, infrastructure, and manufacturing). In today's world, scientific and technological advances drive economic progress. In promoting S&T education in developing countries, therefore, universities can play a vital role in development, by both developing the country's national innovation and its human resources.

It is therefore imperative for universities in developing countries to focus on the engineering sciences and other advanced technological fields. While not all countries need to become adept in all S&T areas, it is necessary to identify and focus on certain key national priority areas and design an action plan accordingly.

Business enterprises are the most important engines of economic change. While learning occurs in a variety of institutions, enterprises are the most critical locus at which learning of economic significance takes place. In other words, technological capabilities of economic importance accumulate at the enterprise level.

2. KNOWLEDGE IN A GLOBALIZING WORLD

The process of technological innovation has become intricately linked to the globalization of the world economic system. The shift from largely domestic activities to more complex international relationships demands a fresh look at policies that seek to integrate science and technology into economic strategies. Despite the increasing globalization of technology, the involvement of developing countries in the production of new technologies and innovations is almost negligible. Globalization of technology can be classified into three categories, according to the ways in which technological knowledge is produced, exploited, and diffused internationally: (1) the international exploitation of nationally-produced technology, (2) the global generation of innovation, and (3) the global technological collaborations.

There are several strategies that developing countries can adopt to promote technological innovation and economic development.

UTILIZE EXISTING TECHNOLOGIES

Use existing technologies to create new business opportunities. Developing countries should focus their policy attention on using technologies that already exist to create new business opportunities. They should implement "fast follower innovation strategies" aimed at making full use of existing technologies. The area of information and communications technologies (ICTs), for example, represents a unique opportunity for building the capacity to utilize available development. A large part of the developing world has been unable to make effective use of the large body of scientific and technological knowledge available, some of which is embodied in ICTs. Also related to this strategy is the availability of large quantities of spatial information that can be deployed for development purposes.

Attract foreign direct investment. Creating incentives and promoting an enabling environment for foreign direct investment (FDI) is one of the most important mechanisms for building domestic technological capacity. The global rules for FDI have changed, as have the modes in which this investment is most useful. Global production systems have changed the ways in which funds flow and how they can be made available in certain parts of the world for long-term growth instead of rapid flight to new, cheaper locales. FDI needs be used as a vehicle for carrying tacit knowledge as well as assisting enterprises in learning where the world technological frontiers are.

Upgrade technological capabilities and systems. Developing countries should formulate strategies that allow firms and research institutions to upgrade their technological capabilities. To move from the position of being fast followers to technological leaders, some East Asian developing countries have pursued a "technological diversification" strategy by building on the existing strength of their process and prototype development capabilities, adaptive engineering, and detailed design. Through technological diversification, late developing firms recombine (mostly known) technologies to create new products or services and expand the company technology base into a broader range of technology areas. This is an attempt to reap technology-related economies of scope.

Join global value chains. Joining global value chains by identifying market opportunities and niches gives firms (in developing countries) a chance to climb up the technological development ladder. The global economy can now be seen as consisting of many product value chains that encompass a full range of activities—including R&D, design, production, logistics, marketing, distribution, and support services—which bring a product from its conception to its end use and beyond. Firms in developing countries need to find a place in the global value chains and gradually move up these chains to engage in the higher value-added activities that contribute to product development and creation of services.

SUPPORT UNDER-FUNDED RESEARCH

Channel resources towards pressing development problems that are currently under-funded. Investment in under-funded research of relevance to developing countries is particularly important in fields such as public health, agricultural production, and environmental management. There are a variety of ways to channel resources towards pressing development problems that are currently under-funded. Bilateral donors could increase their official development assistance to fund research that meets local needs and passes scrutiny under peer review or other professional assessment. Donor support for research could also be funded through an international cooperative project where funds are provided to teams proposing to conduct world-class research that focuses on local or under-represented research activities.

FORGE INTERNATIONAL TECHNOLOGY ALLIANCES

Promote research and development through international technology alliances that take advantage of the growing globalization of research. One of the newly emerging fields where science and technology could contribute to the implementation of the MDGs is the field of genomics—the new wave of health related life sciences energized by the human genome project and the knowledge and tools derived from it. It is primarily concerned with the generation, dissemination, and utilization of knowledge about the genetic attributes of organisms.

Genomics requires the collection and analysis of massive amounts of genetic information. It has only evolved in the last few decades, on the heels of the information technology revolution and technological advances in analytical tools. Automated DNA sequencing and genotyping have made it possible to rapidly characterize large numbers of genes, and genomic knowledge can be creatively used in the development of new diagnostic technologies, treatments, and preventive programs.

LOOK AHEAD AND PLAN FOR THE FUTURE

Use foresight or forecasting as a method for establishing priorities in science and technology funding and policy based on the analysis of current trends and expectations of future developments. This strategy is particularly important for emerging fields such as genomics, new materials and nanotechnology. Foresight studies and exercises have been conducted in many countries since the 1960s for a number of reasons (e.g., defense planning, prioritization, and subsidization). Originally seen as simply a means for identifying new technologies, foresight is now viewed as a tool to aid in understanding the full innovation system.

3. INFRASTRUCTURE AS A TECHNOLOGICAL FOUNDATION

One of the problems that hinder the alleviation of poverty, and indeed the achievement of other MDGs, is the absence of adequate infrastructure services—transportation, water, sanitation, energy, and telecommunications. Infrastructure is the shared basic physical facilities necessary for a community or society to function. The term infrastructure is broadly defined here as the facilities, structures, and associated equipment and services that facilitate the flow of goods and services between individuals, firms, and governments. Economic infrastructure includes: (1) public utilities, such as power, telecommunications, water supply, sanitation and sewerage, and waste disposal; (2) public works, such as irrigation systems, schools, housing, and hospitals; (3) transportation services, such as roads, railways, ports, waterways, and airports; and (4) shared information such as spatial. Adequate infrastructure is a necessary, if not sufficient, requirement for enhancing the creation and application of science and technology in development. Infrastructure services include the operation and maintenance of this infrastructure, and these services' provision should meet a society's needs in an appropriate environmental and economic manner.

Developing countries can adopt strategies to improve their infrastructure in such a way as to promote the technological development necessary for twenty-first century economic growth (or some such language). These include:

INFRASTRUCTURE SERVICES AND ECONOMIC DEVELOPMENT

Enhance the provision of infrastructure services. Infrastructure has an impact on economic development in various ways. It affects the production and consumption of firms and individuals, while generating substantial positive and negative externalities. Because infrastructure services are intermediate inputs into production, their costs have a direct effect on firms' profitability and competitiveness. Infrastructure services also affect the productivity of other production factors Electric power allows firms to shift from manual to electrical machinery. Extensive transportation networks reduce workers' commuting time. Telecommunications networks facilitate the flow of information. Infrastructure may also attract firms to certain locations, which can create agglomeration economies and reduce factor and transaction costs.

INFRASTRUCTURE AND TECHNOLOGICAL LEARNING

Define infrastructure as foundation for technological development. Infrastructure development provides a foundation for technological learning, because infrastructure essentially involves the use of a wide range of technologies and complex institutional arrangements. Governments traditionally view infrastructure projects from a static perspective. Although they recognize the fundamental importance of infrastructure, these governments seldom consider infrastructure projects as part of a technological learning process. They may want to recognize the dynamic role infrastructure development can play in economic growth and take the initiative in acquiring the technical knowledge that is available through foreign construction and engineering firms.

The construction of railways, airports, roads, and telecommunications networks in developing countries could be structured in such a way as to promote technological, organizational, and institutional learning. Before any construction begins, it is usually necessary for a series of in-country studies to be carried out so that the essential infrastructure services necessary to support the achievement of MDGs are identified. In addition, the option of providing infrastructure services through combinations of public and private enterprises should be analyzed.

Understand the role of infrastructure in the creation and diffusion of technology. Without adequate infrastructure, further applications of technology to development are not possible. For instance, electric power, transportation networks, and communications infrastructure are the underlying factors behind any efforts to improve basic science and technological capabilities in developing countries. The advancement of information technology and its rapid diffusion in recent years could not happen without basic telecommunications infrastructure, such as telephone, cable, and satellite networks. In addition, electronic information systems, which rely on telecommunications infrastructure, account for a substantial portion of production and distribution activities in secondary and tertiary sectors of the economy.

Use infrastructure projects to provide opportunities for technological learning. Because of the fundamental role of infrastructure in the economy, the learning process in infrastructure development is a crucial element of a country's overall technological learning process. Infrastructure's dynamic nature is often overlooked in the development and infrastructure literature. Every stage of an infrastructure project, from planning and designing through to construction and operation, involves the application of a wide range of technologies and the associated institutional and management arrangements. Because infrastructure facilities and services are complex physical, organizational, and institutional systems, they require deep understanding and adequate capabilities among the engineers, managers, government officials, and other people who are involved in them.

Promote standards and interoperability. In order for infrastructure to become more effective and extensible, developing countries should focus on the creation and enforcement of infrastructure standards. Beginning in the early design stages, efforts should be made to facilitate the coordination, skills development, and use of these standards to promote interoperability of infrastructure systems.

4. BUILDING HUMAN CAPABILITIES: THE ROLE OF SCIENCE EDUCATION

SCIENCE EDUCATION AND DEVELOPMENT

Investment in science education has been one of the most critical sources of economic transformation. Such investment should be part of a larger framework to build capacities in science and technology worldwide. The one common element to the East Asian success stories is the high level of commitment by the governments in these countries to education and national identity creating through integration. However, the growth of higher education needs to be accompanied by the growth of economic opportunities where graduates can apply their acquired capabilities.

The strategy for countries to achieve the first goal of building science and technology capabilities is rather straightforward: to devote resources or get complementary resources from international cooperation, to help more young people go into higher education, paying special attention to the barriers that appear at the level of secondary education. The second goal is to give incentives to private enterprises, particularly small and medium ones, to hire young university graduates, a strategy that helps to start a virtuous circle of technological upgrading. Although the education MDG is limited to achieving universal primary education, the importance of science education at primary, secondary, and tertiary levels of schooling in the creation of an innovative society cannot be overemphasized.

SCIENTISTS AND ENGINEERS IN THE GLOBAL ECONOMY

Give special policy attention to a country's scientific, technological, and engineering community. The scientific, technological, and engineering community of a country, and associated institutions such as universities, technical institutes, and professional associations, are among the most critical resources for economic transformation. There is a disturbing global trend where enrollment in engineering courses in universities and institutions of higher learning is declining. These courses have also persistently remained unattractive to women, who constitute nearly half of the world's population. This movement away from engineering has been particularly evident in developed countries where engineering departments in universities and institutions of higher learning have closed. With regard to enrollment, the situation in science courses is not any better.

Nevertheless, "brain drain" remains one of the most hotly debated international issues. The home country's loss of skills—and, thus, of educational investment—needs to be set against the experience that scientists and professionals gain while abroad, knowledge that may be available for use upon return. Temporary labor movements also present an advantage over permanent migration with respect to remittances. The traditional concept of "brain drain" is increasingly being challenged by societies that seek to benefit from the globalization of knowledge rather than rely on nationalistic strategies.

HIGHER EDUCATION AND DEVELOPMENT

Invest in higher education as a strategic input into the development process. Higher education is increasingly being recognized as a critical aspect of the development process, especially with the growing policy awareness of the role of science and technology can play in economic renewal. While primary and secondary education have been at the focus of donor-community attention for decades, higher education has only recently been viewed as essential to development. Factors in the contemporary developing world are making higher education more important than it has ever been. Some of these key factors include: an increased demand for higher education due to improved access to schooling; pressing local and national concerns that require advanced knowledge to address; and a global economy that favors participants with technological expertise.

In this respect, vocational institutes and polytechnics in developing countries are very important. Technologists, technicians, and craftsmen are the bedrock on which small and medium enterprises (SMEs)—especially in operations and maintenance—are founded. Many developing countries have made the mistake of turning out more university engineering graduates than technicians and technologists when the home demand for engineers is already being fulfilled.

ENTREPRENEURIAL UNIVERSITIES AND TECHNICAL INSTITUTES

Create entrepreneurial universities and technical institutes that focus on business incubation and community development. A new view that places universities at the center of the development process is starting to emerge. This concept is also being applied at other levels of learning, including colleges, research and technical institutes, and polytechnics. The age of entrepreneurial universities and research institutes (including polytechnics) that are integrated into the productive sector has arrived. Universities are starting to be viewed as a valuable resource for business; the "entrepreneurial university" undertakes entrepreneurial activities with the objective of improving regional or national economic performance, to its own and its faculty's advantage.

In facilitating the development of business firms, universities can contribute to economic revival and high-tech growth in their surrounding regions. There are many ways in which the university can be "entrepreneurial": it can conduct R&D for industry; it can create its own spin-off firms; it can be involved in capital formation projects such as science parks and business incubator facilities; or it can introduce entrepreneurial training into its curricula and encourage students to take research from the university to firms.

RESHAPING HIGHER EDUCATION

Reform systems of higher education to make them relevant to development challenges. Reshaping universities to perform development functions will include adjustments in curricula, changes in the schemes of service, modifications in pedagogy, shifting the location of universities, and creating a wider institutional ecology that includes other parts of the development process. In order to assist universities in adopting a key role in development, national development plans will need to incorporate new links between universities, industry, and government. This is likely to have an impact on the entire national innovation system—including on business firms, R&D institutes, and government organizations.

Developing countries will not be able to become major economic players unless they can catch up quickly in high technology fields. Thus, university S&T curricula are of great significance. Today, the S&T curricula in many developing-country universities are outdated or not cross-disciplinary. In certain departments, the research emphasis needs be slanted towards issues of local and national relevance.

5. GROWING CONCERNS:
SCIENCE, TECHNOLOGY, AND BUSINESS

Economic change is largely a process by which knowledge is transformed into goods and services. In this respect, creating links between knowledge generation and business development is the most important challenge facing developing countries. If developing countries are going to promote the development of local technology, they need to investigate the incentive structures currently in place. There are a range of structures that can be used as a means for creating and sustaining enterprises, from taxation regimes and market-based instruments to consumption policies and sources of change within the national system of innovation. Other policies related to government procurements can be used to promote technological innovation and generate markets for new products in areas such as environmental management. On the whole, the critical element is finding a diversity of measures that help in the creation and expansion of business activities.

UNLEASH INTELLECTUAL CAPITAL

Design policies and incentives that promote the use of intellectual capital in economic transformation. Governments need to promote measures that enable society to make effective use of available intellectual capital through entrepreneurial activities. There are several tools that governments can use to ease these barriers and obstacles to encourage entrepreneurship and new SME creation. Business and technology incubators are one of those tools and they can take many different forms with different sizes, mandates, sponsorships, goals, and services being offered to participating ventures.

The following section introduces the various types of incubators and their best practices for fostering general and long-term economic development through promoting new businesses.

Stimulate the creation and expansion of small- and medium-sized businesses. The small to medium-sized enterprises within a country should be encouraged to take a strong role in the development of new opportunities and use of technology. This may be promoted through the establishment of regional or national road shows, technology days, trade shows, advertising, workshops, and online discussions. There is a particular need to develop, apply, and emphasize the important role of engineering, technology, and small enterprise development in poverty reduction and sustainable social and economic development.

Promote the establishment of business and technology incubators. Business incubators play major roles in the creation and facilitation of small- and mid-sized business. Their roles range from providing affordable space to providing core business support functions, such as business development, financing, marketing, and legal services. In general, several factors that are considered important to determining business incubator success include: public policy to facilitate venture capital creation and provide business infrastructure; private sector partnerships for mentoring and marketing; community involvement; a knowledge base of university and research facilities; and professional networking. Technology incubators are a special type of business incubators that focus on new ventures with more advanced technologies. Although technology incubators share the general goals with business incubators, they focus more on technology commercialization and diffusion of technology by new firms, which are often impeded by the market and institutional failures and greater uncertainty associated with technology development.

Set up technology parks. Technology parks have been probably the most popular of the diverse institutional forms that technology incubators can take and have proliferated not only in developed countries but also more recently in countries in Southeast Asia and Latin America. The key feature is that they have strong R&D components in their organizational structure. From a structural point of view, technology parks need to be based on the possession of property and accommodate university and research facilities—which ensure access to research facilities, simplify technology transfer operations, and allow the incubation of spin-off enterprises that can be launched by the staffs of university and research facilities.

Build export processing zones. Export processing zones (EPZs) are an important mechanism for acquiring technology and diffusing it throughout the local economy. But achieving this goal requires that strategies to promote the establishment of such zones be designed with long-term technological development in mind. EPZs are the areas in developing countries that permit participating firms to acquire their imported inputs duty-free in exchange for an obligation to 100 percent export of their product. This scheme works when selling manufactured goods at world prices is profitable given the low wages of developing countries.

Forge production networks. Networking is a very important factor to create successful incubation activities, because it helps SMEs to access skills, highly educated labor, and pooled business services. While networking has always been an important component for any incubator, greater attention will be paid to groups of firms, teams, and inter-firm networks than individual firms in the rapidly changing technological and global environment, and this makes networking an even more important and critical tool in incubation activities.

UNLOCK FINANCIAL CAPITAL

Restructure banks and financial institutions to enable them to support technological developments. Banks and financial institutions can play an important role in fostering technological innovation. However, their record in this field in developing countries has been poor. There is a need to reform some of the banking and financial institutions in these countries so they can play a role in promoting technological innovation. Sustainable development investment is creating capital opportunities, with investment from superannuation and pension funds making up a large portion of the trillions of dollars that are currently invested internationally.

Promote the creation of venture capital firms. Promote the creation of venture capital and encourage the emergence of angel investors as sources of finance for technological innovation. SMEs have flourished in most developed nations because of the critical role that the capital markets (and especially venture capitalists) have played in creating these businesses. Venture capitalists (VC) do not just bring money to the table; they help groom these SME start-ups into multi-national institutions. Another advantage of bringing venture capital into developing nations may be to ensure the sustainability of the companies in which it is invested.

Encourage the emergence of angel investors and other private sources of capital. Individual or angel investors who supplement shortfalls in the funding for new technology ventures provide a large portion of funding for new technology ventures in industrialized countries. Their contributions, however, remain poorly documented. This is mainly because angel markets are associated with transactions in private equity securities that are subjected to the strict disclosure requirements similar to those in public equities. In addition, there is no institutional mechanism that supports this market, which is fragmented and highly localized.

Use government procurement to stimulate technological development while respecting international trading rules. Government technology procurement can be an important tool in low-income countries, characterized by weak productive sectors and a weak technological demand. While there is an ideological debate about the role of public support for procurement—and World Trade Organization (WTO) members have agreed to look into public procurement in the context of trade liberalization—the fact remains that a multitude of countries have created and nurtured entire new industries or lagging old ones on this basis. In so doing, there have been many examples of the gradual creation of technological capability and of firms becoming competitive globally over time. The critical issues are less whether and why public procurement is needed, but when it ceases and how it assists firms in competing on their own.

Identify opportunities to increase participation in international trade. International trade is one of the most important sources of the impetus for rapid technological innovation. Until recently, the trading system, dominated by the agenda of the WTO, has addressed development only in a piecemeal fashion. Debates on trade at the WTO have been conducted with little reference to a broader vision for how trade fits into development. Concern over the agreement on Trade-related Aspects of Intellectual Property Rights (TRIPS) has taken center stage. For instance, patent law changes have occupied much of the WTO's time and created inordinate pressure on developing countries to harmonize their systems with those of the advanced industrialized countries.

Manage intellectual property rights by balancing between the need to protect the rights of inventors and technological development in poor countries. Protecting intellectual property rights is a critical aspect of technological innovation. However, overly protective systems could have a negative impact on creativity. It is therefore important to design intellectual property protection systems that take into account the special needs of developing countries. Provisions in international intellectual property agreements that promote for technology cooperation with developing countries need to be identified and implemented without further delay.

ENERGIZE HUMAN CAPITAL

Spur technological entrepreneurship. It is important for a developing country to create an institutional environment that encourages entrepreneurship. The motivation and encouragement of graduate students to consider entrepreneurship as a valid means of livelihood through creation, extension, and innovation of new and existing technology is essential to this.

Provide industry extension services, especially in rural areas. Knowledge extension can be applied to help meet the MDGs using science, engineering, and technology in many ways. ICTs could be effectively applied to help in promoting knowledge extension. The person with the knowledge and the person with the problem could be effectively matched using ICTs, and they would not need to be co-located in time or place in order to discuss how to solve a specific problem.

Promote technological innovation as social learning. There are three important elements to institutionalizing technological learning in any economy: government, enterprise, and research-based academia. These elements are embedded in a wider social setting where civil society plays an important role in shaping the direction and pace of technological learning. While an enterprise acts as a locus of learning, the government acts to facilitate this process. Countries should work to create an institutional environment that rewards innovation and takes citizens from being simply traders to full-fledged entrepreneurs

Form international linkages. There needs to be a means of encouraging corporations in developed nations to partner and subcontract with similar companies in developing nations. These include the diffusion of hardware technologies from centers, such as Silicon Valley and Route 128, through diaspora channels to countries like Israel, India, and Ireland. In addition, the potential exists for the establishment of private-public partnerships to invest in new technologies. An often neglected but historically important evolution is the link established between open-source material (often declassified material, sometimes from the U.S. Defense Department) from public sector institutes in all these countries and the private sector.

6. IMPROVING THE POLICY ENVIRONMENT

Government policies play a critical role in creating a suitable environmental for the application of science and technology to development. More specifically, government policies towards science and technology have a critical role to play in economic transformation. One of the key areas requiring policy adjustment in most developing countries is the way governments receive advice on issues related to the role of science and technology in development. There is a need for STI advice to reach policymakers. The first necessary step is to provide the institutional framework in developing countries and commit to support such a framework. Amongst the most successful institutions are the Office of Science Advisor to top political leaders at the presidential or prime ministerial level and national scientific and engineering academies.

STRUCTURE AND PRINCIPLES OF SCIENCE AND TECHNOLOGY ADVICE

Acknowledge diversity in advisory structures among countries. Advising structures differ among countries depending on their governance structures. For example, in Japan the advising structure is a standing committee that serves the prime minister. In Malaysia, the structure includes a publicly chartered corporation within the Science Advisor's Office that serves the prime minister. In the United States, the office has statutory position within the Executive Office of the President. In many cases, academies also provide advice to policymakers.

Identify key features of advisory structures and adapt them to local conditions. Despite the diversity in advisory structures, all of them involve several key features. First, the advising function should have some statutory, legislative, or jurisdictional mandate to provide advising to the highest levels of government. Second, the structure should have its own operating budget and a budget to fund policy research. Third, the advisor should have access to good and credible scientific or technical information, either from within its own government, from the STI community through national academies, or through international networks. Finally, the advisory processes should have some accountability to the public and some method of gauging public opinion. This may involve some outreach through tools such as foresight exercises or regular interaction with legislative bodies.

Support other branches and sectors of government while focusing on advisory services to executive offices.. Advising takes place at all government levels, and advice can be sought in a variety of ways. It differs in: (1) the level at which scientific input is received; (2) how formal or flexible the advisory process is; (3) the relative use of science advice in different (executive or legislative) branches of central and local government; and (4) the degree of decision-making involvement of advisors.

FUNCTIONS OF SCIENCE AND TECHNOLOGY ADVICE

The functions of advising on science and technology follow the same basic principles of trust, credibility, and accountability that appear in the discussion above, but the functions listed below are ones that are common to most science advising activities:

- Advising should seek to create a ***coordination*** function across government—one that takes the different needs and missions of various agencies into account.

- Efforts should be made to seek a ***consensus*** or a process of ***deliberation*** of views about investments and applications of science and technology. This can involve representatives from government, business, and the public.

- ***Adjudication mechanisms*** should be explored to see how to discuss and make decisions on highly contentious issues. The process should be as transparent as possible.

- Advisors should work with experts to determine how to ***assess the effectiveness*** of science and technology investments within government.

- Advisors should work towards collecting internationally recognized ***indicators*** of science and technology operations.

- ***Policy research*** should be nurtured, and best practices from other countries should be imported.

- A process of identifying ***emerging issues*** should be put in place, so that contentious issues can be anticipated and possibly mitigated by open discussion and research.

- A process of ***prospecting*** for best practices and good technologies should be undertaken.

PRINCIPLES OF SCIENCE AND TECHNOLOGY ADVICE

Ensure quality in the provision of advice. Maintaining the quality of expert advice depends on a variety of conditions, including: early and appropriate identification of issues; recognition and appropriate treatment of scientific uncertainty and risk; and diversity of opinion and cross-disciplinary approaches. In this respect, academies of developed countries generally strive for independence and disinterestedness in the outcomes of academy analysis. Academies of developing countries, on the other hand, increasingly work towards improving engagement with government. In general, they all aim towards a broader, overarching accountability to the public.

Promote inclusiveness and openness. Increasing the inclusiveness and openness of STI advice processes can strengthen public trust, while also improving the robustness of the final advice and product. Gathering a diversity of STI perspectives from across disciplines, sectors, institutional boundaries, and stakeholder interests has been said not only to spark public dialogue and accountability, but also to check the accuracy of facts and opinions. Such proactive work in the early stages of providing science advice can help to avert (or at least minimize) controversy in the long term.

Develop review and feedback mechanisms. Governments use a range of different methods to review S&T decisions and obtain feedback from within the system in order to ensure that S&T advice is serving the interests of government and the public good. Three models derived from an analysis of existing review and feedback systems help to illustrate how such review and feedback can work: agency outreach; independent advice; and convened advice. The trade-offs of each model differ according to the circumstances of each country.

Involve the wider society. Science and technology is applied to innovation within a social and economic context. STI has no intrinsic moral or ethical value—ethics emerges as knowledge and its application merges with culture. There may be cases where a local culture understands, but simply decides not to adopt a technology. In other cases, local knowledge can greatly enhance the effective application of knowledge. This process works best when stakeholders (citizens, knowledge workers, politicians) take part in the decision-making process.

BUILD SCIENCE AND TECHNOLOGY ADVISORY INSTITUTIONS

Establish and maintain advisory institutions as an essential component of development planning. These activities are often considered expensive and so their cost-effectiveness is often discussed. But a number of countries have devised methods that not only increase the effectiveness of these activities, but also reduced their costs relative to their strategic importance.

ENHANCE SCIENCE AND TECHNOLOGY ADVISORY CAPACITY

Train decision-makers in science and technology advice. The successful implementation of STI policy requires civil servants that have the capacity for policy analysis, which in turn presupposes the existence of training facilities for policy analysis in local universities and research institutions. In many countries, however, a large number of civil servants are not technically trained. Accordingly, it can aid the process of integrating STI advice into decision-making considerably if these civil servants receive training in technology management, science policy, and foresight techniques.

Establish programs that allow researchers to serve as policy fellows in various branches of government. Professors on sabbatical could be prime candidates for such policy fellowships. Science and technology policy fellows attached to various branches of government can help to improve the quality of decision-making by providing decision-makers with the best available information on trends in science and technology. In addition to formal science and technology training, developing countries could develop a system of science and technology fellows that could be attached to the various branches of government.

Train diplomats in science and technology issues of relevance to international relations. Strengthening negotiators' capacity to handle technological issues is an essential aspect of improving international relations.

Strengthen the capacity of scientific and technical academies to participate in advisory activities. This process may entail reforms to create the necessary linkages between a country's academies and government. Scientific and technical academies of all types (including science, technology, engineering, medicine, and agriculture) can play an important role in providing advice to government. They need to be strengthened or reformed in order to play this function. And where they do not exist, efforts should be made to promote their creation. Scientific and technical academies will need to cooperate with other institutions—especially judicial academies—whose activities influence scientific and technological development.

7. GLOBAL TECHNOLOGY GOVERNANCE

International organizations can play a critical role in promoting the application of science and technology to the implementation of the MDGs. These organizations—especially United Nations organs and allied intergovernmental bodies—have extensive influence on the development agenda through their normative and operational activities. Efforts to bring these organizations in line with the requirements of the MDGs will demand that they focus their attention on their functions and competencies, and not on their jurisdictional mandates.

NORMATIVE ACTIVITIES

Integrate science and technology advice into the guidance and advocacy the United Nations provides on development issues. The five-year review of the implementation of the Millennium Development Goals to be held in 2005 should be used to generate fresh guidance and advocacy that is based on a deeper understanding of the role of technological innovation in economic growth. Policy guidance and advocacy are the central functions of many international organizations. The guidance and advocacy are either provided through universal bodies such as the UN General Assembly or the decisions of the conferences of parties to the various international agreements. The Millennium Declaration is an example of a guidance and advocacy statement. The effectiveness of the declaration will depend largely on the extent to which its elements are translated into the governmental and non-governmental programs. The relevance that governments place on technology for development can be discerned from such guidance and advocacy documents.

Strengthen the United Nations' capacity to use scientific and technical advice its operations. The United Nations should strengthen its capacity to advise nations on the linkages between technological innovation and development. This will entail building competence in science and technology advice in the executive offices of United Nations. The United Nations, especially those organs that address international peace and security issues (such as the Office of the Secretary General and the Security Council), will increasingly address technological issues associated with development. It is therefore imperative that they equip themselves with the capacity to address technological issues. The United Nations Secretary General, for example, could provide leadership in this area by doing more to incorporate science and technology advice into policy formation and encouraging other United Nations agencies to do the same.

Examine the impact of rule-making and standards-setting organizations on developing countries' capacity to use technology as a tool for development. International rule-making and standards-setting institutions such as the World Trade Organization (WTO), the International Organization for Standardization (ISO), and the Bretton Woods institutions set a wide range of rules that affect the capacity of developing countries to build domestic scientific and technological capabilities. Much of the debate on international rules and standards has revolved around issues such as intellectual property rights. Indeed, it is generally assumed that the TRIPS agreement is the most important international treaty affecting technological innovation in developing countries. This view is a misrepresentation. There is a need to review other rule-making and standard-setting activities to determine the extent to which they can be adjusted to suit the interests of developing countries.

OPERATIONAL ACTIVITIES

Enhance the capacity of multilateral and bilateral institutions to bring technology to the core of their activities. Multilateral financial institutions led by the World Bank and the regional development banks should play a leading role in promoting technological innovation in developing countries. Similarly, bilateral aid agencies should place science and technology at the core of their development assistance programs. This process will involve creating and strengthening institutions within multilateral and bilateral agencies that can provide science and technology advice. Multilateral financial institutions are already involved in extensive lending and operational activities that significantly influence technological innovation in developing countries and can play two important roles involving leadership as well as funding. The first task is particularly important because the World Bank has only had modest activities in promoting technological innovation in development. The first step would be for the World Bank to integrate technological considerations more fully into their operations.

Increase UN efforts in strengthening the technological capacity of developing countries. United Nations agencies have a wide range of activities related to research and development. These activities are modest in scope. The strength of the United Nations in this field, however, lies in its advocacy for research in areas of relevance to development. In addition, the United Nations could also contribute to capacity building in developing countries in the engineering sciences and technical education. The UN could create an inter-agency consortium (in partnership with universities, private sector companies, and professional associations) in order to strengthen engineering and technical institutions in developing countries.

Build and expand the open access regime for scientific publishing and technology development. The United Nations has been at the forefront of championing the need to allow open access to information and technology. It can definitely play a critical role in promoting this idea, especially in the field of scientific and technical journals. The Internet has made it possible to share scientific and medical knowledge more widely than ever before. Despite the potential for cost-effective and virtually instantaneous dissemination of new research, however, widespread access to scientific and medical literature still needs to be promoted.

8. FORGING AHEAD

Many of the options for action in this report are already part of the development strategies of most countries. They may, however, not have been formulated with the sense of urgency and priority that has informed this report. Indeed, most of these options will be implemented over the long run or are contingent on complementary adjustments in other countries, regions, or the international economic system. There are, however, a few strategic measures that need to be taken at the national and international levels in the short run. These measures include options related to creation and improvement of science and technology advisory institutions at the national and international levels. Of particular importance in this process are multilateral and bilateral institutions, as well as various organs of the United Nations.

In addition to these measures, developing countries should initiate reviews of their educational systems to examine the degree to which they address the challenges of development. More specifically, the review process should focus on the role of higher education in development and the place accorded to training in science, technology, and engineering within countries' higher education curricula. Finally, developing countries should review and strengthen national programs designed to promote business development. These measures can be achieved in the next five years and will pave the way for the more systematic implementation of additional measures aimed at achieving the MDGs in particular and sustainable development in general.

INTRODUCTION

This paper outlines elements of a global action program to apply science, technology, and innovation in order to meet the Millennium Development Goals (MDGs) adopted in the year 2000 by the United Nations Millennium Summit. In this report, the phrase "science, technology and innovation (STI)" is used interchangeably with the phrases "science," "technology," "science and technology," and "science, engineering, and technology." It is intended to refer to the application of all types of scientific and technological innovations, as well as associated institutional adjustments, to the advancement of the implementation of the MDGs. STI will thus be used to include all forms of useful knowledge derived from diverse branches of learning and practice ranging from basic scientific research to engineering to traditional knowledge.

This report focuses on how a diversity of sources can be brought together—especially through institutional organizations—to solve practical problems associated with the MDGs. In the context of STI, we operate under the assumption that "science" includes both the basic and applied sciences, "technology" is the further application of this science (including engineering and other fields such as medicine), and "innovation" includes all of the processes taking this technology to market (including business processes). In essence, STI means the generation, use, and diffusion of all forms of useful science and technological knowledge as well as the evolution of associated institutional arrangements (Nelson 1994).

The MDGs include: halving extreme poverty and hunger, achieving universal primary education and gender equity, reducing under-five mortality and maternal mortality by two-thirds and three-quarters respectively, reversing the spread of HIV/AIDS, halving the proportion of people without access to safe drinking water, and ensuring environmental sustainability. They also include the goal of developing a global partnership for development, with targets for aid, trade, and debt relief. As a strategic vision, the idea is to see achieving the MDGs as steps towards longer-term targets for developing global learning mechanisms, which facilitate the building of internal capacity in developing countries such that the institutions for learning can act as an engine for sustainable growth in these countries over the long run.

The Millennium Project Task Forces are structured accordingly around issues such as poverty, hunger, primary education, gender equality, child and maternal mortality, HIV/AIDS, malaria, TB, and other major diseases, as well as access to essential medicines. In addition, MDGs stress sustainable development, safe water, upgrading slums, open rule-based trading systems, and global partnerships for development that include technology transfer.

However, science, technology and innovation underpin every one of these goals. It is impossible to think of making gains in health and environmental concerns without a focused STI policy, and it is equally true that a well-articulated and focused STI policy can make huge gains in education, gender equality (often having to do with education and health care itself), or living conditions. Much of the improvement in human welfare over the last century can be accounted for technological innovation in the fields of public health, nutrition, and agriculture. These improvements have taken the form of reduction in mortality rates and improved life expectancy, for example. Similarly, improvements in areas such as environmental management will also increasingly rely on the generation and application of new knowledge. In essence, implementing the MDGs will require the application of new knowledge and associated institutional adjustments.

Furthermore, there cannot be a viable science and technology policy if it is not underpinned by well-designed measures for addressing issues such as learning, technology, technology diffusion and transfer, research and development (R&D), and technology commercialization. This is particularly true in areas that have an impact on education, health, or environmental issues—such as agricultural and medical biotechnologies, pharmaceuticals, computer networks, and telecommunication systems. These technologies can also have a strong influence on water and energy usage in developing countries. Envisioning the fulfillment of the MDGs requires focusing on the creation of policies and institutions that facilitate the cumulative application of STI to each of the Millennium Development Goals (often expressed in the form of building scientific and technological capabilities).[1] It is this process of *technological learning* or *technological competence building* that forms the basis of the work of the Task Force on Science, Technology and Innovation.

This report is divided into three parts: assessing the situation; working the system; and governing the future. Part I provides a status review of development trends and the associated challenges. It also outlines the relevance of technological change to the implementation of the MDGs.

Part II offers a conceptual framework under which economic change is viewed as a learning process by which knowledge is transformed into goods and services through systemic interactions among various parts of the economy. Under this framework, emphasis is placed on the role of government can play as a facilitator of technological learning, and on enterprises as the focus point at which such learning occurs and where technological capability accumulates. The report therefore highlights interactions between government, industry, and knowledge-generating institutions as a central feature of economic change. Additionally, this part of the report also stresses the linkages between development and national security. It notes that there can be no durable national security without corresponding improvements in living conditions among the poor in developing developed countries. Part II outlines priority areas that require immediate policy focus. These include managing technological innovation in a rapidly globalizing world; redefining infrastructure development as a foundation for technological innovation; building human capabilities with specific emphasis on the scientific, technological, and engineering sciences through institutions of higher learning; and enhancing entrepreneurship though the creation and expansion of businesses (covering issues such as the effective use of intellectual, human, financial, and social capital).

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[1]. For such capabilities to generate the necessary economic dynamism, they require certain complementary inputs, including organizational flexibility, finance, quality of human resources, support services, and information management and coordination competence.

Part III deals specifically with the policy innovations needed to bring science and technology to the core of development efforts. Emphasis is placed on strengthening the role science and technology advice can play at the national level and realigning the activities of international institutions to reflect the technological imperatives of the MDGs. This realignment of the goals of existing development agencies will not only deploy available resources to meeting the MDGs, but such a process will also help in identifying gaps in the available resources. These efforts need to be undertaken in the context of a better understanding of the sources of economic growth. In this regard, the report calls on the United Nations to rethink this issue as it prepares itself for the five-year review of the implementation of the MDGs.

The report uses a systems approach under which it is difficult to discern the impact of individual technologies on the economy. What is important, however, is how these emerging technologies interact with each other and create new production combinations. Indeed, the approach adopted in this report would encourage the upgrading of current production practices in developing countries, which will necessarily involve the integration of new knowledge into existing technologies.

The main focus of the report is to provide policy guidance that can be adapted by policymakers at the local, national, regional, and international levels. In this regard, the report draws from a diversity of sources and experiences and does not restrict itself to specific countries. This broad coverage of experiences is informed by the view that responses to development tend to have more in common than is usually acknowledged. The tendency to categorize countries into certain groups has often deflected focus away from more a systematic identification of common features of development lessons that can be shared among countries and regions.

In other words, there are many more lessons that can inform development activities around the world than the ones that are currently being utilized. The choice of lessons should be guided by a deeper understanding of the nature of problems facing society and not by theoretical constructs that limit the scope of social learning. Developing countries should consider all existing and historical development lessons in designing their own solutions; there is now a much larger universe of ideas than was available to those countries that first developed them. The limits to learning are therefore not in the lessons available, but in theoretical frameworks that undermine open inquiry and experimental thought. The enquiring mind knows no limits.

By focusing on institutional processes associated with technological innovation, especially those related to learning, this report does not deal with the role of specific technologies. This partly because technological choices and combinations are usually site-specific or industry-specific and are better dealt with at the appropriate levels. The report also emphasizes that the general tendency to identify certain groups of technologies as more important than others is often misguided. However, there are some generic technologies such as information and communications technologies (ICTs) and genomics that are pervasive in their scope and deserve special attention. But ultimately, it is the confluence between different technological systems and the associated institutional arrangements that matter, not the individual impact of any specific technologies.

This report does cover all aspects of science, technology, and innovation. It would be presumptuous to think that this is possible. In selecting the scope of coverage, the Task Force was guided by the need to avoid repetition and the identification of significant themes that currently receive little policy attention. In regard to the first point, this report should be read in conjunction with other important reports on reports related to science, technology, and innovation such as the *Human Development Report 2001* on "Making Technology Work for Human Development" by the United Nations Development Programme; *Industrial Development Report, 2002/2003,* "Competing Through Innovation and Learning" by the United Nations Industrial Development Organization; *Strategic Approaches to Science and Technology in Development* by the World Bank; and *Inventing a Better Future: A Strategy for Building Worldwide Capacity in Science and Technology* by the InterAcademy Council.

The main contributions of this report therefore lie largely in its emphasis on defining development as a learning process. In this regard, the report focuses on institutional aspects of this process, which include science and technology advice, building human capabilities (especially through science education), and promoting enterprise development. It also seeks to redefine infrastructure as a foundation for technological innovation and recognizes the importance of designing science and technology policies that respond to the challenges of globalization. The guidance provided in this report can then be applied to with the appropriate modifications to the relevant aspects of thematic activities or sectors such as agriculture, health, water and sanitation, environmental management and energy.

PART I. ASSESSING THE SITUATION

1. DEVELOPMENT TRENDS

INTRODUCTION

A nation's ability to solve problems and initiate and sustain economic growth depends to some extent on its capabilities in science and technology. Science and technology has been shown to be linked to economic growth, and certainly, the ability to provide clean water, health care, infrastructure, and healthy food all have a component that includes science and technology. In other words, a review of development trends around the world needs to evaluate the role of science, technology, and innovation plays in economic transformation in particular and sustainable development in general.

1.1 Development in perspective

There are large differences between regions of the world and the ways in which they have faced historical, economic, political and social challenges. These differences, and the priorities for economic development that they induce, are visible not just in developing countries (the usual focus of international economic development efforts), but also within regions in the developed world where sub-regional disparities are substantial. For example, Europe, although prosperous on the whole, suffers from pockets of relative poverty and lack of access to basic amenities and political representation. Huge countries like China, Brazil, and India suffer both national-scale poverty, but also hide huge sub-regional variations in social, economic, and political fortunes. East and Southeast Asia have regional economic and political crests and troughs, as well.. Myanmar, Laos, and Cambodia have not enjoyed the same economic growth as other East and Southeast Asian countries. Equally critical are the challenges facing relatively small countries, especially island states of the Caribbean and Pacific regions.

Within our own lifetimes, the countries of East Asia have generated extraordinary economic success, often accompanied by a substantial improvement in overall equality (particularly through access to education). At the same time, gains made in earlier decades within countries of the former Soviet bloc have been eroded to different extents, particularly within the former Soviet Union itself, where life expectancies and the public health infrastructure have badly suffered along with the decline of legal, financial, and political institutions. Sub-Saharan Africa and South Asia have not fared well either, although pockets of visible economic and political strength have emerged in these regions.

But, in painting regions with one broad brush, we run the risk of losing the details that make for institutional learning and micro-environmental change that leads to long-term economic and development gain. We have mentioned earlier how East Asian countries diverged from countries in other regions in the ways they approached the microeconomic details of their industrial paths; indeed, their macroeconomic paths looked very similar. Looking over the very long term, we see that the wealth of countries rises and falls, sometimes in response to environmental or political pressures, but sometimes because of institutional capabilities or the ability to organize in response to major systemic change. These historical shifts provide lessons, as well.

Within the MDGs, there are certain pressing regional trends that need attention. For example, many African and South Asian countries are facing severe HIV/AIDS and TB problems, with the former exacerbating what was thought to be a relatively well-controlled TB phenomenon in many areas. In addition, malaria continues to be of serious concern with high mortality rates in most tropical regions (and worsening in parts of Africa), which also have high poverty rates and a poor health infrastructure. The STI policy focus needs to be oriented towards finding vaccines and medical solutions, while also creating new institutional frameworks from which new research collaborations can spring.

A encouraging example of what can be achieved through a good mix of political determination and collaboration is the recent breakthrough of a synthetic vaccine against *Haemophilus influenzae* B Type (Hib), developed by an academic joint venture between research groups at the universities of Havana and Ottawa, generating the first common patent between Cuba and Canada. Type B Influenza is considered one of the worst pathogens affecting children all over the world, causing illnesses like sepsis, meningitis, and pneumonia. The breakthrough is not the vaccine itself, which was already known, but the invention of a synthetic vaccine—not only substantially cheaper that the one available on the international market, but much easier to manufacture as well. Today, companies producing the original vaccine are able to deliver 100 million doses a year, while the need is five times this figure. However, with the new synthetic vaccine, it is estimated that Cuba alone will be able to manufacture 50 million doses a year.

Overall, progress has been made by developing countries in regards to poverty, with the average percentage of the world's population having an income of less than $1 per day decreasing from 32 percent in 1990 to 25 percent in 1999. But most of this decline is due to progress in East Asia (mostly China), and thus paints a grimmer picture for most developing countries. Globally, education indicators are also not on track to fulfill the MDGs, especially if we take into account gender and regional educational inequalities. Predictably, these are serious problems in South Asia, Sub-Saharan Africa, the Middle East, West Asia, and North Africa—all regions with significant societal inequalities between men and women. These same regions demonstrate gender inequalities in child and adult mortality rates, child and adult malnutrition, HIV/AIDS, and other public health problems, where girls and women suffer the most.

A region that deserves special attention is Africa, where economic development indicators show a wide range of fluctuation and where sub-Saharan Africa has moved into the twenty-first century with some promise. Yet, per capita income levels are only a third of those in South Asia, another extremely poor region, and forty-eight sub-Saharan countries together account for the gross domestic product (GDP) of an industrialized country's output from a town of 60,000 (World Bank 2000).

Overall, both savings per capita and income in sub-Saharan Africa have declined since 1970, and the situation has not been helped by environmental losses and rapid population growth in some sub-regions. Other basic needs are also not met: food, water, sanitation and public health access need significant attention. War, civil conflict, and natural disaster also constantly threaten the region. Gender inequalities are rife, with women constituting well over half the labor force in some countries, but facing dire lack of basic amenities.

Thus, sub-Saharan Africa's priority areas may be seen to lie in a huge push to satisfy basic needs while at the same time building up the infrastructures and institutions that could support a thriving private enterprise sector in manufacturing, agriculture, and services. Countries in the region also vary sharply in the extent of state reforms that have been undertaken, and the extent to which non-governmental actors will play an institutionalized role in their future development. In short, a multi-pronged approach is needed in the countries of this region, stressing the inter-connectedness of the policy reform process and the creation of institutions.

In particular, any reform process in sub-Saharan Africa needs to account for the need to foster a robust private enterprise sector—with all its accompanying financial, legal, and political institutions. As part of this process, we need to be particularly conscious of the significant economic role women and the young already play in the economies of these countries, although it is a role largely unrecognized by statistics or policies. Higher productivity growth could be an aim in itself, because this region of Africa does need higher economic growth rates to make any real dent in the basic needs of the population. More importantly, however, private enterprise growth could lead to the building of long-term institutions that have an impact on other aspects of sub-Saharan societies—in civil society, production across sectors, and the government.

While both governance and the HIV/AIDS issues have received attention as Africa's crisis points, in reality, there is a delicate play of cause and effect with the continent's weak institutional structure undermining gains that might have been made on these two fronts. Many countries in the area have instituted macroeconomic reforms, but there needs to be much more micro-level attention given to the structure and growth potential of producers at the local level.

An STI thrust that takes into account the fact that fulfilling basic needs and promoting economic competitiveness are intertwined will recognize that sub-Saharan Africa's problems are ones of institutional interconnectedness. Within the learning framework, this means that learning within enterprises needs to go hand-in-hand with the government deliberately investing to institutionalize this learning (and to itself learn along the way) (Marleba 1992). In addition, we cannot discuss the AIDS epidemic in Africa without paying attention to economic opportunities for the labor market, cultural and traditional prejudices, or problems of weak government. However, we can specify how the STI base can create technological and institutional innovation that assists in long-term economic transformation.

Fundamentally, countries need to set their own priorities. However, in order to institutionalize the learning process of governments, private sectors, universities and non-profit groups, there need to be deliberate investments in skill-building and the enhancement of institutions that will sustain learning in the long-term. Whatever choice is made regarding science and technology, it follows that corresponding political and institutional choices are also necessary. Even if developing countries were to structure their learning through doing everything by themselves, this "learning-by-doing" does not arise entirely spontaneously; it still requires a large, conscious investment in building indigenous innovative activity (Mathews 2001).

Finally, countries, firms, and governments are all affected by STI policies and the institutionalization of learning, but to different degrees and in fundamentally different ways. They also have different capacities and limits in achieving this learning. Thus, as we structure the guidelines for STI-oriented learning, we need to be mindful of these fundamental organizational and institutional differences. In addition, there may be varying degrees of control we have over the process of acquiring knowledge as manifested by technological understanding (being strong and reliable), and acquiring knowledge as manifested by organization routines and practice (weak and unreliable).

1.2 The false macro/micro dichotomy

Much of the analysis on economic growth tends to focus on the distinctions between macroeconomic and microeconomic factors. This is a false dichotomy that should be replaced by new approaches that have emphasized interactions between various sections of the economy. National policies and the institutions they created did not preclude the need for micro-institutions, both in scale and location. However, a huge gulf has emerged in the dichotomies between policies espoused for the industrialized and developing worlds. In the former, the focus and support has been with micro-level details, while with the latter macroeconomic policies have taken precedence.

While there is no separation between causes and effects in the relation between macroeconomic and microeconomic policies, using one or the other excessively has only led to skewed emphasis on where innovation is supposed to occur. Indeed, conventional economic policies seem to have overly stated the degree to which macroeconomic policies determine the outcomes of industrial policy. Both South Korea and Taiwan, for instance, relied heavily on sustained microeconomic "imperfections"—in that they targeted industries, meddled with loan decisions, preferentially allocated credit to good performers (particularly for good exporters), relied heavily on the public sector for industrial development, and did not liberalize imports until well into the 1980s (Amsden 1989). On the macroeconomic front, these countries shared an orthodox interpretation of fiscal issues and foreign exchange.

However, the two country's microeconomic strategies, though they had much in common, differed considerably from what the free-market pundits espoused. These strategies distinguished the East Asian experience, more broadly, from the Latin American experience. Countries like Argentina and Mexico were both conservative macro-economically as well as micro-economically. From a technological capacity and innovation standpoint, however, Mexico and Argentina look considerably different from the East Asian countries. East Asian countries selectively invited foreign investment, built R&D around increasingly adding value to that process, and deliberately moved up the value chain, while Latin American countries were less selective in encouraging FDI and made far less efforts to build endogenous S&T capabilities.

The results of these discrepancies are well known: while the newly-industrialized countries (NICs) of East Asia were able to move up along the value chain, Latin America was stuck into a situation described as a "truncated process of industrialization" (Amsden 2001). This meant that they had fewer links in the knowledge chain as this feature of manufacturing become increasingly important to economic growth. Countries like India, on the other hand, did not suffer from macroeconomic imbalances until the balance of payments crisis of the early 1990s. This crisis has been followed by both macro- and micro-level initiatives to foster technological growth.

In the case of India, many of the micro-level institutions have much to do with both centrally led efforts to build distributed capacity locally as well as state government-led efforts to compete with each other and lure investments, create technology transfer, and assist domestic companies. This has been particularly visible in the southern states of Andhra Pradesh (Hyderabad) and Karnataka (Bangalore), which have seen competition and success in both computer services and emerging biotechnology competence.

1.3 Market failure, information, and innovation

Markets are a critical avenue through which human creativity expresses itself by means of exchanges in goods and services. However, markets are not necessarily a sufficient mechanism for directing technological innovation. The inability to make effective use of the available technological information is possibly the most critical market failure that deserves urgent remedy.

A standard market failure model for state intervention argues that the latter needs to be a last resort and adopted only in the cases of public goods, externalities, information asymmetries, and so forth. However, it is widely accepted that most STI policy measures and the goals they seek to achieve are rooted in the simple case of common resources, public goods outcomes, and the mitigation of negative externalities. (Positive externalities can be absorbed analytically under public goods availability.) Market failure modes of even this simplest type can prove paralytic for the development and diffusion of new and useful technologies relevant to the developing world.

Dependence on markets alone would create a demand function representing those with purchasing power—that is, the ability to "voice" their vote through the exchange mechanism of markets. These markets are often flawed due to unequal representation (not just on the basis of income) in the exchange mechanism itself, unequal information, and unequal risk to certain technologies. Technology markets face failures even in advanced industrialized countries that have functioning markets, robust institutions, and clearly delineated intellectual property rights.

For example, a common example of why markets alone cannot solve all development problems is illustrated by the case of certain malaria vaccines that have yet to come on the market. Most significantly, markets for such products often are absent altogether or highly underdeveloped. This is the "extreme market failure mode." There are a host of other reasons even in functioning markets why failures might arise. First, most people who need the vaccine are poor and are not an immediately attractive customer for firms targeting high profit margins. Second, many poor people, unlike rich retirees in the advanced industrialized world, are often not able to organize effectively to lobby their governments for cheaper drugs or more relevant medicines for their ailments. Third, information asymmetries are rife in the pharmaceutical industry, with developers of the medicines often having access to significant information and knowledge of new technologies.

To summarize, policymakers in the developing world need to also survey non-market institutions and models of development. This means looking at the experiences of those countries that have already gone through the development process and "made it"—Finland, South Korea, and Taiwan being good examples—to show us that development is not simply about structuring the institutional mix to become "more perfect" (read less government), but in fact may require specific types of policies that are quite interventionist by the free-market standard.

A related point concerns the institutional setting within which markets function. Conventional economic analysis has generally treated institutions as contextual, but this has changed in recent years as economists have given increasing attention to the role of "institutions" in the functioning and transition of economic systems. This has become especially important with respect to S&T in underdeveloped countries, where evidence indicates the increased need for fundamental changes. The main issue in developing countries concerns how to deal with large and unproductive public R&D systems. In fact, during the years following de-colonization, many Third World countries invested heavily in organizations whose function was to conduct R&D of relevance to economic development. The belief was that "investment" in public science would create possibilities for more rapid rates of innovation than would the interplay of market forces. We now know that such expectations were never likely to be realized, that their underlying assumptions were hopelessly oversimplified, and that relations between "science" and economic production are very complex indeed.

Meanwhile, however, huge infrastructures have been created in developing countries whose economic impacts are certainly sub-optimal and, in extreme cases, probably negative. Enormous sums of public money are tied up in unproductive assets including "human capital," the key resource for a dynamic economic system. At the same time, economic production routinely accesses new technology from other sources (usually from external bodies in the industrialized world). The result is that very often the rate of technology development in poor countries is too slow to ensure rapid economic growth.

However, the term "institution" is a tricky one. Some writers see institutions as "social rules and norms" and therefore as cultural traits shown by social groups. Others see them more as specific organizations designed to fulfill a given set of functions. In this vein, it is useful to make the distinction between "rule-oriented" institutions and "role-oriented" institutions (Brinkerhoff and Goldsmith 1992). The former are the "rules of the game" in a society or constraints designed by society to govern human interaction. The latter are defined as organizations that have acquired special status or legitimacy (North 1990). Role-oriented institutions are essentially legally identifiable organizational systems that bring together people with different social backgrounds, knowledge, and techno-scientific skills to collectively address specific socioeconomic problems and uncertainties. Such institutions have certain life spans and generate specific outputs in the process of dealing with problems and uncertainties.

The "institutional economists" usually adopt the sociological meaning of the term, referring to things that pattern behavior—routines, norms, shared expectations, morals (Edquist and Johnson 1997). The "new" institutional economists such as North (1990), suggest that the emergence of these rules and regulations, which can be informal as well as formal, are a mechanism for reducing transactions costs and other forms of market failure. Generally, the institutional economists' position is that understanding the rules and regulations that govern behavior helps to explain shortcomings of conventional economic theory.

The practice in the more recent "innovation systems" literature is to use the term "institution" in the everyday meaning of the word: that is, as a physical organization dealing with research and development (R&D) and economic activity. Examples include research centers, universities, private companies, research foundations, farmers associations, co-operatives, and so forth. In reality, there is some ambiguity among authors, some tending only to analyze the behavior of physical organizations, whereas others focus more on the rules and regulations environment. The confusion arises because generalizations from empirical observation indicate that both behaviors and regulations are involved in and shape the outcome of innovation. The real problem is that institutions in the "rules and norms" sense are often intimately related to the physical or tangible nature organization of these institutions, and in one sense organizations help define and operationalize the "rules of the game." In other words, they are mutually embedded concepts. This report follows the more inclusive innovation theorists' definition of institution rather than the institutional economists' more narrow definition of the term. The term *institution* is hence used to mean the combined environment of "rules of the game" and physical organizations, and the interplay of the two.

Investment in public science in developing countries has certainly not been managed appropriately. And this is due, among other things, to a poor understanding of its complex relations with economic development. At the same time, it is also true domestic firms rely heavily on foreign technology suppliers. How do these two things relate to one another? Does such reliance on foreign technology suppliers yield better public science investment results in developing countries with well-managed domestic innovation policies? Yes, it does; and this appears to be the right line of inquiry: economic development is maximized when, among other things, domestic innovative skills and capabilities fully utilize foreign technology inflows that are, in turn, used to spur domestic innovation.

The imperfections in the market for technology, such as the relative ignorance of buyers vis-à-vis sellers, are certainly a source of sub-optimality. The experience of developing countries that have carried out effective technological capability and learning policies suggests that such a situation can be tackled by means of a strategy that: (a) deals with innovative technology inputs as an engine of productivity growth and as a competitive weapon; (b) provides the necessary public goods, particularly through the domestic technological infrastructure; and (c) and offers the necessary incentives. However, as a rule, the allocation of resources in developing countries, especially in industry and in S&T institutions, is not premised on such a strategy.

This brings up the issue of institutions as role-shapers. For instance, maximizing returns on primary exports while investing part of the rents in establishing centers of excellence in science may make sense at certain point in history. But this approach may become as ingrained in the decision-making system of society as to persist even when it is no longer warranted or sustainable. The challenge then is to change the underlying institutions so that technological innovation is factored into the competitive performance by design.

1.4 Technology in a global setting

Technological change is at the heart of development in most developed nations. Yet, the conventional development advice meted out to developing countries is that they struggle (and fail) because of "poor governance"—associated primarily with governmental corruption and the inability to develop or sustain basic infrastructure. We need to analyze more thoroughly the structural and institutional characteristics of the environment in which technological change occurs. While the governance of a nation is important to the story of development, one should interpret "bad governance" stories with caution, because they hide the simultaneous presence of good and bad, of gains on some fronts and failures on others, and because broad-sweeping labels hide the process of micro-level change where institutions are created for long-term economic development.

For example, failing economies and low levels of overall development in Africa are usually attributed to war and corruption. Certainly, these factors can be, and have been, debilitating for economies and for political liberties that sustain long-term economic gains. But some of the countries with the greatest economic and technological success stories of recent decades of the twentieth century—those of East Asian nations and economies like South Korea, Taiwan, Singapore, Hong Kong, and more recently of some others—have had distinctly uneven commitments to human rights, gender equality, and political freedoms. Indeed, the South Korean industrial rise is a story of not only building on a high level of commitment to education and educational homogeneity, but also building on the backs of exploitative gender dynamics in factories and on a crack-down against union voices and labor representation. Indeed, the East Asian successes are not about the absence of corruption (of which there has been plenty), but of the nature of the institutions that were designed to facilitate local technological capabilities even when reliance on outside expertise was a cheaper option.

However, these are not the only technological and developmental success stories of the last century. Finland, for example, is a good example of poverty, even famine as late as the 1870s, extreme climactic conditions and lack of significant natural resources. Yet, it ranks today as one of the most R&D intensive, high technology economies of the world, with one of the highest per capita publication rates for STI and a high patenting profile. But once again, the role of institutions and learning were very important to Finland's success.

Appendix A shows the different levels of achievements of countries in this area. The technological achievement index (TAI) was first introduced in United Nations Development Programme (UNDP) *Human Development Report 2001* and is presented here with updated data. The TAI presents a snapshot of countries' average achievements (rather than efforts or potential) in creating and diffusing technologies and in building human skills to master new innovations. Of course, many important aspects of these areas cannot be measured, but the TAI gives a useful overview of the strengths and weaknesses of each country's situation in three areas: (a) technology creation, where data on patenting and royalty receipts highlight research and development capacity for creating new products and processes; (b) the diffusion of new technologies (measured by Internet usage and exports of high- and medium-technology goods) and old technologies (telephony and electricity); and (c) human skills, a vital component for reaping the benefits of technological process, which is captured in the TAI through mean years of schooling and the gross tertiary science enrollment ratio.

A fundamental problem today is that development strategies that worked in a particular case in the past cannot necessarily be generalized into a common rulebook. A host of "successes" have been analyzed and advertised widely, but the global rules governing market exchange and intellectual property rights have changed, causing developing countries today to face constraints (but also opportunities) that their predecessors did not. For example, South Korea reached its present industrial strength through a vast array of import-protecting measures, as well as the selective use of foreign investments; such conditions, however, would be difficult to recreate under the present global trading regime. India's strengths in the chemical and pharmaceutical sector were also developed in part under the umbrella of a patent regime recognizing only process patents. Although this was not at all unusual, as many advanced industrialized countries did the same at earlier times in history, this option is less possible today due to the tightening of intellectual property protection and other factors that limit technological spillovers.

Thus, we need to account for the vastly different global structural environment in which technological change now occurs. One manifestation of this change is the existence of globalized production networks dependent on geographically dispersed cost and logistical differences. This signifies a big shift from a few decades ago, when foreign direct investment (FDI) had other implications and modes of entry and impact. Another illustration is the changed geopolitical climate that has allowed certain countries preferential access to the United States and other advanced technology markets for new technologies, access to new export markets, and significant amounts of development assistance. A third is the changed intellectual property regime already mentioned, which has played such a critical role in early development of certain industries of advanced and newly industrialized countries. A final example is that the information and communication technologies and biotechnology revolutions—and particularly the potential of the Internet in the way it links the world—have created new pressures and opportunities on skill sets and organizational practices within enterprises, universities, and other R&D and manufacturing sites.

In general, while the devastating effect of challenges such as war, civil strife, and natural disaster on even healthy political climates cannot be disputed, analysis needs to focus on how gains are made on some fronts despite these challenges. This report addresses in an inductive way how countries emerge from these challenges and what role the international community can play in assisting them in this growth.

Governance debates alone cannot address all development problems, even economic ones. Even if problems of poor governance were "fixed", there would be crucial moments in time where the lack of robust institutions that underpin the development process would eventually undermine any development hopes. In sum, "good governance" (and good government) is a necessary, but not sufficient, basis for long-term development, economic or otherwise. In particular, countries that have been told by international agencies and other countries that they would succeed if only they were able to depose a corrupt government, or if only they could call a ceasefire, or if they only follow a specific economic path (privatization, opening of the economy, etc.) are faced with serious disappointments along the road. Once the cessation of the "evil" in question occurs, these countries are left with even fewer options. The very destruction of present causes of debilitation also undermines institutions that contribute to long-term growth: a strong government, judicial capability, infrastructure, and scientific and technological solving-problems capabilities.

In particular, with their economies devastated, these countries have little fallback resources for development but still have to deal with devastating burdens of poverty. The lack of scientific and technological capability, or ways of building these assets over time in the face of processes that destroy accumulated skills, puts these countries significantly behind STI leaders, and the lack of STI institutions and policies gradually undermines their position over time. Thus, innovation policies that encompass both STI issues as well as the systematic institutionalization of learning over time in industry, agriculture, and services are a vital part of any economic development or reconstruction process.

Conventional wisdom has interpreted the development of economies as a question of capital accumulation, rather than one of investments in public and quasi-public goods, which includes STI. While a shift in thinking is gradually occurring to embrace the evidence that supports the latter analysis, changes in technological regimes are not simple. An area within STI that resonates particularly well with shifts in national political and economic regimes is how to initiate transitions in the technological regimes and support innovative technological niches.

From a geopolitical standpoint, a leading explanatory variable for a country's induction into privileged circles of trade negotiation, economic treaties, and preferential status is its technological capability. Countries with rapid economic growth rates clearly attract foreign attention, because they represent new markets for goods and services from leading industrial powers, and they are considered larger players in regional political power considerations. Both China and India in Asia and Brazil in South America present good examples of increased inclusion into select economic and political clubs on the grounds of economic growth and advanced technological capabilities. . Thus, there is no substitute for scientific and technological bases, which under-gird everything from agricultural self-sufficiency to public health coverage to lucrative licensing options for indigenous technology advances.

The push to develop STI policies in a comprehensive way also allows for the creation of institutions that serve broader economic goals—a proactive state at different levels, innovative industries, strong research universities that are locally responsive, as well as regulatory, legal, and financial capabilities that support STI. African countries (such as Kenya, the Republic of South Africa, and Tunisia) that have paid greater attention to these issues have also been able to address broader issues of political and economic representation and social unrest. While their record is mixed, these countries' industrial and STI bases have provided a platform upon which other learning institutions are structured.

While the benefits of technology vis-à-vis the governance framework are usually laid out in terms of transparency of government through the use of information and communication technologies, there are other ways we should consider STI policies' contributions to enhancing government. For example, more educated populations are often more participatory, have greater economic clout, and more constituent power. Different population groups can also interact with each other in ways that might allow for a kind of national integration that was not possible before. This type of broad participation helps to positively integrate science and technology into the economy and social life of a country. Public understanding of science helps, for example, to stem unanticipated consequences of poor use of technology. The prerequisite is the availability of physical transportation and communications infrastructure within the nation. Globalized production networks could not have occurred without such infrastructure around the world.

Of course, STI policies, when well constructed, also directly address other pressing basic needs in agriculture, social services, water, sanitation, and infrastructure. Acknowledging that STI policies could constructively contribute to the analytical debate requires a movement beyond the antagonistic models of state versus society, or state versus market. Instead, gains from STI can be used as a powerful leverage by states to sell their image and to integrate into the global knowledge network. By generating "catch up" opportunities for developing countries on multiple fronts, STI policies can create the fertile ground on which the seeds of new knowledge can help solve problems and build wealth, eventually bringing developing countries into full partnership with the international community.

CONCLUSION

The role of technological innovation in economic transformation is emerging as one of the least studied (yet most critical) sources of productivity. Indeed, economic historians are currently revising our understanding of human history and placing greater emphasis to the role of technology and the associated institutional innovations (Rosenberg and Birdzell 1986; Mokyr 2003). The role of technological innovation in economic transformation has become a central theme in the growth strategies of the industrialized countries. However, lessons derived from these experiences have not been applied to planning in developing countries. To the contrary, technological change remains a marginal part of these countries' growth strategies. The MDGs offer an opportunity for the international community to plug into this policy deficit.

2. MILLENNIUM DEVELOPMENT GOALS AND GLOBAL SECURITY

INTRODUCTION

At the Millennium Summit in September 2000, world leaders passed the Millennium Declaration, which formally established the Millennium Development Goals (MDGs). Since then, the MDGs have become the international standard of reference for measuring and tracking improvements in the human condition in developing countries. The welfare of these countries is also intricately intertwined with the security of the industrialized countries, making development a truly global venture. Indeed, countries such as the United States have started to classify human development challenges that are prevalent in developing countries, such as HIV/AIDS, as national security issues. This is the beginning of a process that recognizes the emergence of a globalized world that requires collective action to deal with issues that would otherwise be considered as strictly national. The MDGs have the advantage of (1) a political mandate agreed upon by the leaders of all UN member states, (2) offering a comprehensive and multidimensional development framework, and (3) setting clear quantifiable targets to be achieved in all countries by 2015.

2.1 Charting new development paths

This Task Force addresses MDG Number 8 ("Develop a Global Partnership for Development") and Target 18 ("In cooperation with the private sector, make available the benefits of new technologies, especially information and communications.") Its remit has been broadened to how science and technology can be enhanced and put to use to help all countries achieve the MDGs. The mission of the Task Force is guided by the understanding that most MDGs cannot be achieved without a strong contribution from a framework of action that seeks to place science and technology at the center of the development process. Besides ICTs, other significant new technologies addressed in this report are biotechnology (especially genomics), spatial information technology and materials science.

Science and technology offer tools for solving acute problems (such as earthquake detection, weather tracking, and disaster mediation), as well as for encouraging growth. This use of science or technology can and should include a collection of experts from anywhere in the world. The aid they provide can help meet the Millennium Development Goals over the short term. The extent to which *any* country can solve acute problems often involves collective action.

However, if long-term goals will be achieved, and growth and problem solving is to become indigenous and sustainable, then STI capabilities need to become a localized resource for developing countries. This latter goal is our focus, and it is one that requires a particular approach to STI as a system of interconnecting capabilities, each of which need attention. Governance is one, but education, institutions, advice, collaboration, and many other factors are also needed for STI. These are addressed in this report.

Box 1: Millennium Development Goals

Goal 1: Eradicate extreme poverty and hunger

- **Target 1:** Halve, between 1990 and 2015, the proportion of people whose income is less than one dollar a day
- **Target 2:** Halve, between 1990 and 2015, the proportion of people who suffer from hunger

Goal 2: Achieve universal primary education

- **Target 3:** Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling

Goal 3: Promote gender equality and empower women

- **Target 4:** Eliminate gender disparity in primary and secondary education, preferably by 2005, and to all levels of education no later than 2015

Goal 4: Reduce child mortality

- **Target 5:** Reduce by two-thirds, between 1990 and 2015, the under-five mortality rate

Goal 5: Improve maternal health

- **Target 6:** Reduce by three-quarters, between 1990 and 2015, the maternal mortality ratio

Goal 6: Combat HIV/AIDS, malaria and other diseases

- **Target 7:** Have halted by 2015 and begun to reverse the spread of HIV/AIDS
- **Target 8:** Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases

Goal 7: Ensure environmental sustainability

- **Target 9:** Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources
- **Target 10:** Halve, by 2015, the proportion of people without sustainable access to safe drinking water
- **Target 11:** By 2020, to have achieved a significant improvement in the lives of at least 100 million slum dwellers

Goal 8: Develop a Global Partnership for Development

- **Target 12:** Develop further an open, rule-based, predictable, non-discriminatory trading and financial system
- **Target 13:** Address the Special Needs of the Least Developed Countries
- **Target 14:** Address the Special Needs of landlocked countries and small island developing States
- **Target 15:** Deal comprehensively with the debt problems of developing countries through national and international measures in order to make debt sustainable in the long term
- **Target 16:** In co-operation with developing countries, develop and implement strategies for decent and productive work for youth
- **Target 17:** In co-operation with pharmaceutical companies, provide access to affordable, essential drugs in developing countries
- **Target 18:** In co-operation with the private sector, make available the benefits of new technologies, especially information and communications

Source: United Nations, 2000.

The proposed strategies of the Task Force are not meant to be a replacement, but rather a complement, for other approaches. For example, science and technology plays an important role is addressing challenges associated with poverty and hunger (MDG #1). It reduces poverty through its contributions to economic development (e.g., creation of employment opportunities, low-cost housing, manufacturing opportunities, improved agricultural productivity through new agricultural technologies, and novel services such as call centers). It also plays a role in alleviating hunger through enhanced nutrition, improved cash and subsistence crops, better soil management, and efficient irrigation systems. But these scientific and technological measures do not in themselves solve the challenges of poverty and hunger; they need to be part of an integrated strategy with other approaches needed to improve overall human welfare.

Science and technology can also play an important role facilitating implementation of the MDGs on education, gender, health, and sustainable development. Information and communications technologies (ICTs) can contribute to primary, secondary, and tertiary education through the use of distant learning devices as well as remote access to other educational resources and other solutions. Many technologies hold the promise of significantly improving the condition of women in developing countries (e.g., through improved energy sources, better agricultural technology, increased access to water and sanitation). This is particularly important in areas where women play dominant roles.

A broad number of health interventions require the development of new treatments and vaccines through improved science (e.g., anti-malarials, HIV treatment and prevention, drug-resistant tuberculosis, vitamin and other micro-nutrient deficiencies in children and mothers, etc.). In addition, the production of generic medicines holds the promise of improving the poor's access to essential medicines. A particularly important contribution of science and technology in this area lies in improved monitoring systems for pharmaceutical quality.

Improved science and technology at the local level will be indispensable for the monitoring and management of complex ecosystems such as watersheds, forests, and seas. This will help predict (and thereby manage) the impact of climate change and biodiversity loss. Access to water and sanitation will require continuous improvement in low-cost technologies for water delivery and treatment, drip irrigation, as well as sanitation.

The outcomes of the World Summit on Sustainable Development (WSSD) have amply demonstrated the importance of science and technology. However, the scientific, engineering, and technology communities have yet to be fully integrated into a system that encourages and enables development. For example, while we have very capable engineering organizations and expertise available to address acute problems such as natural or other disasters, we do not have the same ability to draw upon the commitment, expertise, or scale to put these resources to use for long-term sustainable development in developing countries.

The field of energy offers another example of the role of science and technology in sustainable development. Although access to energy is not in the MDGs, it is included in the five priority areas of WSSD, namely WEHAB (Water, Energy, Health, Agriculture and Biodiversity). Energy remains an important input into the development process. Energy generation and use is also the subject of considerable technological innovation and will continue to be of strategic policy interest for all countries.

It is widely recognized that over the long term, the use of fossil fuels is unsustainable. What we currently burn will not be available to future generations. Burning fossil fuel results in the emission of carbon dioxide (CO_2) and a worsening of the greenhouse effect. The single most important component responsible for about 80 percent of all climate warming is increased emissions of CO_2. The aim in the current energy debate is to reduce the emission of greenhouse gases. The simplest approach is to use less energy. The opportunities for doing so arise in almost all human activities and not least in domestic usage. It is an intriguing goal—the only approach to the overall problem that has no evident downside except possibly slower economic growth. One abiding problem is that energy is relatively cheap in the developed countries, which may reduce these countries' willingness to use less.

Box 2: Sustainable development and engineering

A number of international engineering organizations play important roles in international development. For example, the Registered Engineers for Disaster Relief (RedR) that have worked in the forefront of refugee relief in all the hot spots like Bosnia, Kosovo, Angola, Rwanda, Cambodia etc. RedR manages a register of carefully selected engineers who can be called on at short notice to work for front-line relief agencies. However, RedR has yet to spread into the developing world where it could play an important role building local engineering capabilities. Efforts are now being made to extend RedR worldwide as it is realized that the immediate response to any disaster situation is a well-trained corps of local engineers.

These efforts are complemented by national examples around the world. The China Association for Science and Technology, which is the largest nonprofit science and technology organization in China, commissions a special-purpose train with frequent stops in poor rural areas with explicit focus on applying STI for basic needs such as conducting surgeries, solving technological problems, and giving lectures. It also hosts a mobile exposition with learning materials to spread the interest in science and technology across areas that need it most.

Source: http://www.redr.org/

One promising solution may be to develop small power plants, units, and systems that are environmentally benign. The medium-term prospects are promising. An August 2000 issue of the *Economist* featured a most encouraging report on small power devices and systems, showing the economical viability of hydrogen fuel cells and gas fuelled micro turbines. There is a dramatic increase in venture capital investment in these technologies in the United States. Giant power manufacturers like General Electric, Siemens, ABB, and large oil corporations are investing in fuel cells and renewable energy.

For instance, British Petroleum (BP) has not only made a big shift towards natural gas but has also placed hedging bets on renewable energy and hydrogen fuel cells. This is attributed to the deregulation and privatization of the electricity supply market. The European Union (EU) has made a big political push for renewable energy. It is forecast that the share of renewable energy in electricity generation in EU countries will increase to 10 to 30 percent in 2010 from the current level of less than 5 percent. Denmark has made a huge a successful effort to include wind energy into its energy mix: it is said that wind accounts for almost 20 percent of the energy used in the country.

For the two billion people mostly in the rural areas of the developing world who currently do not have access to commercial energy, and for the four billion projected to be added to the world's population by 2100 (mostly in urban centers in the developing world), the overriding energy issues are access and affordability. In the light of current promising world development with regard to new and renewable energy options, scarce capital should not be expended in developing countries on the development and expansion of power grids and the concomitant installation of large and conventional fossil-fuelled power generating units. Money will be better spent in new, renewable, and environmentally benign power generating devices. The developed world can contribute by letting developing countries make use of the technology of small power generation devices that are deemed not sufficiently energy efficient by the developed world's stringent standards and are either rejected or subject to further R&D. Such devices may be of immediate application for developing countries that are not as concerned with energy efficiency as with energy accessibility and affordability.

Box 3: Powering future cars

The RAC (Royal Automobile Club, U.K.) Foundation has recently carried out a major study into the future of motoring—towards 2050. It states: "The 2050 car will look relatively familiar from outside. The average European car of 2050 will be much the same size as today's car, and will weigh about the same. It will however embody many features that will make it more versatile. It will have a fuel cell power-train, almost certainly using compressed hydrogen gas as its fuel. Thus its on-road emissions will be zero, except for a small amount of water vapor. Its energy consumption will be substantially less than half that of current cars, and it will be exceptionally quiet, which will highlight the need to extend the adoption of 'quiet' road surfaces to urban areas." What is even more promising is the active participation of all the motor vehicle manufacturers, demonstrating in no uncertain way that fuel cells for cars will be a commercial reality. DaimlerChrysler expects to have fuel-cell cars on the market by 2004. Honda, Toyota, and General Motors also say their fuel cell cars will be ready by then. BMW has recently unveiled a prototype version of its 7-Series saloon car with hydrogen-power internal combustion engine.

Source: http://www.racfoundation.org/index2.html

As stated above, transportation has a major sustainability dimension. In the developed world there is great anxiety about the impact of increasing wealth in the developing world leading to massive increases in car ownership, and thus to greatly increased levels of local, regional, and global pollution. The developing world, not unreasonably, is reluctant to accept advice that it needs adopt the pollution-free methods of transportation that the developed world has found it difficult to implement. Transportation is a massive consumer of energy and it has a profound environmental impact, yet modern lifestyles depend on modern transport systems. The motorcar produces pollutants, which contribute to the greenhouse effect, acid rain, health problems, and a range of issues associated with "quality of life"—including noise, physical division of communities, and visual intrusion. The conflict between economic development and protecting the environment pervades the transportation debate.

Some experts have suggested that hydrogen will be the most positive development for energy and transportation in sustainable development. We need to prepare developing countries for hydrogen fuel's short-term economic and employment (possibly adverse) impact on their petroleum production and distribution industries and their motor vehicle manufacturing. It might also affect their whole energy and transportation infrastructure, as well as the exciting prospects on cost saving on environmental pollution measures and opportunities for new industries.. Scientists and engineers from developing countries should now participate actively in the R&D efforts in developed countries. This may be one of the best ways to transfer technology and spread technological awareness regarding hydrogen fuel cells in developing countries.

Box 4: Technology and growth: Elements of success

The successful development processes in the Asia Pacific and Southeast Asia suggest that, for least developed countries to lift themselves out of poverty and achieve MDGs, they need at least three critical elements.

First, they will need to build basic infrastructure including roads, schools, water, sanitation, irrigation, clinics, telecommunications, and energy.

Second, they will need to foster the growth of basic industries, namely small and medium enterprises (SMEs) for supply of goods and services to agricultural and natural resources exploitation industries. This means developing indigenous operational, repair, and maintenance expertise and a pool of local technicians. Without this technology base, indigenous industries cannot upscale and economy cannot uplift.

Third, to implement the above, the science and technology advice systems in developing countries need reorientation, with more government support and funding for the establishment and nurturing of academies of engineering and technological sciences, professional engineering and technological associations, industrial and trade associations, and the like. These human resource and supporting institutional framework in the private sector and in NGOs would spur sector-wide innovations in the development processes.

MDG (Goal 8) Target 18 links the private sector and new technologies like ICT to developing nations' ability to participate in the global knowledge economy by enhancing their capacity to generate new products and improving their competitiveness. In this connection, small and medium enterprises (SMEs) in developing countries will play a crucial role. With available and affordable computer hardware and software, knowledge accessibility through the Internet, and robotics and modern instrumentation, product research and development can be carried in any SME anywhere focusing on innovation leading to profitability. This paradigm shift will mostly occur in SMEs with young professionals in charge as they are without the traditional baggage of caution, conservatism, and the gender and generational inequity of the business community. SMEs will spread wealth far more equitably in developing countries than high-tech mega-ventures with multinational corporations.

Box 5: Tapping the energy of youth for development

There are already a number of existing programs that tap into the energy of young professionals in the international, non-governmental, and UN arenas. Within the United Nations, United Nations Educational, Scientific and Cultural Organization (UNESCO) formed the International Forum on Young Scientists during the World Conference on Science in Budapest in 1999.

The UN Program on Space Applications has formed the Space Generation Advisory Council (ages 20 to 35). The World Bank (age < 35), the Organisation for Economic Cooperation and Development (OECD), the Food and Agriculture Organization (FAO) (age < 35), and the International Labour Organization (ILO) (ages 25 to 35) all have young professionals programs, designed to both develop and learn from young professionals around the world. Regionally, groups from the Asian Coalition for Housing Rights and the London Business School have young professionals and many of the main organizers of NGOs are young professionals themselves.

There are also a large number of existing young professional networks around the world that can be immediately engaged, from the Waikato Young Professionals in New Zealand (ages 25 to 35) to networks in Pittsburgh, Philadelphia, Chicago, and Toronto (ages 25 to 40), the Thai American Young Professionals Network (ages 25 to 35), Young Professionals Kesher (ages 25 to 35), and the International Young Professionals Foundation (ages 25 to 35). These networks are diffuse, and while for many the main focus of the group is networking, many also understand that professional development can be achieved through sustainable development.

With the right assistance from the UN, international development agencies, governments and business Corporations, and with young professionals driving their own networks and organizations, these young professionals will be the most potent force in achieving the MDGs. A good example is the Australian Young Ambassadors for Development Program, which places young professionals in developing countries, sponsored by AusAid and organizations in both Australia and the recipient countries. Extensions of this concept could include two-way exchanges of young professionals, like the reverse Colombo Plan fellowship scheme of Malaysian alumni of Australian Universities that brings young Australians to study and work in Malaysia.

Young professionals (typically 25 to 35 years old) comprise around 15 percent of the world's population and nearly a quarter of the world's eligible work force. In the developing world, young professionals are some of the main sources of economic productivity. In the current knowledge economy, a large number of young professionals in both the developed and developing world have become captains of cutting-edge industries in ICT and other emerging technologies. Solidarity has always been strong among young people: knowledgeable young people, in developed and developing countries alike, can surely be mobilized in an orderly way to provide help for development purposes, following the leading example of Doctors without Borders. This can be a major force to harness S&T to development.

2.2 Development and national security

To varying extents, science and technology innovations may contribute not only to economic growth, but also to national stability and international security. While it is true that science and technology have historically been put to nefarious uses, it is also true that modern improvements in social monitoring and dialogue can serve to reduce and redirect the chances of this happening. For example, the Pugwash conferences, the International Institute for Applied Systems Analysis (IIASA), and the development of national technology councils show that well-organized dialogue at top levels and informed public opinion can help assure positive outcomes from the spread of science and technology.

Over time, economic growth fuelled by innovations in science and technology can contribute to increased social cohesion, stability, and democratization. Brazil and South Korea exhibit similar patterns where, over a forty-year period, economic growth led to a virtuous cycle in which first labor and then an emerging middle class began to insist on greater social, economic, and political participation. Advances in education, science, technology, and economic growth in these and similar transition countries are improving the prospects for both democracy and stability.

Along the way, increases in democratic practices, economic growth, and innovation normally lead a nation to increase its participation in international trading regimes. As this occurs, the trading countries must establish a wide range of harmonized practices, such as standards, regulations, and tariffs. Even if not fully harmonized, the trade ties that are established usually have positive effects on political relationships between countries. Indeed, historians have found that democratic countries with trade interdependencies are usually less likely to go to war with each other than are isolated or totalitarian states.

As scientific and technological innovations work to foster economic growth along with political stability and democracy, countries become, on the whole, better international citizens and stakeholders in security. They also become more open to understanding that security often has important non-military dimensions. The recent redefinition of AIDS by the United States as a security crisis is one example of this broadened view of security in the twenty-first century.

Most past international disputes and conflicts have revolved around access to land, commodities, and natural resources—all of which exist in limited amounts. These economic factors continue to play a role today, of course. However, the world is now entering the information age and will be increasingly composed of knowledge-based societies. For these countries, economic value will be increasingly derived from a factor that has no specific limits and that could grow at exponential rates: knowledge, especially scientific and technical knowledge. Knowledge-based societies will not develop without conflicts of their own, but traditional warfare based on mercantilism or land grabs will take different forms.

One of the major new forces emerging in today's world is global civil society, and it promises to become ever more important a force as the information age deepens. Many of the NGOs and NGO networks comprising it derive their capacity from their usage of advanced information and communication technologies, and many have a keen interest in seeing that science and technology, broadly defined, serve peaceful democratic purposes and create open societies. One of the key challenges ahead is to better integrate NGOs into policymaking mechanisms and forums at local and international levels, forums that have been traditionally dominated by state and corporate actors.

CONCLUSION

The MDGs have become the international standard for measuring and tracking improvements in the human condition in developing countries. They provide a political mandate agreed upon by the leaders of all UN member states, offer a comprehensive and multidimensional development framework, and set clear quantifiable targets to be achieved in all countries by 2015. They also present an opportunity for linking development goals to global security. Indeed, the welfare of developing countries is also intricately linked to the security of the industrialized countries, making development goals a global objective.

PART II. WORKING THE SYSTEM

3. SCIENCE, TECHNOLOGY, AND INNOVATION

INTRODUCTION

An analysis of Western economies and their history suggests that the prime explanations for the success of today's advanced industrialized countries lies in their history of innovation along different dimensions: institutions, technology, trade, organization, and application of natural resources. Similar factors explain the economic transformation of recently industrialized countries in the developing world.

Scientific and technological innovations come about through a process of institutional and organizational creation and modification; one does not neatly precede the other in time. Certainly, defining characteristics of the Western growth rates have been the institutionalization of private enterprise and its financial and legal rubric, along with constantly attaining lower cost of production and introducing new products on the market. There was also an exploitation of opportunities provided by trade and natural resources. This was a tribute not just to carrying through with new opportunities, but to the private sector and the state's ability to recognize new opportunities and the ways in which to exploit them.

3.1 Technological origins of economic growth

The rise of science and technology, particularly the institutionalization of the scientific method in the seventeenth century, also created a forum for shared experimentation, exchange of findings, and advancement and refinement of method. It was, in fact, a celebration of experimentation and uncertainty through the support of risk-taking and the rewarding of discovery. These were manifested eventually in the transformation of organizational types in the private sector as well as in new institutions that could weather economic uncertainty over time. Incentives for investment followed. What is characteristic of this history is the novelty of products, services, organizations, and institutions being created that were suitable to the local microclimate, but also the sheer diversity of such products, services, organizations and institutions. In the increasingly globalizing world, developed countries and their corporations tap the world's natural resources, have access to the best and brightest in human resources from around the globe, manufacture in the most cost effective locations, and have the whole world as their market.

However, even within this framework, our most recent successes lie in the newly industrialized nations and economies in East Asia. High growth rates were certainly a necessary part of the story, but they were buttressed by diverse and adaptable institutions that oversaw new production regimes, export orientation, and compacts between state and private enterprise, as was the case in Japan (Hobday 1995). This was also a period that saw repression of other institutions of labor and gender in East Asia, for example. What stands out were the deliberate choices made by governments in some cases, and the rapid adaptation to changed economic circumstance in others, which allowed producers to reap significant rewards while also requiring them to demonstrate a certain commitment to national goals. Legitimacy for governments in this region was derived in part by higher economic growth rates. Economic development became a vehicle for buttressing democracy—both South Korea and Taiwan elected and are now governed by presidents from previous opposition parties without adverse effects on economic growth.

The Finnish example is also telling in terms of science, technology, and innovation (STI) policies and institution building: the establishment of the Centre for Promoting Technology in 1983, particularly strong in microelectronics; the establishment of technology centers that have united the interests of municipal authorities, local universities, and local firms; venture capital and development companies managed by parliament; a strong push towards science and technology vocations, resulting in no less than a half the total number of annual degrees at universities or technical colleges being granted in engineering and natural sciences.

As a result, Finland was already doing a good amount of trade in high technology during the 1980s, surpassing Norway and equaling Denmark. From a developmental point of view, the Finnish example shows that it is possible to harness sound STI policies to sustainable economic growth and, in the same movement, to pay strong attention to concerns about equity through social welfare programs. Moreover, in some sense, the latter seems to have been a prerequisite regarding the former.

3.2 Technological divergence among countries

Countries have different capacities to conduct scientific research and technological development. As we have highlighted in this report, many factors contribute to scientific or technical capacity: national infrastructure—for example, communication and transportation systems, legal and regulatory structures; the pool of scientists, engineers, and other trained workforce; laboratories and other research facilities; and academic institutions. Capacity building is a continuous process even in the most scientifically advanced countries. Nevertheless, the term generally refers to efforts to enhance science in developing countries where a shorter (or no) history of investing in S&T limits their ability to solve domestic problems or participate in research and development at the international level.

The productivity and return on S&T investments in developing countries will most likely be lower than when the same funds are spent in developed countries. Increases in R&D funding, for example, will not increase capacity if only a few educated scientists are available to put those resources to work. However, there are not many measures that demonstrate the productivity of R&D dollars spent by any one country or institution. Yet it can be observed that scientific spending in advanced countries results in more research papers overall and in greater economic externalities than funds spent in developing countries. Even so, it is very difficult to show the relationship between S&T capacity, productivity, and output.

A review of the data revealing science and technology capacity in countries of the world suggests that countries can be grouped into four large categories. As part of a World Bank project, the RAND Corporation developed four broad categories (scientifically advanced, scientifically proficient, scientifically developing, and scientifically lagging countries) to characterize countries relative to each other in terms of science and technology capacity. (The original characterizations were based on the outcomes of the analysis of eight different indicators of science and technology capacity.)

These categories, in turn, can provide a framework within which to consider questions of research collaboration, teaming for capacity building, joint research, technology transfer, funding and investment priorities, and the productivity and effectiveness of aid. (Collaborative research is shown to be most contributory to capacity building, for example, when the subject is tied to a problem or issue where the developing country has direct experience and where some indigenous capacity exists.)

3.2.1 Scientifically advanced countries

The nations having the most positive ranking in scientific and technological capacity could be called *scientifically advanced countries* (SACs). In most of the areas that would be considered as contributing to S&T capacity, these nations show a positive relationship to an international mean, and they all have greater S&T capacity than the international mean. These countries also generally have capacity in *all* major areas of S&T. They are the ones that are responsible for the vast majority of all scientific articles published in internationally recognized journals, and they fund between more than 80 percent of the world's R&D. As a rule, these countries have made S&T investment a national priority for more than fifty years, and, in some cases, for more than one hundred years.

3.2.2 Scientifically proficient countries

Another group of world nations could be classified as *scientifically proficient countries* (SPCs). These countries together possess an overall S&T capacity at or above the international average, but they are not as uniformly capable as the scientifically advanced countries.

Investments in some SPCs may exceed the international average, while others may fall below the mean. Some of these countries display world-class strength in particular disciplines or subfields of science. These countries have made investments in the infrastructure and R&D required to build a science base, and their investments are showing results. A number of these countries have experienced significant gains over time in their roles in international S&T. Some of these countries have been making investments in S&T for over twenty years. In other cases, a country may have a longer tradition of national S&T, but it has been disrupted by war or other catastrophe.

3.2.3 Scientifically developing countries

Another set of countries could be called *scientifically developing countries* (SDCs). Although these nations have made some positive investments—reflected in the fact that some components of the index exceed the international mean—their overall scientific capacity is below the world average. The investments that they have made, however, do allow these countries to participate in international S&T in some cases. These countries are seeking to invest further in science and, in some cases, they have good capabilities that attract international partners. Several of these countries are poised to move into the "proficient" category, but factors such as overall GNP or other infrastructural factors are keeping them from being considered among the scientifically proficient countries.

3.2.4 Scientifically lagging countries

Those countries where investments in science and technology have not been made (or for which adequate data is not available) fall in a category called *scientific lagging countries* (SLCs). These countries fall below, and in most cases well below, the international mean for all the components that reflect S&T capabilities. In many cases, these countries have little or no capacity to conduct world-class science. In a number of cases, scientific capacity that does exist has resulted from a natural or geographical resource located in these countries. In other cases, these countries' problems with infectious disease, natural disasters, or pollution mean that international partners are interested in helping them. However, the international partners often find little indigenous capacity to tap for collaborative projects. This is not to suggest that these countries lack knowledge, education, or learning—it is simply that they do not translate that knowledge into the institutions or types of activities that many would recognize as science and technology.

3.3 Technology, innovation, and income levels

Technology affects human development through two major paths. Through innovation, it can directly affect human well-being by increasing functionality of existing means to reduce poverty and increase human capabilities. This is most evident through technological innovations in public health, agriculture, energy use, and information and communication technologies. Secondly, it can also indirectly affect human well-being by enhancing productivity and thus economic growth and incomes. This productivity enhancement may be seen through increased output of workers, higher agricultural yields, and heightened efficiency of services, while the higher incomes can again help people meet their basic needs. In addition, productivity enhancement provides important assistance in overcoming the barriers of low-incomes and weak institutions.

STI capacity has been shown to be positively correlated to economic growth, although the extent to which the two are linked is not clear. Many fields of science have little connection to economic development, and many areas of economic growth do not rely on STI. Human development itself strengthens technology development. One cannot talk about the productivity of industries, agriculture, or the services sector without referring to the critical components that make up such systems: people and their knowledge.

An important force driving the adoption of technology, whether old or new, is higher income. Yet it is circular logic to argue that technology depends directly on higher incomes, when in fact technology may be a cause, and not a result, of increased consumption. An important additional point is that innovation itself may not necessarily be driven by higher incomes, but may be a result of the adoption of certain technologies.

In summary, while it may help for a country to be richer, the evidence is fuzzy about whether this is a result or a cause of technology use and diffusion. Indeed, innovation may thrive on increased resources being thrown at the problem, particularly finances, but it is no guarantee that innovation will occur when this happens. However, in developing countries, innovation through STI will almost certainly not occur without funding. In this sense, funding is necessary, but it is certainly not sufficient for STI. The specific institutional mix of actors—individuals, firms, the state, and other organizations—all determine the milieu in which a technological innovation occurs.

The mutually reinforcing thrusts of human development and technological development serve to create a basis for a relationship between certain technologies and specific aspects of human development. For example, medical breakthroughs are linked to basic health, cheaper medicines, and lower mortality rates; higher food production is linked to better seeds, water sources, and more efficient and less toxic fertilizers); ICTs serve to enhance information and participation through telephone, radio, TV, fax and increasingly through computers; and finally, manufacturing technologies drive industrial expansion, employment and worker incomes.[2]

Yet, in addition to this seeming one-to-one relationship between certain technological advances and human development, each of the separate technological advances acts to reinforce the others. This is especially visible in medical technologies, where breakthroughs in genetics, coupled with computing advances, has opened up a world of pharmaceutical discovery, development, and manufacturing. Similarly, advances in ICT technologies have themselves fuelled further gains in the agricultural, manufacturing, and the services sectors.

3.4 Technology transfer as an outmoded concept

The classical view that presents an image of technological flows from the industrialized to the developing countries is being replaced by new approaches that emphasize complex interactions between nations. This systems view allows countries to think strategically of different ways in which scientific and technological knowledge is acquired, retained, diffused, and improved. The 1960s and 1970s generated a somewhat utopian view of technology transfer from industrialized to

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[2]. Many medical breakthroughs can potentially raise the cost of diagnosis and treatment, so we tread a fine line in the management of technological innovation once it occurs.

industrializing countries, but subsequent evidence has highlighted the over-simplistic models on which these visions were based.

While technology development is a relatively uncluttered and uncontested concept, the same cannot be said for technology transfer, which is neither costless nor straightforward. The more recent evidence on technology transfer is hopeful. On the one hand, transfers from developed to developing countries are limited due to a variety of causes. On the other hand, this situation forces both developed and developing countries alike to be concerned (perhaps for very different reasons) about how to spur endogenous innovation in developing countries, while still benefiting from the existence of and access to mature technologies worldwide.

International technology policy discussion continues to be wrongly focused on new technologies without considering the economic context in which these technologies could be applied. Similarly, international policy debates have tended to focus on potential barriers to the transfer of such technologies and ignored the fact that new technologies can hardly be of value in economies that do not have basic technological capabilities to absorb them.

In order to achieve MDGs, mature technologies such as mechanization of small farms, small-scale irrigation and potable water installation, small energy systems, rural roads to market, and basic communications and computer facilities will be most helpful. Similarly, technologies that enhance the productivity and profitability of SMEs would provide wider employment opportunities and better income equity. The reorientation to appropriate technology in the developing world would not only require increased funding from developed countries, but also a paradigm shift from political leaders and intelligentsia including STI elites in developing countries from investing prematurely and wastefully in high and cutting-edge technologies and related R&D in an imitative way. There need to be creative approaches to blending new technologies with old ones to provide the best possible solutions to pressing problems. Learning from countries that have had success in technological transitions would also improve South-South cooperation.

In essence, technology, taken in its broadest sense is a knowledge system, only one of whose elements is actual physical technology and equipment. It relies heavily on modes of learning, adaptation to new technologies, educational systems, STI and industrial policies, the nature and composition of the private sector, and the capabilities already inherent in the public sphere.

Moreover, technology relies heavily on the demand side: a strong demand for technological solutions directed to local capabilities can be one of the strongest incentives to learning accumulation. It also depends heavily on the flows of knowledge, resources, and people between public and private domains of knowledge and the mechanisms by which information on specific innovations is shared, developed, commercialized, and diffused. The incentive structure that causes different parties to become involved and stay committed to technological enterprises also needs careful attention from policymakers.

Furthermore, the technological knowledge system, far from being monolithic, is a set of interconnecting networks embedded in a wide array of global institutions. These networks include communications (both written and verbal), knowledge (both tacit and explicit), and actors. The complexity of the interaction of these networks means that no single group (governments, NGOs, corporations) controls the outcomes. Defining the scope and use of new technologies is influenced heavily by the dynamics of these networks. Countries then are not in full control of how they channel technologies to certain domestic sectors, nor do they control the markets where they will sell technologies once they are developed. Understanding the dynamics operating at regional, national, and global levels is important to moving the development agenda into the twenty-first century.

3.5 Technological learning and public policy

3.5.1 Innovation systems

The process of technological innovation involves interactions between a wide range of actors in society, forming a system of mutually reinforcing learning activities. These interactions and the associated components constitute dynamic "innovation systems" (Freeman 2002). Innovation systems can be understood by determining what varies in the institutional mixture—that is, what is local and what is external. Indeed, "systems" may suggest a closed entity, but one needs to think of "open" systems, whereby new actors and institutions are constantly being created, changed, and adapted to suit the dynamics of scientific and technological creation. On the other hand, the notion of a system offers a good framework that conveys the idea of the existence of parts, their interconnectedness, and their interaction and changes over time. Thus, within countries, the innovation system can have some common features, but can also have regional variations where technological dynamism is more visible. Regional variations in innovation levels, technology adoption and diffusion, and the institutional mix are significant, even in the most developed countries.

In addition to comparing the innovative capacity of countries, policy attention is shifting to regions within countries. India is a case in point. While there are plenty of skilled scientists, engineers, and doctors around the country, Bangalore is identified as the prime innovation hub, and Hyderabad as an emerging one. This is a case where skilled professionals in a developing country gravitate to regions with adequate facilities and enabling environments. Thus, the national policy environment, while defining the early basis on which these city centers became competitive, has given way to an increasingly innovative local policy and entrepreneurial climate that have generated significant computer, telecommunications, and, more recently, pharmaceutical and biotechnology outputs.

While the it is unclear as to whether it is the local state governments or the private entrepreneurs who have been more responsible for this process in India, most people agree that large and small firms, universities, and government laboratories have all played a part.

It has been advocated since long ago that government, private sector, university, and research institutions are important parts of a larger system of knowledge and interactions that allow diverse actors with varied strengths to come together around common broad goals for innovation. In many developing countries, the state and private sectors have varying capacities. The state often has the greatest capabilities—built up through a history of import-substitution policies when the public sector had a predominant role in the country's economy. Meanwhile, private sector capacity for adapting tacit knowledge and mature technology, and for absorbing new knowledge, has varied by country, region, and sector.

Universities, for the most part, have languished across the developing world, with an unclear mandate, limited funds, and a lack of flexibility to meet either basic needs (often dealt with by public research centers in "mission mode") or promote competitiveness (dealt with by the private sector or government training institutes). It should be stressed, however, that in vast regions of the developing world, namely Latin America, universities, and more specifically public universities, are responsible for more than 75 percent of all R&D activities (Arocena and Sutz 2001).

However, universities often lack both the resources and the demand from a sound productive economic sector in their home country that is eager to benefit from the knowledge these universities and their students might create. They suffer, thus, from a "loneliness syndrome" from which they cannot escape alone. To reverse this syndrome is one of the real challenges for development, one that cannot be fulfilled by pushing universities to change while everything else remains the same. A better approach is to channel energies within the university environment to fulfill a combined research, teaching, and application mandate, with different types of universities taking on different challenges, and with government and industries engaging in effective interaction with these different universities.

This is not a path without dangers, however. One potential problem is that the pendulum could swing too far in the direction, where universities simply become outposts for government or private sector service functions, or only engage in applied research. Incentives need to be calibrated so that as universities continue to produce knowledge, they also seek to transfer that knowledge to useful applications where appropriate. Any informed science, technology, and innovation policy needs to account for the fact that universities need continue to have local relevance while still fulfilling broader mandates of education and knowledge acquisition and diffusion.

It is perhaps easier to identify what does not make for innovation, rather than what does. Importantly, even if local environments are important for technological innovations such as malaria vaccines, wireless internet distribution and access, or using Global Positioning System (GPS) technology for farming or fishing, they are all faced with the challenge of keeping up with increasingly stringent global regulatory environments.

In the pharmaceutical industry, for example, these regulations may be reflected in food and regulatory rules—and certification for manufacturing facilities and output quality—that may be administered differently according to new trading rules and WTO guidelines. In the information technology and telecommunications industry, these regulations may take the form of pressure from network externalities and the need to tie into critical mass usage of a certain system or standard. Thus, neither innovation alone, nor even cutting-edge technology, determines the eventual market uptake of the technology or the ability to keep up with regulatory pressures.[3]

Both the East Asian and Western successes are characteristic of the "right" mix of institutional, technological, and organizational elements that have given rise to STI (Lall 2000). The challenge for underdeveloped countries is to rethink this powerful approach that has worked elsewhere and to adapt it to their specific conditions. Developing countries must also bear in mind the factors that make this approach particularly well-suited for development purposes: it explicitly acknowledges the political as well as institutional and cultural aspects of innovation processes; it stresses the importance of interactions between actors and organizations; it takes into account multiple actors with different roles and goes beyond the dichotomy "state or market," making room for more "bottom-up" and associative networks; and it highlights user-producer interactions, assigning an important role to usually neglected actors such as workers or consumers.

In Latin America, many governments have collapsed in a spiral of macroeconomic troubles fuelled by social deprivation, falling confidence levels in both economy and polity, and low investments in institutionalizing learning successes. Innovation in the sense of new products, processes or institutional creation, has been at best sporadic. Thus competitiveness has fallen, and with it, the ability of governments to provide for basic needs has also fallen. Undoubtedly, capital flight from the region and the difficulty in attracting new investments has exacerbated existing rigidities. Yet, countries like Brazil and Mexico have made systematic attempts over the years to upgrade industry, access new technologies, and invest in education and training particularly for the working class. However, the downside is that education and training, particularly when higher education is taken into consideration, continues to be extremely elitist, as far less than 20 percent of the young people in higher education age reach tertiary studies, against the 50 percent average in OECD countries. Regional attempts at science, technology, and broad-based innovation exist; but they need to be revitalized and given a broader mandate for change.

3.5.2 Government as a learning facilitator

Government plays an important role as a facilitator of technological learning. But most governments do so in an implicit way. Facilitating technological change will

[3]. A classic US example is the standoff between Betamax and VHS, and we know which one won the video standard race, even though many agreed that Betamax might have had superior technological advantages. In the developing world, more serious implications arise when the technologies and their applications affect food, health, or education. STI policy's inability to promote wider diffusion of oral rehydration therapy (ORT) or the Internet in the developing world is cause for concern. The need for commercialization and distribution of these technologies may need country-by-country analysis and policy support.

require governments to act as active promoters of technological learning. There are at least three ways to think about the government's involvement in promoting technological learning: market mechanism, technology, and time.

The first, the market mechanism, deals with the demand and supply side of technology development. Although STI policy is often thought of more narrowly as a manifestation of the supply side, it is, in fact, a critical player in demand-side policies (more traditionally thought of as industrial policy, broadly speaking) fashioned by technological capability.

Even if indigenous capabilities exist, they may remain un-commercialized. Those who envision and design the products and processes leading to innovation need to remain connected to the task of commercialization. It is often insufficient for inventors to hand over their findings to the private sector because the proof of concept itself is not easily transferred. Nor can those commercializing an innovation stay aloof from STI research personnel once a project is past the prototyping stage. The web of capabilities stays enmeshed, and effective "systems" of innovation use a variety of skills from many sources at every stage. No one component stays isolated, seeking either appropriate supply or demand of inputs. Thus, STI policies become a core of the industrial, agricultural, and services policies and create explicit links between market and non-market institutions—for example, linking universities and state R&D laboratories to unions, community development organizations, and firms. Technology licensing offices may be one form of link between universities and firms, while agricultural extension services may provide a link between farmers and seed or animal vaccine firms. The extension approach has been successfully applied in advanced countries to both the agricultural and the manufacturing sectors, and it is a path that should be encouraged in underdeveloped countries. However, successes and failures, particularly in agriculture and industry, must be documented. These "good" learning practices need to be institutionalized into structured relationships between market and non-market organizations.

The second aspect of government facilitation of technological learning deals with how it can create technology flows. These may be transfers of foreign technologies, domestic diffusion of foreign technologies, as well as indigenous R&D efforts to innovate. While industrial policy usually covers these, STI policy often does not, leaving critical elements of acquisition, absorption, and generation of technologies with no immediate link to the marketplace. In particular, those countries where STI policies directly form the basis for industrial and agricultural policies are at a greater advantage in terms of rapidly changing external economic conditions, or where the technological frontiers of the sector are moving rapidly outward. This is particularly true of advances in the medical sciences and computer systems.

In essence, the role of the government in all its policies needs to be to enhance learning by strengthening a variety of learning institutions such as schools, universities, government research organizations, firms, and community-level technology diffusion initiatives. The development equivalent of the "triple helix"—with a mix of firms, universities, and government—can play a significant role. However, community development organizations, which have been so important in environmental, primary health, and agricultural realms, are important sources of innovation and diffusion, but are also the articulation of future directions of governmental STI policies. Particularly important in STI policies for development are government technology procurement (GTP) tools. A multitude of countries have created and nurtured entire new industries or lagging old ones on this basis. In so doing, there have been many examples of gradual technological capability being built and of firms becoming competitive globally over time.

3.5.3 Science, technology, and engineering education

Indigenous capacity needs to be created by training scientists, technologists, and engineers in relevant fields. Such a strategy will help address local concerns (health, food security, infrastructure, manufacturing). In today's world, scientific and technological advances dominate economic progress. In promoting S&T education in developing countries, therefore, universities can play a vital role in development, by both developing the country's national innovation system as well as its human resources. It is therefore imperative for universities in developing countries to focus on the engineering sciences and well as other advanced technological fields. While not all countries need to become adept in all S&T areas, it is necessary to identify and focus on certain key national priority areas and design an action plan accordingly.

The increasing presence of multinationals and foreign firms in developing countries provides an additional impetus for these countries to focus on technical education, since these organizations require increasingly skilled and educated workers for competitive reasons. Efforts to participate effectively in the global economy, made through trade, FDI, and firm location, have made it necessary for developing countries to hire and train more educated workers in local firms as well, so that new technology can be adopted and adapted.

S&T education has traditionally been accorded low priority in most developing countries (with the notable exception of some East Asian countries). A mistaken (but common) view has been to view S&T as a luxury that is irrelevant to the immediate needs of a developing country. Another misconception is that technology destroys jobs. However, technology has merely *changed* employment patterns, in that it has (1) reduced the number of jobs in production of goods relative to services, (2) increased the relative importance of high-skill occupations within sectors, and (3) broadened skills within occupations.

3.5.4 Enterprises as the locus of learning

While learning occurs in a variety of institutions, business enterprises are the most critical locus at which learning of economic significance takes place. In other words, technological capabilities of economic importance accumulate at the enterprise level. Even the most state-friendly explanations of economic development in the academic, empirical, and policy literature acknowledge that while government acts as a facilitator of institutionalizing knowledge acquisition, the locus of that learning rests in enterprise—both public and private. The structure of industrial organization and the nature of the production process itself provide returns of varying amounts based on input factors of skilled labor, robust management practices, other factors of production. The returns to deliberate investments that build innovative capacity show varying returns based on the resource-base, institutional environment, and other factors.

Enterprises, particularly those involved in manufacturing, show great promise as centers of upgrading technology and organizational practices for developing countries. In addition, those enterprises that develop capabilities in design, research, and product development also establish themselves along a global value chain that allows for more opportunities and increased profit margins through innovation and product differentiation. Yet, manufacturing remains a core skill important to long-term enterprise learning. Historically, industry has been a critical source, user, and diffuser of technological progress and associated skills and attitudes. Industry is therefore not just an input, but also a critical node in the development process. Both the fact that manufacturing can experiment with endless permutations of inputs in the production process—as well as the fact that it can benefit from the increasing returns to scale of many industrial technologies—gives manufacturing a special place along the long road of economic development.

Furthermore, manufacturing is also an engine of innovation because relative to formal R&D processes, manufacturing actually affords a much greater opportunity for experimentation in engineering and production, as well as innovation in the procurement, quality, and other management aspects of the organization. Furthermore, enterprises with manufacturing capability have been critically important historically not only for creating the new products, but also for diffusing new processes, organizational practices, and learning opportunities for the labor force. In turn, manufacturing enterprises act as a locus for spreading innovation outwards into the agricultural and service sectors.

At the outset, the scope of an enterprise is to master imported technologies and to gradually improve upon them in ways that benefit local production. Although this is called "imitation," is not an entirely straightforward process of replication (Kim 1997). It involves complex learning activities and interactions with other players in the economy, including the original source of innovation.

Perhaps most importantly, from an institutional and learning standpoint, is the historical role played by manufacturing enterprises in spearheading institutional changes, particularly financial and legal changes, to support production processes worldwide. The extent to which these national institutions conform or diverge from global practice or those from first-mover countries also defines the extent of convergence of learning speeds and economic development across countries.

This is not to make the case that we need homogeneity of institutions—in fact, evidence shows the opposite. To the extent that these national institutions are compatible with or open to other extra-national institutional changes, such as regulatory changes or trading rules, the more likely it is that national governments and domestic enterprises can make decisions that quickly transform local conditions to be more in line with the external economic and geopolitical climate. The modernizing environment that was created by governments and firms alike in East Asia, by exposure to severe competition in export-oriented markets and by the disciplinary measures hoisted on corporations by the governments of these countries, accelerated the investments made and the type of learning that took place across manufacturing enterprises in these countries.

However, the extent to which enterprises, and particularly SME, can play a role in innovation and social well-being is largely dependent on the internal skills they have at their disposal. These skills are not only important for internal R&D, but even more important for making sound decisions regarding imported technologies. One of the biggest challenges for developing countries is the scarce participation of researchers in enterprises. Among Latin American countries, Argentina, Brazil, Chile, Mexico, and Uruguay have only 20 or 30 percent of their researchers working in firms, compared with 70percent in the United States. Programs for helping SME to hire young engineers and other S&T professionals, like those implemented in many European countries, can be critical to redress this weakness.

3.5.5 Technological convergence and learning

Technological learning involves bringing together a wide variety of disciplines, research cultures, and traditions. It is largely a product of convergence between different technological traditions (covering modern and traditional knowledge) and therefore demands significant investment in coordination and management. A major hurdle preventing the commitment of the science, engineering, and technology community to sustainable development is its preoccupation with maintaining and strengthening its own disciplinary turf. Achieving the MDGs requires a cross-disciplinary and holistic approach. Science, engineering, and technological knowledge is not created within a single office or laboratory. An active process of sharing insights, problems, issues, experimental approaches, and outcomes creates knowledge. This occurs among people who have common interests, but they are not necessarily people within the same field of science, engineering, or technology.

In fact, the most interesting findings are increasingly emerging from the nexus of two or more fields of science and technology. As STI institutions are created, nurtured, and encouraged in developing countries, it is important to tie their missions to specific problems and to enable a rich cross-sectoral exchange of knowledge to occur. Care should be taken not to create a “physics center” that is physically distant from the chemistry laboratory. The same is true for biology and materials sciences. The sciences and the technologies emerging from these disciplines grow by interaction. The social sciences are also an integral part of this process, creating a context in which to understand the source, modes of creation, dissemination, and impact of STI.

Promoting the convergence across many areas of science, engineering, and technology means encouraging organization that enables flows of information among them. This can be done using ICT, as well as by pointing out the success stories of universities and research institutions that have "de-institutionalized" their departments and encouraged cross-sectoral research. A specific way to promote convergence across STI is to develop a particular style and method of technology assessment like the one performed by NOTA (the Netherlands Office of Technology Assessment), where social and economic goals in need of innovation are translated into R&D programs.

The biggest obstacle to cross-sectoral learning is the exaggerated pattern of narrow specialization that nowadays characterizes the search and application of knowledge. Encouraging the organization of research efforts by problems and not by disciplines, both in developing and developed countries, is a good way of fostering cross-sectoral learning. The problem is that researchers usually do not know how their knowledge can be utilized for addressing developmental problems; it is thus the responsibility of policymakers to devise strategies to help researchers find out how they can best contribute to development.

CONCLUSION

Economies change over time through processes of social learning that involve the generation, use, and diffusion of new knowledge. New knowledge is therefore the currency that drives economic systems. This section has emphasized the role played by government and enterprises in the process of technological learning. While government acts as a facilitator, technological capabilities accumulate in enterprises. However, this interactive process is incomplete without the inclusion of knowledge-based institutions. The emerging picture of economic transformation is no longer a world in which singular macroeconomic interventions trigger the process of economic adjustment. What is becoming increasingly evident is that economic transition involves a mosaic of complex interactions involving a wide range of players. The role of knowledge expressed in the form of technological change and institutional innovation lies at the center of this process of economic transition.

4. KNOWLEDGE IN A GLOBALIZING WORLD

INTRODUCTION

The process of technological innovation has become intricately linked to the globalization of the world economic system. The shift from largely domestic activities to more complex international relationships demands a fresh look at policies that seek to integrate science and technology into economic strategies. Despite the increasing globalization of technology, the involvement of developing countries in producing new technologies and innovations is almost negligible. The production of technological knowledge is concentrated in industrialized countries. There are thus major variations in the generation of knowledge not only between developed and developing countries, but also between developing countries themselves.

Globalization of technology can be classified into three categories, according to the ways in which technological knowledge is produced, exploited, and diffused internationally: (1) the international exploitation of nationally-produced technology, (2) the global generation of innovation, and (3) global technological collaborations (Archibugi and Pietrobelli 2003)

The first category, international exploitation, includes innovators' attempts to gain economic advantages by exploiting their technological assets in foreign markets. Multinational corporations (MNCs), as the agent of this type of technological globalization, often maintain their national identity, even when their technologies are sold in more than one country. MNCs exploit their technological assets in overseas markets by: (1) selling their innovative products; (2) selling their technological knowledge through licenses and patents; and (3) establishing local production facilities through foreign direct investment (FDI).

The second category, global generation¸ refers to the situation when technologies are produced by single proprietors on a global scale. Again, multinational corporations are the key players in this category, which utilize the international but intra-firm networks of R&D labs and technical centers. Three main approaches of MNCs can be identified. First, the center-for-global approach, when the core strategic resources—such as top management, planning, and technological expertise—are located at the headquarters. Second, the local-for-local approach is adopted when the firms' subsidiaries develop their own technological knowledge and know-how to serve local demand and preferences. The interactions among subsidiaries are limited in terms of the development of technological innovations. The third approach is local-for-global, in which MNCs distribute their R&D activities in multiple locations.

The third category, global technological collaborations, has become more significant in recent years. Technological collaborations occur when two different companies establish joint ventures or formally agree to develop technical knowledge and/or products, while maintaining their own respective ownership. Many partnerships are among firms located in different countries, thus contributing to technological globalization.

4.1 Utilizing existing technologies

4.1.1 Enhancing capacity for adapting available technologies

Focus on "fast follower innovation strategies" aimed at making full use of existing technologies. The area of information and telecommunications technologies (ICTs), for example, represents a unique opportunity for building capacity to utilize available development. A large part of the developing world has been unable to make effective use of the large body of scientific and technological knowledge available, some of which is embodied in ICTs (James 2002). There is ample historical evidence of the use of such strategies in industry and agriculture.

The Green Revolution, for example, entailed adapting varieties developed in the industrialized countries to local conditions in developing countries. The process was not merely relocating seed from one place to another, but involved extensive investment in local research. This was particularly necessary because agriculture is a knowledge-intensive activity. Changes in environment (involving biotic and abiotic stresses) as well as shifts in markets demands continuous investment in research and development. Developing countries can today benefit significantly from the use of existing ICTs and the large quantities of spatial information that can be deployed for development purposes.

ICTs have changed the way we view the interconnectedness of people, locations, sectors, organizations, educational content, and more. What ICTs have achieved is a new way of viewing how different industrial, agricultural, and service elements link together in ways that distinguish more than just the economic contribution of these different growth segments. They also challenge us to find new ways in which human efforts can enhance institutional life and sustain technological learning in developing economies so that gains in one area are automatically translated and multiplied as gains in learning in another area.

Nowhere is it more evident that innovation in technology affects human development than in the use of ICTs: (a) through increasing functionality of existing means to tackle problems in health, agricultural productivity, and energy use, and (b) by enhancing economic growth and income through higher productivity. Even without direct increases in income, ICTs have been shown to help development over and over again, in particular by circumventing barriers of income and educational access. It does not open all doors of opportunity, but more often than not, it appears to prop them ajar.

Generally, ICTs can be applied to the challenge of meeting the MDGs in at least three areas. First, information and communications technologies play a critical role in governance at various levels. Because of the fundamental link between technological learning and the way societies and their industrial transformations evolve, it is important to situate technological innovation and the application of ICTs at the center of governance discussions. Second, ICTs can have a direct impact on the efforts to improve people's quality of life through better information flows and communications. Third, ICTs can help to enhance economic growth and income through higher productivity. This can in turn have positive influence governance and the quality of life.

While there are many examples of the positive transformational impact of technology and information and communication technologies (ICTs) in particular, there is still much debate about how and to which extent their application relates to the achievement of social goals and economic growth. There is considerable interest in identifying ways of measuring the socioeconomic impacts of ICTs and their potential contributions to the implementation of the MDGs. Much of the information available on this subject has not received substantial policy attention, and as a result, popular claims about the impact of the ICTs on development continue to lack strong conceptual and methodological foundations.

In this context, the United Nations ICT Task Force is working on defining precisely how ICTs can be used to further the achievement of basic development objectives. Building upon the foundation provided by the MDGs and the indicators already developed by the United Nations, the Task Force is conducting a qualitative as well as quantitative analysis to explain the role of ICT in supporting each of the goals.

This exercise aims at mapping the role of ICTs in helping to achieve the MDGs by identifying a series of ICT-specific targets and suggesting possible indicators for measuring progress. The overall objective is to design a progress-tracking tool, which could be used to illustrate in practical terms how ICTs can help to meet the development challenges expressed by each of the MDGs. The initial results of this work were presented at the World Summit on the Information Society in December 2003 in Geneva. Work is continuing, in particular by identifying a group of pilot countries where the proposed indicators could be used to help governments assess their national progress in using ICTs for achieving the MDGs.

The benefits of the new technologies are the result not only of an increase in connectivity or broader access to ICT facilities *per se*, but more importantly accrue from the facilitation of new types of development solutions and economic opportunities that ICT deployment makes possible. When strategically deployed and integrated into the design of development interventions, ICTs can enable development resources to go that much further by facilitating the development of cost-effective and scalable solutions.

Networking technology can be deployed to enable developing countries to benefit from new economic opportunities emerging from the reorganization of production and services taking place in the networked global economy. It is believed that ICTs will increasingly become one of the main enablers in the pursuit of poverty alleviation and wealth creation in developed and developing countries alike. At the same time, as a facilitator of knowledge networking and distributed processing of information, ICTs can be used to foster increased sharing of knowledge, including new models for research and development driven less by "brain drain" and more by "brain circulation."

A fundamental problem in regard to enhancing scientific and technological capabilities is that researchers in developing countries often suffer from a distorted reward system. If they work on problems of interest to international science, they will probably be able to have a harvest of published production, however far the problems they research may be in relation to development. However, if they work on important problems for their country or region, they risk not being able to publish their findings in mainstream journals or not being invited into intellectual circles of international standing. One important way to create incentives for research on development needs, then, is to rethink and "endogenize" the academic reward system. A faster way to create incentives is to organize calls for research proposals directed to solve developmental problems, particularly those that affect the poor. This does not mean scholars should concentrate exclusively on "applied" research. After all, real-world problems do not come organized by type of research, and more often than not, a variety of knowledge types is necessary to solve the very complex issues that affect deprived populations.

Another significant problem in developing countries is the absence of demand for value-added and more sophisticated technological activity. One of these technological activities is R&D as it relates to enterprises' collective learning functions—that is, their organizational path to assimilating and innovating new technologies. If this important function is left unattended, enterprises remain largely dependent on imported technologies that are expensive and are not suitably adapted for local conditions. If demand for future high-level technological activity is not transmitted to enterprises through appropriate policies, countries run the run the risk of only importing equipment without the complementary generation of domestic innovations. One element of successful interventions in East Asia has been precisely this type of demand-side boost, which complements the market mechanism, to create incentives for enterprises to invest in R&D and raise levels of R&D spending significantly.

Yet another problem for less developed countries is the relative isolation of their research institutes and laboratories. In particular, commercialization of R&D faces problems of scaling up from laboratory findings to industrial output. There is no easy solution for this situation except to create opportunities for R&D laboratories in the public domain to work with private industry. In Taiwan, for example, R&D consortia are formed to foster cooperation between various laboratories in the government-funded Industrial Technology Research Institute (ITRI) and local SMEs to transfer technologies and develop innovative processes and products (Amsden and Chu 2003).

Industry associations such as Taiwan Electrical and Electronics Manufacturers' Association (TEEMA) were involved in identifying interested enterprises to join R&D consortia and in performing administrative work for the consortia that were established. These R&D consortia are formed to overcome the size limitations of SMEs and to develop the kind of economies of scale for innovation that are usually only enjoyed by larger firms. The subjects to be researched and developed by consortium members vary, including products, process technologies, and even technical standards. Private companies spinning off from ITRI and some of its laboratories successfully commercialized new and innovative products resulting from joint R&D activities (Hsu et al. 2003).

Box 6: R&D consortia and spin-offs in Taiwan

In Taiwan, there is an explicit strategy to blend private and public sources of knowledge with the view to commercialization through group R&D efforts. More than 30 R&D consortia have been formed in Taiwan since the 1980s to transfer technologies and develop electronics and opto-electronics materials, as well as computing and communications products. Examples are laptop computers, high-definition televisions (HDTVs), videophones, laser faxes, broadband communications, digital switching devices, satellite receiving stations, and smart cards.

There are examples of private enterprises in the ICT industry spinning off from government-sponsored research institutions to facilitate technology transfer and diffusion. United Microelectronics Corporation (UMC) was the first of a series of spin-off ventures from Taiwan's government-funded Industrial and Technology Research Institute (ITRI) to establish private-sector semiconductor capability. Established in 1980, UMC was a spin-off from the pilot fabrication operations of Electronics Research Service Organization (ERSO), one of ITRI's laboratories. One of the world's first silicon foundries, Taiwan Semiconductor Manufacturing Company (TSMC), was created by ITRI in 1986 as a joint venture with the Dutch multinational Philips and a group of Taiwanese firms, with the support of the Taiwan Development Fund—thus creating a new breed of world-class enterprises playing an important role in facilitating technology learning and transfer.

An earlier example of new product consortia/alliances in Taiwan is The Taiwan NewPC Consortium (TNPC). With the assistance of the Computer and Communication Research Laboratories of ITRI, TNPC was formed comprising local manufacturers of PC and related computer products to transfer technology from leading IT firms including Apple, IBM, and Motorola in order to make PowerPC microprocessors and products using such chips, which challenged Intel-chips based products. More recently, the Information Appliances Alliance (IAA) was formed (with the assistance of the Office of Committee for Information Industry Development and Market Intelligence Center under the auspices of the Ministry of Economic Affairs). Its aim is to transfer from foreign leading companies the components, hardware and software technologies required to local manufacturers in the production of information appliance for sale in international markets. As many information appliances are still in their early stages of development, IAA was established to strengthen the links between Taiwanese manufacturers and overseas organizations competing to define their architectural standards.

Source: Poon, 2002.

Through such public-private collaboration of joint R&D, developing countries such as Taiwan were able to enter a product market right at the beginning of the high growth stage. The innovation strategy had therefore been changed from one of "catching-up" to one of being a "fast follower"—able to keep at the leading edge of technology and remain responsive to shifting market trends. Even the "fast follower innovation strategy" is ineffective as a strategy to upgrade technologically in face of the changing nature of more dynamic industries that are essentially an integration of selected industrial sectors. A good example is the ICT industry, which represents an integration of the information technology, consumer electronics, and the telecommunications sectors. To overcome such a problem, the government in Taiwan assisted local firms to form new product consortia and alliances to ensure that Taiwanese manufacturers were not left out in the initial stages of developing novel products or new architectural standards considered to have the potential to become popular.

4.1.2 Attracting foreign direct investment

Create incentives and promote an enabling environment for foreign direct investment, which is of the most important mechanisms for transferring technologies across nations. The global rules for FDI have changed, as have the modes in which they are most useful. Global production systems have changed the ways in which investments flow and how they can be made available in certain parts of the world for long-term growth instead of rapid flight to new, cheaper locales. FDI needs be used as a vehicle for carrying tacit knowledge as well as assisting enterprises at the frontiers of world technological learning (Liu and Wang 2003).

Under the right conditions, foreign companies can contribute to local industrial development through FDI by providing capital, markets, and technological and business skills. They can also increase the local content of their products through subcontracts with local SMEs. FDI leads to subcontracting, original equipment manufacturer (OEM) arrangements, and even own design and manufacture (ODM) arrangements—giving opportunities for local firms to imitate and learn from the parent companies or contractors that give out production orders.

As such, FDI should be promoted. It is undoubtedly the case that countries with robust infrastructure, a highly trained workforce, or large domestic markets are better able to negotiate to extract maximum value from foreign companies, particularly multinational corporations (MNCs). Successful experiences show that a strategy for promoting FDI that will contribute to development should target specific sectors and activities. For less developed countries, a good target is commodity diversification and complementary reforms in global trading systems to reform tariff rules that impose an economic penalty on countries that add value to their local material for export.

4.1.3 Upgrading technological capabilities and systems

Develop strategies that allow firms and research institutions to upgrade their technological capabilities and move up the innovation ladder. To move from the position of being fast followers to technological leaders possessing the capabilities to undertake basic, applied, and pure scientific research, some East Asian developing countries have now adopted an intermediate position of pursuing a "technological diversification" innovation strategy. This approach builds on the existing strength of their process and prototype development capabilities, adaptive engineering, and detailed design (Lall 2000). By technological diversification, the late developing firms recombine (mostly known) technologies to create new products or services and expand the company technology base into a broader range of technology areas. This is an attempt to reap technology-related economies of scope (Ernst 2003).

With a reasonable level of technological expertise and a good supply of lower-cost R&D personnel, some developing countries are now able to attract MNCs to outsource to the former some of their R&D activities. These are more established channels for local firms in developing countries to learn and upgrade technologically. Taiwan, South Korea, Singapore, and China are now primary locations where such R&D centers are set up. There are also specialized clusters in the Philippines, Malaysia, Thailand, Indonesia, and Vietnam where R&D centers are established by foreign capital (Ernst 2003; Chen, Liu, and Shih 2003).

Investing in long-term research capacity in the public sector is most successful when it is tied to specific missions. These can be responding to local issues, such as health or environment, or building local capabilities or resources, such as earthquake monitoring. A mission focus, particularly when it is tied to a threat (hunger, earthquakes, etcetera), can help to generate and maintain critical political support when funding is needed to renew budgets or to help disseminate knowledge to specific users. The challenge, however, is to sustain political support and public interest for more "normal" development problems, which have no short-term fixes.

Box 7: Benchmarking technological innovation

Each country's technological trajectory is unique, based on historical choices, circumstances, and different institutional forms. It is difficult to create comparisons that are useful. Nevertheless, considerable effort by a variety of researchers and policymakers has gone into the process of making comparative indicators robust. One such recent exercise has resulted in the United Nations Industrial Development Organisation (UNIDO) benchmarking industrial performance and its determinants for eight-seven countries between 1985 and 1998, where, for example, R&D financed by productive enterprises rather than total R&D is used as one indicator of industrial success. This benchmarking comparison is useful not only for countries to compare themselves to others. In the longer-term interest of building learning institutions, it creates incentive for requiring enterprises, universities, and governments to report and collect such data.

For instance, in 2000 and 2001, three countries—Australia, Canada and the United States—have published national surveys of research commercialization with comparable indices. This survey intends to give a snapshot of the innovative capability of a country and allows it to be benchmarked internationally. The information contained in the survey is aimed to give a measure of the commercial outputs being generated from research and includes metrics such as start-up companies, patents awarded, and licensing agreements and income.

Private sector capacity can be built in a number of ways, some of which are dependent upon the nature of the industry itself. In general, however, financial incentives to invest in research equipment or training can help to build long-term research capacity. Easing legal restrictions on cooperation among companies can help build networks for shared research. Changing intellectual property laws can help encourage firms to participate in international collaborations that may provide needed information and access to skills. Direct funding for a specific line of research, along with promises of procurement of final products, can also be an excellent way to promote long-term investments in private research capacity.

One way to work explicitly towards solving development problems while developing long-term capacity in both public (particularly academic) and private sectors is highlighted by an example from South America. A few years ago, the Venezuelan National Science and Technology Council developed a new strategy to foster long-term research capacity related to development goals. It consisted of selecting a few large complex problems and funding competitive proposals around them—encouraging interdisciplinary teams, including firms, to address different aspects of each issue. The selected problems included those associated with the oil industry, urban violence, and fighting against a virus that had attacked the cacao crop. The importance of this initiative in Venezuela goes beyond the results obtained: it points to shifting the academic reward system away from pure "paper counting" to prizing the ability to work on problems related to the nation's wealth and people's well-being.

4.1.4 Joining global value chains

Join global value chains by identifying market opportunities and niches. These opportunities will expand as production becomes more globalized. With fast pace of technological advancement and an increasing desegregation of the value chains, the global economy is now characterized by an integration of trade but, paradoxically, a disintegration of production of goods and services across firm and national boundaries. The global economy can now be seen as consisting of many product value chains which encompass a full range of activities—including R&D, design, production, logistics, marketing, distribution and support services—to bring a product from its conception to its end use and beyond. These activities are dispersed and carried out in an unprecedented number of developing and developed nations. Some activities along various global value chains (GVCs) command a higher proportion of value-added than others. To have a chance to climb up the technological development ladder, local firms in developing countries had to initially insert themselves in the GVCs and then gradually move up to engage in the higher value-added activities that contribute to product development and the creation of services along the chains.

An analysis of the value chain linkages provides insights into how these linkages facilitate or impede technological and industrial upgrading of the developing countries. It is therefore imperative for policymakers in developing countries to understand how and why existing GVCs structure and function are the way they are and under what conditions and in what ways these chains will change over time. Three major variables influence how GVCs are governed. They are the complexity of transactions, codification of transactions, and competence of suppliers.

The more complex the transaction between buyers and suppliers is, the greater the possibility for GVCs to be organized in one of the three network governance patterns—modular, relational, and captive value chains. GVCs will be organized in the form of modular supply chains if explicit codification schemes exist to allow easy exchange of complex information between buyers and suppliers, and if the suppliers are competent enough to receive and act on such codified information. If suppliers are not competent enough, buyers might have to keep the activities in-house, leading to more vertical integration (in a hierarchy), or outsource such activities to a supplier in the captive value chains that had to be tightly controlled and monitored. Alternatively, if a codification scheme in the form of known standards or protocols does not exist, buyers might have to rely on highly idiosyncratic methods based on intensive interaction to work with the suppliers in relational value chains.

Value chain governance patterns will change with a change in any of the variables discussed above. For example, if a new technology renders an established codification scheme obsolete and effectively lowers the competence level in the supply-base, one might expect modular value chains to become more relational. Should there be difficulties finding competent suppliers, captive networks or vertical integration would then become more prevalent. Conversely, rising supplier competence might foster a move of captive networks towards the relational type and better codification schemes might give rise to more modular networks.

4.2 Supporting under-funded research

Invest in under-funded research of relevance to developing countries. This is particularly important in fields such as public health, agricultural production, and environmental management. The area of pharmaceutical research is particularly affected by low-level of investment in problems that occur in tropical countries (Mrazek and Mossialos 2003). There are a variety of ways to channel resources towards pressing development problems that are currently under-funded. Bilateral donors could increase their official development assistance to fund research that meets local needs and which also passes scrutiny under peer review or other professional assessment. Donor support for research could also be funded as an international cooperative project where funds are provided to teams proposing to conduct world-class research that focuses on local or under-represented research activities.

Good practices could be provided to donors as a source of ideas to develop effective bilateral development programs. An example of good practice is Sweden's International Development Cooperation Agency (SIDA), which is active in many developing countries. In Cuba, for example, SIDA has helped develop a very effective domestic public health sector. This strategy could develop guidelines for national government officials to identify sectors, projects, and activities (at the local, national and regional levels).

Private companies already committed to being good corporate citizens for development could be further engaged in this regard. The first step would be to identify the companies and group them by the sector and region where they operate, by, among other things, reviewing membership lists of gatherings like the UN Global Compact and the U.S. Council for International Business. Targeted messages could be developed for each group. A forum could be provided for discussion between companies, governments, and others to identify specific areas of involvement. The UN Global Compact could be engaged to promote more actively public-private sector partnerships for development among its members worldwide.

Box 8: Funding research through cess

One way to target sector-specific technological needs is to introduce an industry-wide cess. For example, cesses on rubber, palm oil, and timber have been imposed by Malaysia to fund the Rubber Research Institute, the Palm Oil Research Institute, and the Forestry Research Institute, respectively. A cess on tea helps fund tea research and tea marketing in Sri Lanka. Hong Kong, Singapore, and Malaysia have each established a Construction Industry Development Board (CIDB). The funding for a CIDB comes from a compulsory cess on every construction contract. The revenue is used in capacity building and promotion of innovations in construction materials and techniques.

Apart from cess on export products, a cess on imports designed to mobilize funds for industrial development and STI is also logical, although it may face objection from the WTO. In order to encourage stock markets that are largely speculative in developed and developing countries to contribute to sustainable development in developing countries, a cess of 0.05 or 0.1 percent of the turnover of stock markets could be imposed and used to establish a global fund for sustainable development.

Another instrument is cross subsidy. A cess is imposed in Malaysia on the turnover of corporate electricity generators to fund rural electrification and renewable energy development throughout the country. In Malaysia's private sector housing developments, 30 percent of the housing units are required to be low-cost and are subsidized by the sale of medium- and high-priced units. This has prevented the identification of income level with location in urban centers and has assisted in arresting the spread of slums.

4.3 Forging technology alliances: The case of genomics

Promote research and development through international technology alliances that take advantage of the growing globalization of research. One of the newly emerging fields where science and technology can help contribute to the implementation of the MDGs is genomics, the new wave of health related life sciences energized by the human genome project and the knowledge and tools derived from it. It is primarily concerned with the generation, dissemination, and utilization of knowledge about the genetic attributes of organisms. Genomics requires the collective and analysis of massive amounts of genetic information. It has only evolved in the last few decades, on the heels of the information technology revolution, as a result of technological advances in analytical tools. Automated DNA sequencing and genotyping have made it possible to rapidly characterize large numbers of genes. The genomic knowledge can be used creatively in the development of new diagnostic technologies, treatments, and preventive programs.

There may also be direct economic benefits of genomics. Genomics will be a significant contributor to the biotechnology sector, which, although still in its infancy, has major income generating potential. The genomics-based pharmaceutical market is expected to grow from US$2.2 billion in 1999 to US$8.2 billion in 2004. It is not only the major economic players in the world that expect to benefit from genomics. Cuba, for example, has invested heavily since the 1980s in research infrastructure and manufacturing in biotechnology. The country has produced several successful products, including the world's only meningitis B vaccine, and holds at least 400 patents in the field of biotechnology. As a result, biotechnology is poised to become a major export industry in Cuba.

Box 9: International partnerships

International partnerships also provide avenues for funding research in neglected fields. One example is in operation in Singapore. It is the Novartis Institute for Tropical Diseases (NITD) established by the Swiss pharmaceutical company, Novartis and the Singapore Economic Development Board (SEDB). The primary aim is to create increased access to drugs (initially for TB and dengue fever) by making new drugs available to poor people in developing countries at the lowest possible price. This includes the possibility of differential pricing strategies (refinancing the research through higher prices in developed country markets) as well as additional partnerships for development, manufacturing (considering Singapore as a manufacturing location), and distribution of drugs. Novartis will patent novel compounds, but patents will not interfere with the goal to make drugs affordable for the poor.

This represents a new business model for Novartis, and a commitment to social responsibility. Novartis's interest is to broaden its research base in infectious diseases as well as to fulfill commitments to help find new treatments for diseases that are becoming an increasing public health challenge. This latter goal also fulfils the company's role as a good corporate citizen through its commitment to the UN Global Compact. The commercial interests are also clear for the company: it strives to refinance the institute's activities and make it economically sustainable—Novartis retains marketing rights for compounds that have a significant commercial potential in developed markets.

In terms of the Singaporean national interest, the SEDB desires to strengthen the country's technology platform, develop its manpower capabilities, and commercialize technologies and products arising from NITD. SEDB anticipates that such partnerships will have positive spin-off effects, potentially leading and contributing to the proliferation of local biomedical start-ups. This example could be replicated, even though persuading multinational corporations like Novartis to base a research institute is not so easy in other developing countries. Countries that have strong research capabilities can influence the decisions of such firms to base their operations in their territories.

A mentoring scheme where a developed country institution or firm becoming involved in an STI initiative with a more developed developing country could be persuaded to team up with a less developed developing country might be an answer. If the Novartis Institute for Tropical Diseases based in Singapore also involves Bangladesh where there are opportunities for human resource development through farming out of projects, movement of scientists, technology incubators and spin-offs. This would encourage Bangladesh to devote more resources to R&D. Such involvement will not take place without a mentoring scheme being organized through an international agency, which could identify potential partners and promote their collaboration.

Source: http://www.nitd.novartis.com/index.shtml

In order to reap direct economic benefit from genomics, countries will have to be active participants in the development and manufacture of genomics products. Countries that will benefit the most from genomics are those that have appropriate health products to improve the welfare of their populations and who are active in developing and supplying those products.

Box 4.6: Genomics technologies of benefit to the MDGs

1. Molecular Diagnostics: Molecular diagnostics involving rapid DNA-based diagnostic methods is identified as the technology with the highest impact for MDGs. Molecular diagnostics present a powerful set of methods to held combat child mortality. Each year, an estimated 11 million children die before reaching their fifth birthday. The major cause of infant mortality is infectious disease (especially pneumonia, diarrhea, measles and malaria). While improving the public health infrastructure for disease prevention is crucial to the achievement of the goal of reducing child mortality, it is also true that once disease strikes, diagnosis and treatment methods are essential. Rapid diagnosis of these diseases not only increases chances of survival, but also avoids the subsequent waste of resources on inappropriate treatments and helps prevent the further spread of disease.

2. Recombinant vaccines: Vaccines are compounds that stimulate the body to produce a protective immune response and thereby reduce the likelihood of serious infection. They are arguably the most important medical advances of the last 100 years. Advances in vaccine research are expected to have an impact on not only communicable diseases, but also on non-communicable ones such as cancer. In addition to being safer and more effective, recombinant vaccines may also prove to be cheaper than traditional vaccines because of innovative production methods and, in some cases, because improved storage characteristics do not require them to be refrigerated. Much progress is being made in recombinant vaccine development. Success stories in the fight against virus-related diseases in humans include development of a recombinant vaccine against hepatitis B. The majority of HIV vaccines currently in clinical trials are recombinant vaccines.

3. Vaccine and drug delivery: Closely related to advances in vaccines are improved methods of vaccine and drug delivery. Consequently, these new technologies will also serve to meet the fourth, fifth and sixth Millennium Development Goals: reducing child mortality, improving maternal health, and combating HIV/AIDS, malaria, and other diseases. Thousands of children die each year from vaccine-preventable diseases because universal vaccination is prohibitively expensive. Refrigeration ("the cold chain") is a major expense in all vaccine programs, in some cases accounting for up to 80 percent of the budget. Unsanitary drug and vaccine injections are associated with the spread of blood-borne diseases among the population, particularly HIV and hepatitis. It is estimated that 80,000 to 160,000 new cases of HIV/ AIDS, 8 to 16 million new cases of hepatitis B, and 2.3 to 4.6million new cases of hepatitis C are caused each year by the reuse of needles. The improvement in vaccine and drug delivery will enhance efforts to prevent and cure these diseases.

4. Bioremediation: Bioremediation is the use of bacteria or plants to clean up the environment. There are two main types of pollution threatening the health and well-being of human populations: organic waste and heavy metals such as lead, mercury, and cadmium. Bacteria can detoxify both. Plants can break down most forms of organic waste, but, with very few exceptions, are unable to metabolize heavy metals. They can, however, store harmful metals in their tissues, accumulating them over time, and therefore making it easier to collect, harvest, and even recycle metal waste. A reduction of pollution in water supplies and in the food chain will help to reduce mortality and improve health.

5. Female-controlled protection against sexually transmitted diseases (STDs): Genomics and other biotechnologies are enabling the development of a number of new forms of female-controlled protection against STDs, such as recombinant vaccines, monoclonal antibodies, and new approaches to the development of vaginal microbicides. These technologies are appropriate for the third Millennium Development Goal—promoting gender equality and empowering women—and they also have an indirect effect on reducing child mortality by improving maternal health.

The Canadian Program on Genomics and Global Health of the University of Toronto Joint Centre for Bioethics has identified the top ten technologies that would help improve health in developing countries within the next five to ten years. Research in many of these technologies requires a strong infrastructure in science and technology and an absorptive capacity that is lacking in many developing countries (Kim 1995). Although the target group to benefit from these technologies is in developing countries, research in some of these technologies can only be carried out in research environments found in industrialized countries

However, developing countries need to develop their own research capacity and participate in research (in collaboration with developed countries if necessary) if they are to find solutions to their problems. Developing domestic research capabilities will improve the country's capacity to absorb the technology and promote innovation in the field.

Of the ten technologies identified as providing the greatest health benefits to developing countries, some could be of immediate benefit to the poor and marginalized. They include technologies for the development of recombinant vaccines and vaccine and drug delivery that should have an immediate impact on the health of the rural poor in developing countries.

Of the technologies that may encourage local research, the three areas that stand out are: (a) bioremediation, which seeks solutions for problems found in many developing countries; (b) crops enhanced through new biotechnology tools; and (c) bioinformatics (where research is affordable and where the strong research infrastructure that is required for most research in biotechnology is not required). But very few developing countries have been able to formulate regulatory frameworks to deal with biotechnological issues and even fewer have the capability to carry out risk assessment on biotechnology products. Since public views on biosafety are molded by ethical and political controversies that obstruct the scientific evaluation of biotechnology and its products, it is essential that domestic capacity in these areas be strengthened in developing countries.

4.4 Looking ahead and planning for the future

Use foresight or forecasting as a method for establishing priorities in science and technology funding and policy based on analysis of current trends and expectations of future developments. This is particularly important for emerging fields such as genomics, new materials, and nanotechnology. Foresight studies and exercises have been conducted in many countries since the 1960s for a number of reasons (i.e., defense planning, prioritization, subsidization). Originally seen as simply a tool for identifying new technologies, foresight is now viewed as a way to aid in understanding the full innovation system.

The usefulness of forecasting depends upon first identifying the key participants; delineating goals, especially the balance between desired process and product outcomes;

defining how the foresight exercise would be used to stimulate innovation; and tying the foresight process into the national decision-making structure. In addition, a well-planned foresight process should consider issues of: governance and auspices; how the inherent uncertainty attending all innovative processes and future projection will be addressed; and perhaps, the means for evaluating the success of the foresight process as a whole.

Box 10: New materials

Materials are playing an increasingly important role in technological innovation. Research into materials is of vital importance for technological change and is particularly important for developing countries in achieving many of the Millennium Development Goals (MDGs). The development of low-cost building materials could for example boost construction of schools and shelter for the homeless in developing countries and help meet the MDGs of universal primary education. By providing a better living environment, low-cost building materials could contribute to the reduction of child mortality, the improvement of maternal health and ensure environmental sustainability. Moreover, making the benefits of new technologies available to developing countries (in cooperation with the private sector) requires the formulation of a strategy to ensure that they have access to the new technologies such as materials science.

A sound knowledge of science and technology of materials such as metals, semiconductors, polymers, ceramics and composites, magnetic and radioactive materials and their mechanical, electronic, ionic, and nuclear properties is necessary for the efficient utilization of materials in industry. Investment in higher education and research in materials science should form part of developing country's strategy for industrial development. Materials—both natural and man-made—are rich with properties that can be harnessed for modern technological needs and these properties are directly related to interactions at the atomic or molecular level. The study of underlying principles with respect to materials properties is essential for the development of new materials with desired properties suitable for new technologies.

The continual miniaturization of manufactured goods has now created nanoparticles, modern technological products significantly smaller than microparticles. While these products of nanotechnology could have positive and negative effects on public health and the environment, they form the cutting edge of research in materials science and provide opportunities for research for developing countries. Most of the opposition to nanotechnology has surfaced from the fear of advanced nanotechnology or molecular manufacturing that involves working with particles at molecular levels to make larger objects with atomic precision. The technology, although still in a conceptual stage, has generated negative reactions worldwide and concerns regarding its safety and possible abuse.

Most developing countries are in the tropics and the development of cells created from new materials and photo-electrochemical cells could help them formulate a strategy to exploit renewable sources of energy. Semiconductor research can lead to the development of new generations of integrated circuits and the solid-state memories used in ICTs, semiconductor lasers, light-emitting diodes, and light-detecting devices, and technologies like photolithography.

Newer ceramic materials such as piezoelectric ceramics, bioceramics, and electronic and electro-optic ceramics provide technologically important alternatives to traditional ceramic materials. Ceramic composites, ceramic coatings, ceramic films, and glass materials (including glass-ceramics, glass- ceramic composites, and conducting glasses) are important materials for industry. Special purpose polymers could be used in applications such as artificial muscles and light-emitting devices. Devices using solid-state ionic materials (such as solid electrolytes and electrode materials) form the basis for new types of batteries, fuel cells, and sensors. All these materials could provide developing countries with windows of opportunity in their path to economic development.

In order to be a part of the world market for new technologies, enterprises need to be aware of the opportunities being presented by technological development. Sometimes called "leapfrogging," the opportunity to enter a new market as new technology is being introduced is potentially an excellent way for enterprises in developing countries to join the global system.

Box 11: Spatial information for development

Spatial information is information related to a particular geographic location or area. For example, a home address is spatial information because it relates to a specific geographic location. The average household income for families in a particular region is also spatial information because it relates to that specific geographic area. Spatial information enables information to be viewed at a range of resolutions and allows information to be represented visually in map form. For example, the distribution of income across India (and everywhere else around the world) can be viewed as a grid, as has been undertaken by the Socioeconomic Data and Applications Centre at the Centre for International Earth Science Information Network. This information can be used to target areas for action, understand trends in demographics, and can highlight geographic regions that may not be able to be separated from other information at larger scales.

As the MDGs are defined with quantifiable metrics, it is possible for these to be represented spatially. This can be used not only to highlight the key areas for action, but also to monitor progress. By using spatial information, more targeted information is available to policymakers.

Spatial Information also plays a role in the successful achievement of Millennium Development Goal 7: Ensure environmental sustainability. For example, spatial information through Satellite or Airborne Remote Sensing can be used to understand natural land capability and water use efficiency. While irrigation, fertilizers, and other additions can improve farm yields, the long-term productivity and viability of an enterprise is dependent on the efficient use and conservation of the natural resources available to the property. These natural resources include the soil, surface, and groundwater resources, as well as native plants and animals; knowledge of how natural resources function and interact can help farmers use their water and soil resources more efficiently. The Committee on Earth Observation Satellites' report to the World Summit on Sustainable Development has catalogued many applications of remote sensing to environmental sustainability

New technologies are being developed for more accurate and timely estimation of risk. Spatial information about fire, rainfall (in both extremes causing flood and drought), wind, and salinity may help us better identify and estimate risk. A key use of this information may be by emergency services, terrorist response units, and disaster response teams. One of the main limitations to the use of spatial data is its interoperability (the limited compatibility of the systems used to process spatial data). The creation of open and extensible software application programming interfaces for geographic information systems (GIS) enables information sharing between different agencies and organizations. Specifying spatial information data standards can greatly assist with the development of spatial information infrastructure and the multiple uses of a single data set.

There is a great deal of information that is currently available to developing countries for use in making policy decisions, but is either not released (for example satellite data) or there are no systems or skills to manage the available data. Both capacity building and information donation/exchange would significantly address this issue.

Foresight can occur within business associations or be led by government or university groups. Specifically, for "information harvesting," for example, satellites and spatial information can provide new or finely graded information of significance to less developed countries. Geographical Information Systems (GIS) can be used to map out settlements and ecological implications for various policies. For entry into new markets, some biotechnologies and computer technologies have provided opportunities for rapid ramp up and learning in some developing countries.

Technology prospecting can provide the tools for developing countries to keep abreast of new developments. One way would be for researchers in developed and developing countries to identify methods, sources, and assessment tools for understanding new sciences and technologies as they emerge and to provide these tools to developing countries. Another possibility would be to establish a global database of information on centers of excellence where groundbreaking research is taking place. These can be the "places to watch" for countries, regions, and enterprises interested in tapping into and developing new technologies. A third way would be to create public-private partnerships that track, transfer, and train developing country consortia in technology prospecting and the application of technology to business.

CONCLUSION

Technological change has become intricately linked to the globalization of the world economy. Traditional technology policy approaches that were designed in the 1960s and 1970s need to be revised to take into account the globalization of technology. This section has emphasized the need to rethink technology policies in light of: (1) exploitation of existing technologies; (2) generation of new innovations; and (3) global technological collaborations. Strategies that seek to apply technological innovation to the MDGs will need to consider these three issues. Indeed, much of the technology that is needed to advance the MDGs is already available, so the priority for most developing countries is technology prospecting, which involves identifying useful technologies and markets for the resulting products.

5. INFRASTRUCTURE AS A TECHNOLOGICAL FOUNDATION

INTRODUCTION

One of the problems that hinder the alleviation of poverty in the developing world, and indeed the achievement of other MDGs, is the absence of adequate infrastructure services—transport, water, sanitation, energy, and telecommunications. Here we define infrastructure as the shared basic physical facilities necessary for the functioning of a community or society. The term infrastructure is broadly defined as the facilities, structures, and the associated equipment and services that facilitate the flows of goods and services between individuals, firms, and governments. Economic infrastructure includes: (1) public utilities, such as power, telecommunications, water supply, sanitation and sewerage, and waste disposal; (2) public works, such as irrigation systems, schools, housing, and hospitals; (3) and transport services, such as roads, railways, ports, waterways, and airports. Indeed, adequate infrastructure is a necessary, if not sufficient, requirement for enhancing the creation and application of science and technology in development. Infrastructure services include the operation and maintenance of this infrastructure. The provision of these services should meet society's needs in an appropriate environmental and economic manner.

5.1 Infrastructure services and economic development

Infrastructure affects economic development in various ways. It affects the production and consumption of firms and individuals, while generating substantial positive and negative externalities. Because infrastructure services are intermediate inputs into production, their costs directly affect firms' profitability and competitiveness. Infrastructure services also affect the productivity of other production factors. Electric power allows firms to shift from manual to electrical machinery. Extensive transport networks reduce workers' commuting time. Telecommunications networks facilitate flows of information. As an "unpaid factor of production," infrastructure effectively enables labor and other capital to gain higher returns. The availability of infrastructure may also attract firms to certain locations, which create agglomeration economies and reduce factor and transaction costs.

Infrastructure services also contribute to welfare of individuals. The availability and quality of infrastructure services, such as clean air, water supply, sanitation and sewerage, and transport and communications, serve as the basic requirements for living, and are a measure of an individual's welfare. Environmental amenities, such as parks, open spaces, and educational and healthcare facilities improve people's quality of life. Infrastructure services are also the means individuals can use to obtain other goods and services. The price of infrastructure services relative to other goods affects an individual's overall level of consumption, given budget constraints.

This analysis of infrastructure excludes the provision of adequate shelter. But basic transport is essential to supporting the provision of shelter, whether for the movement of people or goods, the latter of which is important for access to provisions and employment. In addition, clean water and the removal of liquid and solid waste are essential to human well-being. The basic availability of energy is essential for cooking, and sometimes for heat, light, and productive power. Telecommunications can also be mobilized to assist the poor through information provision or shared communications systems.

Thus, a reduction in costs and an improvement in quality of infrastructure services can contribute greatly to the enhancement of human capital. Infrastructure investment can involve large amount of investment that has macroeconomic implications. It can generate employment in the construction sector and other sectors through multiplier effects. These effects can lead to increased purchasing power and greater aggregate demand.

For these reasons, infrastructure investment is often used as a macroeconomic measure to counter business cycles by boosting domestic demand and consumption. However, the multiplier effects could dampen quickly, and the investment expenditures on infrastructure projects could crowd out private investment. Moreover, in order for infrastructure investment to have positive effects on the economy during a recession, there needs to be a sustained inflow of funding. Most developing countries cannot rely on public deficit expenditures or foreign sources for this purpose.

Box 12: Malaysia's Multimedia Super-Corridor

As part of its STI efforts to enhance its technological base in the information and communications technology (ICT) sector, the Malaysian government initiated the Multimedia Super-Corridor (MSC) Project in 1995. Located in the corridor between Kuala Lumpur and Putrajaya, the new administrative capital of Malaysia, the MSC has been developed to accommodate a cluster of firms in the information technology sector. Although the MSC is considered as part of STI policies, with the provision of liberal investment incentives and favorable legal and institutional arrangements for multinational firms, the key element of the project is the provision of high-quality infrastructure.

To attract high-tech multinational corporations, from large corporations such as Microsoft and Oracle to small and medium high-tech firms, the government has invested heavily in developing physical and communications infrastructure in Cyberjaya and other "cybercities" in the MSC. The infrastructure provided in the MSC include digital telecommunications infrastructure designed to meet the highest international standard in capacity, reliability, and pricing. This includes a fiber-optic backbone with an estimated 2.5-10 gigabits per second capacity that has links to international centers, open standards, high-speed switching, and multiple protocols. In addition, the MSC project is complemented by other large infrastructure projects, such as transportation routes that link the MSC with Kuala Lumpur and the new international airport. Recognizing that human resources are also the key to technological development, the MSC project provides other infrastructure services and amenities that aim to improve quality of life. It is clear that the Malaysian government considers infrastructure development to be a key component of its STI policy.

It has been long recognized that the contributions of infrastructure to economic development do not come automatically with the availability of physical facilities and structures, but require efficient operation and servicing of those facilities, as well as supporting institutions.

Since the early 1990s it has become fashionable to argue that infrastructure provision, or at least some of it, does not contribute to the alleviation of poverty. This is due in part to the sense that the developed world, including some international financial institutions, has occasionally foisted inappropriate technology on developing countries that, variously, has: despoiled the environment; not been affordable; ignored the resources needed for subsequent operations and maintenance; and overlooked the need for adequate local capability to make the most of the infrastructure provisions. Highways and high dams are highlighted in the literature as examples of this type of problem.

Box 13: The World Commission on Dams

The World Commission on Dams was formed in 1997 to review the development effectiveness of large dams, assess alternatives for water resources and energy development, and develop internationally acceptable criteria, guidelines, and standards for the planning, design, appraisal, construction, operation, monitoring and decommissioning of dams. The commission highlighted that over the last fifty years the social and environmental impacts of large dams have included the fragmentation and transformation of the world's rivers, while global estimates suggest that 40 to 80 million people have been displaced by reservoirs. However, it also found that dams have made an important and significant contribution to human development.

The commission found that it was important for infrastructure projects to be undertaken with a number of key values in mind: equity, efficiency, participatory decision-making, sustainability, and accountability. This includes the creation of a number of standards and guidelines used for ensuring that the social, economic, and environmental issues involved in the development of infrastructure are identified, and then addressed, in a participatory manner.

In the planning phases of infrastructure projects, development needs and objectives should be clearly formulated through an open and participatory process before the identification and assessment of infrastructure options. Planning approaches that take into account the full range of development objectives should then be used to assess all policy, institutional, management and technical options before the decision to proceed with any program.

In order to incorporate sustainability into the design of a project, social, and environmental aspects should be given the same significance as technical, economic, and financial factors in assessing options. In addition, increasing the effectiveness and sustainability of existing systems should be given priority in the options assessment process. It should also be noted that the provision of infrastructure as hardware may be separated from the service that this infrastructure provides; it is the service that is relevant to the poor. Thus physical infrastructure as hardware is merely a means to an end, with many different design paths now open to countries, each with various levels of social, environmental, and economic input. Distributed systems are one example of this.

Source: http://www.dams.org/

Recently there has been a revival of interest in the role of infrastructure services in tackling world poverty and achieving the MDGs. In 2003 the World Bank approved a new Infrastructure Action Plan. This plan was developed in response to strong client country demand for infrastructure and includes innovative ways of financing infrastructure projects. The World Bank has recognized that, after a strong emphasis on "bricks and mortar" investments in the 1980s and a shift in strategy to service delivery, there was an expectation of large private sector involvement. This did not materialize, leaving huge infrastructure needs in the developing world unmet.

Box 14: Infrastructure services and sustainable growth: A U.K. view

The United Kingdom Department of International Development argues that investment in infrastructure services can contribute to sustainable growth by:

- Reducing transaction costs and facilitating trade flows within and across borders.
- Enabling economic actors—individuals, firms, and governments—to respond to new types of demands in different places.
- Lowering the costs of inputs used in the production of almost all goods and services.
- Opening up new opportunities for entrepreneurs, or making existing businesses more profitable.
- Creating employment, including in public works (both as social protection and as counter-cyclical policy in times of recession).
- Enhancing human capital, for example by improving access to schools and health centers.
- Improving environmental conditions, which link to improved livelihoods, better health, and reduced vulnerability of the poor.

Source: http://www.dfid.gov.uk/

In the United Kingdom, the Department for International Development seeks to change the view of many in the international development community that the infrastructure sector, especially major infrastructure, is the preserve of old-fashioned and discredited forms of aid. "Infrastructure services" are not just hardware, but also the associated institutional arrangements and outcomes for people that should be highlighted in the alleviation of poverty agenda. A focus on accountability, capacity building, and environmental management could help address some of the concerns raised in regard to infrastructure. In addition to providing services, infrastructure development plays a critical role in shaping a country's technological direction. Indeed, historical choices in economic activity have shaped the direction of infrastructure development in many countries. For example, railway lines that lead to mines have made little contribution to agricultural development in many parts of the developing world. Infrastructure development is thus intricately linked to technological innovation.

5.2 Infrastructure and technological change

Infrastructure development provides a foundation for technological learning, because infrastructure essentially involves the use of a wide range of technologies and complex institutional arrangements. Governments traditionally view infrastructure projects from a static perspective. Although they recognize the fundamental role of infrastructure, they seldom consider infrastructure projects as part of a technological learning process. They may want to recognize the dynamic role infrastructure development and take a more active role in acquiring the knowledge in infrastructure development, which is available through foreign construction and engineering firms. Building railways, airports, roads, and telecommunications networks could be structured to promote technological, organizational, and institutional learning.

There are two ways in which infrastructure contributes to technological development in practically all sectors of the economy. First, infrastructure serves as the foundation of technological development, and its establishment is, in effect, technological and institutional investment. Second, the infrastructure development process provides an opportunity for technological learning.

5.2.1 Infrastructure and technological development

The creation and diffusion of technology relies on the availability of infrastructure. Without adequate infrastructure, further applications of technology to development are not possible. For instance, electric power, transportation networks, and communications infrastructure are the underlying factors behind the efforts to improve basic scientific and technological capabilities. The advancement of information technology and its rapid diffusion in recent years could not happen without basic telecommunications infrastructure, such as telephone, cable, and satellite networks. Electronic information systems, which rely on telecommunications infrastructure, account for a substantial portion of production and distribution activities in secondary and tertiary sectors of the economy. Many high-technology firms, such as those in the semiconductor industry, require reliable electric power and efficient logistical networks. Efficient transportation and logistical networks also allow firms in manufacturing and retail sectors to adopt process and organizational innovation, such as the Just-In-Time (JIT) approach to supply chain management.

The concepts of innovation systems and triple-helix relationships, mentioned earlier in this report, stress the links between firms, educational and research institutes, and governments. These concepts cannot be implemented without the infrastructure that supports and facilitates the connections. Particularly in the era of globalization and knowledge-based economy, the quality and functionality of information and communications infrastructure, as well as logistical infrastructure, becomes essential for the development of academic and research institutions.

While the efforts to expand the use of technology in development depend on the existence of infrastructure, the development of new innovations and technology also contribute to infrastructure development. For example, the advancement in communications and data processing technologies has fostered the development of Intelligent Transportation Systems (ITS) for more efficient traffic management. The use of Geographic Information Systems (GIS) and remote-sensing technologies enables engineers to identify groundwater resources in both urban and rural areas. Infrastructure and technological innovation for development thus maintain a co-evolutionary relationship in which they reinforce each other.

Box 15: Republic of Korea's high-speed train

The Republic of Korea has long considered infrastructure development to bean important part of its industrial and technological development. In recent years, one infrastructure project has drawn special public attention—the development of high-speed train networks that link the capital Seoul with Pusan and Mokpo, the two major cities on the southeast and southwest coasts. According to the current schedule, the first phase of the project will be completed in April 2004. The network will cover a total distance of about 800 kilometers and will cut the original travel time by half. As the largest civil engineering project in the Korean history, the high-speed train project has been a subject of political controversy since it was launched in 1990. Because of frequent design changes, delays, and pork-barrel politics, the overall construction costs more than doubled to 18.44 trillion won ($16.3 billion). Notwithstanding its political and financial problems, the technological aspect of the project deserves special attention.

In 1993, the Korea High Speed Rail Construction Authority (KHRCA) announced it had selected a French consortium to build its high-speed train networks. Although the French retain the rights to export le Train à Grande Vitesse (TGV) to Europe and North America, the Koreans are considering the prospects of exporting their to Asia itself, where they will be free to export once their own high-speed railway is in operation.

The South Korean government also expects that industrial and technological effects of the project will be enormous, because high-speed rail spurs the development of advanced aerodynamics, civil engineering, and mechanical and electronics technologies. Such technologies can also be applied to materials, automation, information, aerodynamics, and other future industries. The country's overall design capability for mass transportation, such as general railroads, subways, and light railroads, is also greatly enhanced, while automatic computer control and self-diagnosis technologies can be applied to automation of industrial robots.

Experience with French technology has already helped South Korea develop its own bullet train system. A locally manufactured high-speed train broke the milestone speed of 300 kilometers per hour in a test run in September 2003. This makes South Korea the world's fifth nation to possess such advanced technology. The speed of 300 kilometers per hour is, in fact, 50 kilometers per hour faster than the high-speed trains built by Alstom. The successful development of the world-class South Korean bullet train will help the country's manufacturers advance on overseas markets. The South Korean experience shows that an infrastructure project is, in many respects, a technological and institutional investment. It also shows that a government can structure an infrastructure project in such a way that domestic industries can benefit from the technology transfer and related organizational and institutional arrangements.

For these reasons, the construction and maintenance of infrastructure is in itself an act of technological and institutional investment. As a prerequisite for the application and creation of technological innovation in development, infrastructure is a fundamental element of a comprehensive and effective STI policy.

5.2.2 Infrastructure and technological learning process

Infrastructure also contributes to technological development by providing the opportunities for technological learning. Because of the fundamental role of infrastructure in the economy, the learning process in infrastructure development is a crucial element of a country's overall technological learning process. This dynamic aspect of infrastructure is often overlooked in the development and infrastructure literature.

Every stage of an infrastructure project, from planning and designing through to construction and operation, involves the application of a wide range of technologies and the associated institutional and management arrangements. Because infrastructure facilities and services are complex physical, organizational, and institutional systems, a deep understanding and adequate capabilities are required on the part of engineers, managers, government officials, and others who are involved in these projects. For instance, the development of an international airport and mass rapid transit systems in Singapore has provided the local firms and public agencies with the opportunities to learn and acquire systems perspectives, which are necessary in any large-scale projects.

Many developing countries, however, do not have the required technological, organizational, and institutional knowledge and capability for developing infrastructure. Generally, construction and engineering consulting firms in developed countries are the key sources of the knowledge in infrastructure development, although their counterparts in the higher-income developing countries are becoming competitive. Depending on the level of domestic capability, the degree of foreign participation could vary in infrastructure projects in developing countries. Infrastructure facilities and services that require more sophisticated technological and managerial knowledge tend to have greater foreign participation in various stages of the projects.

While foreign participation had always been active in large infrastructure projects in developing countries, foreign direct investment (FDI) in infrastructure increased substantially in the 1990s. Several factors contributed to the supply of infrastructure FDI, including favorable FDI policies and a reduced risk of expropriations in developing countries, as well as innovative financing strategies, such as non-recourse project financing and securitization. Increased foreign participation in infrastructure projects, particularly in the form of FDI, means that there are now more opportunities for developing countries to use infrastructure development as part of their technological and institutional learning process.

Infrastructure plays another crucial, albeit indirect, role in STI efforts in developing countries. It is one of the most important factors in attracting foreign direct investment.

Although there are many determinants of foreign direct investment, infrastructure is always one of the key factors that multinational corporations (MNCs) consider in deciding the location, scope, and scale of their investments. Given that MNCs are one of the key sources of technology for developing countries, the important role of infrastructure in STI efforts is significant. One of the most important issues regarding infrastructure is who should invest in it. Infrastructure has some production and consumption characteristics that make it subject to special policy attention. Its production characteristics are related to the general features of the delivery systems.

One important feature of infrastructure delivery systems is *connectivity*. Infrastructure services are generally delivered through network systems that are designed to service multiple users. Because the delivery systems are connected through networks, the efficiency of infrastructure services depends greatly on the coordination of the service flows. This interconnectedness also means that the benefits from investment at one point in the network depend on service flows and capacities at other points. A second important feature is *exclusivity*. The networks are, in most cases, dedicated to carry only goods. For instance, piped water, sewerage, and telecommunications each has its own network. A third important feature of infrastructure systems is *irreversibility*. The investment in the delivery systems is often "sunk," in that networks cannot be converted to other uses or moved elsewhere. With large initial investments, however, economies of scale often occur in infrastructure services. The average costs of infrastructure services tend to decrease with an expanded level of output. Economies of scale are widely thought to be an important source of natural monopoly.

On the other hand, many infrastructure services have consumption characteristics that make them distinct from many economic goods. First, there is an essential minimum level of infrastructure services that individuals or firms need to sustain their survival. Clean water is a classic example. Second, beyond the essential minimum level, the demand for infrastructure tends to be diverse. Because infrastructure investments tend to be large, it is often difficult for infrastructure providers to adjust the availability of supply to a diverse and changing demand. In most cases, infrastructure delivery systems are not designed so that the services can be differentiated. In addition, users cannot easily obtain substitute infrastructure services, because many infrastructure structures and facilities are geographically immobile and their products are non-tradable.

Historically, private provision was common for transportation, telephone, and other infrastructure services in many countries in the nineteenth century and the early twentieth century. However, the overwhelming trend during the twentieth century was that governments and public agencies, particularly in developing countries, were assuming the key role in constructing infrastructure facilities and in providing the services. The public-goods characteristics are the main rationale for the public sector to take responsibility in providing infrastructure services. Governments often find infrastructure to be of strategic economic and political importance. The tendency towards natural monopoly in infrastructure services also requires some form of public ownership or social control to assure that these services are priced efficiently.

However, with the increasing global trend of privatization since the early 1980s, and the increased supply of infrastructure FDI in the 1990s, many governments have allowed more private participation in the construction and provision of their countries' infrastructure services. With the support of the Bretton Woods institutions and private financial institutions, many infrastructure projects in recent years—ranging from transport to telecommunications—are planned, financed, and operated with the active involvement of the private sector.

Box 16: Infrastructure construction in Algeria

As foreign participation in infrastructure projects in developing countries increases, the issue of technology transfer in infrastructure development becomes even more important. Especially in the construction sector, different types of contract arrangement with foreign firms could result in differences in the degree and type of technology transferred to local construction companies.

Empirical evidence on technology transfer suggests that government policies regarding the types of contracts for infrastructure construction can influence the degree of technology transfer. In Algeria, the construction industry has been considered in the Central Plan since the 1970s as one of the "industrializing industries," which generate a large part of employment and contribute to GDP. The government encouraged the purchase of complex and advanced, though costly, systems of technology from foreign firms. Sophisticated and highly integrated contracts, such as turnkey and product-in-hand contracts, were used to assemble and coordinate all the project operations—from conception through implementation to installation—into one package. The aim was to transfer the entire responsibility to the foreign technology supplier.

Unfortunately, these types of contracts did not lead to as much technology transfer as hoped for by the Algerian government. Although the turnkey contracts required that the foreign supplier take full responsibility in the project, they did not include the sourcing or training of local skills. This meant the continuous reliance on external assistance on management and skilled operations, and/or the inefficient operation by local management due to a lack of understanding and skill.

The use of turnkey contracts, with the emphasis on hardware acquisition, requires the adequate level of local knowledge, skill, and experience. These factors were not available when Algeria started using the integrated contracts. The product-in-hand contracts are the improved version of the turnkey contracts, in that they include the procurement and training of labor force required by the projects. However, because foreign suppliers take responsibility in the technology transfer process, there are limited opportunities for local managers and construction organizations to gain hands-on experience in project design, implementation, and installation. The lack of involvement of end users and local managers often results in unsuccessful technology transfer.

Having learned from its past failures, the Algerian government later encouraged "decomposed" or "design and installation supervised" contracts, under which infrastructure projects are more fragmented and involve more local firms than under the integrated contracts. Local firms now take charge of the phases prior to installation (such as exploration and planning), functions that are done by foreign technology suppliers under integrated contracts. With the technical assistance and supervision of foreign suppliers, local managers carry out the projects. This new approach not only reduces the uncertainty in implementation, but also facilitates the process of learning-by-doing in local firms and thus enhances their technological capability. The approach has also contributed to the development of investment and managerial capability of local managers, as they have more opportunities to participate in the technology implementation.

The issues as to who should, when to, and how to provide infrastructure services, particularly for STI, need more policy attention now than ever before. Rapid technological changes in many sectors of the global economy require fundamental changes in infrastructure provision and investment. Two types of infrastructure need special attention—namely, transportation and communications. Historically, transportation infrastructure has been designed and built in sparse and rigid networks to serve a relatively low volume of traffic. Increasing globalization of production and consumption in recent yeas has forced transportation infrastructure to incorporate more multi-layered, dense, and flexible networks. Transportation facilities and networks now have to have high capacity for regional, continental, or global movements of goods and people.

Meanwhile, communications infrastructure has changed from low-capacity national networks to high-capacity global networks. The structure of nodes and links that used to be centralized and based on materialized information transfer has become more decentralized and dematerialized. The market that was once dominated by national monopolies has also become more competitive, with the entry and exit of more national and international communications firms.

Policymakers need to realize that this trend has direct implications for the roles of government in infrastructure provision. For developing countries in particular, the shift from common-carrier communications infrastructure to the system of inter-connected private networks means both opportunities and challenges. On the one hand, governments may no longer need to provide every single aspect of the infrastructure and may limit its role to supporting the development of private networks.

On the other hand, governments need to design and implement the rules and regulations that govern the private networks that are no longer under public control. The governments also have the option of building up the infrastructure that replaces private networks. Considering that the global economy has increasingly relied on information and knowledge flows, governments are faced with strategic options that they need to choose from, which could have significant implications for their STI policies.

Examples abound in which infrastructure is a necessary requirement of the application of science and technology in development efforts. Computers and Internet connections are of no use without electricity. High-tech medical devices are of little help without basic healthcare facilities.

5.3 Planning for infrastructure development

Infrastructure serves as a strategic foundation for economic transformation in general and the application of technology to development in particular. It is an essential element of the long-term development efforts and should include direct links with human resource development, enterprise creation, and R&D. Some literature suggests that the types of infrastructure needed by developing countries depend on their level of economic development and that the composition of infrastructure stocks changes significantly as income levels increase. Basic infrastructure—such as water, irrigation, and, to a lesser extent, transportation—is important for low-income countries. For middle-income countries, most of the basic consumption demand for water and sanitation is satisfied while the share of agriculture in the economy decreases, thereby reducing the need for irrigation. In addition, more transportation infrastructure is provided, and electricity is available to more households and firms. As income levels increase, the share of power and telecommunications in investment and infrastructure stocks becomes larger.

This stage-by-stage approach to infrastructure development could sometimes be misleading. It is true that governments need to prioritize infrastructure investment according to the degree of needs and the investments' potential impacts on the economy and the society as a whole. This does not mean, however, that developing countries should focus merely on basic infrastructure and not invest in the types of infrastructure that are of strategic importance. Quite the contrary, these countries need to consider more seriously about how to upgrade those types of infrastructure so as to tap into the opportunities that may arise from the rapid technological change and increasingly integrated global economy.

An essential aspect of economic planning in developing countries is fostering the human capabilities necessary to develop and maintain the infrastructure that is appropriate to local conditions and consistent with ecological and other principles. Foreign construction and engineering firms will continue to play an important role as the main source of technological, organizational, and institutional knowledge for infrastructure development. Yet, governments in developing countries should devise policy measures to encourage technology transfer and build local capabilities in infrastructure projects. Research and development activities for the development and maintenance of infrastructure should also be promoted, and linkages should be built with both domestic and overseas research networks.

Infrastructure services should be provided through combinations of public and private enterprises. Governments may reduce their role as producers of infrastructure, but may retain their roles as regulators, financiers, suppliers, or even competitors of private providers. Whatever roles they play, governments first need to recognize that different types of infrastructure require different policies and approaches. Although infrastructure services have several common characteristics, they also have important differences.

For example, telecommunications is less essential than water, energy, and transportation. Its pricing is, therefore, less politically sensitive and reflects the true financial, if not economic, costs. This could mean that the payback periods for investments in telecommunications are shorter than other types of infrastructure. Meanwhile, different types of infrastructure have different technologies and organizational arrangements. Governments may need to assume a direct role in certain infrastructure projects, if they see a strategic importance in fostering the transfer, and building up the local capability, of the required technologies.

It is necessary for a series of in-country studies to be carried out so that the essential infrastructure services necessary to support the achievement of the MDGs are identified. The location of the poor (particularly as between urban and rural areas) and their critical infrastructure service needs should be pinpointed. The cost and cost-effectiveness of the infrastructure interventions to meet these needs should be calculated. Another fundamental task will be to highlight and address problems of implementation.

Infrastructure projects should be conducted in such a manner that the engineering profession, both in-country and from the developed world, is mobilized to give high priority—working with others—to the planning, prioritization, financing, and implementation of necessary services. Attempts should be made to harness the enthusiasm and drive of young professionals, many of whom are looking for every opportunity to serve the developing world.

Because of the cross-cutting nature of the issues and policies required, infrastructure projects will require more than just know-how and skills. They also present a major project management challenge to put programs into place and carry them through to fruition. This task is enormous, and the challenge for those involved will be to simultaneously take a “broad brush” yet focused approach.

The challenges involved in infrastructure development and maintenance touch on the main themes of this report—science, technology, and innovation. To be successful, institutional capacity is paramount, as well as the building of human resources. Furthermore, in developing countries, processes for technological learning need to be enhanced.

Finally, in order for infrastructure to become more effective and extensible, focus should be given to the creation and enforcement of standards. Efforts should be made to facilitate the coordination, skills development, and the use of standards to promote the interoperability of infrastructure systems from the early design stages.

CONCLUSION

The goal of infrastructure and infrastructure services in developing countries is to meet the needs of the poor while building in-country science and technology capability. The challenge to the STI community is to identify and implement the infrastructure services necessary for the achievement of the MDGs. The challenge to policymakers is to undertake infrastructure development in a manner that not only promotes equity, efficiency, participatory decision-making, sustainability, and accountability, but also in a way that can be linked with science and technology capability development in developing countries.

6. BUILDING HUMAN CAPABILITIES: THE ROLE OF SCIENCE EDUCATION

INTRODUCTION

Investment in science education has been one of the most critical sources of economic transformation in the newly industrialized countries. Such investment should be part of a larger framework to build capacities worldwide as articulated by the InterAcademy Council (InterAcademy Council 2003). The one common element of the East Asian success stories is a high level of commitment to education and homogeneity within the countries. South Korea's commitment towards higher education shows that spectacular results can be achieved in a few decades.

However, the growth of higher education needs to be accompanied by the growth of opportunities for graduates to apply their acquired capabilities, a lesson also provided by South Korea. The strategy to achieve the first goal is rather straightforward: to devote resources or get complementary resources from international cooperation to help more young people to go into higher education, paying special attention to the barriers that appear at secondary education. The second goal is to give incentives to private enterprises, particularly small and medium ones, to hire young university graduates, a strategy that helps to start a virtuous circle of technological upgrading.

Box 17: Primary education and the Internet

The mostly widely adopted primary science education program that is being promoted by the InterAcademy Panel (IAP) and the International Council for Science (ICSU) is the La Main a la pate (LAMAP) program of the French Academy of Sciences. The LAMAP methodology is hands-on and discovery-based. The French government has now adopted this methodology. Morocco, Senegal, Egypt, Colombia, Brazil, Hungary, China, Vietnam—and soon Malaysia—are also implementing LAMAP. Among primary science educations programs, LAMAP has the most imaginative use of ICT and the Internet. It has a well designed and well used website and is now the best resource for French primary school teachers.

Apart from its pedagogical resources and references, LAMAP is also an active teachers forum. The website has a parallel forum of scientists and engineers to whom teachers can refer any problems. Scientists and university science students act as advisors to teachers in class. However, they are not encouraged to interact directly with the students so as not to undermine the authority of the teacher and her rapport with her class. The support of advisors is a great help to the teacher. Similarly, in Germany, there is a junior civil service for youth with at least a secondary education to help primary school children to strengthen their learning ability by devoting time to help them master the concepts given in class.

Although the education Millennium Development Goal (MDG) is limited to achieving universal primary education, the importance of science education at secondary and tertiary levels in the construction of an innovative society cannot be overemphasized. Developing countries that have been shown good economic growth have invested heavily in education. For example, Tunisia spends 30 percent of its budget on education. Developing countries should be encouraged to adopt curricula, which ensure that all students completing secondary education in any field will have been exposed to at least one area of science at the secondary level. They should also be encouraged to invest in science education at secondary and tertiary levels in order to maximize output of scientists, engineers, and technologists. The human resource base would then promote the utilization of STI in the country's development process.

If developing countries are going to make efforts to move into high-tech development, changes will also need to be made at the high school level. High-school curricula will need to be adjusted to prepare students for the rigorous materials being introduced at universities. Teaching methods at schools should be changed too, with a spirit of scientific inquiry infused into the children through independent projects, guest lectures from experts, and field trips.

Box 18: The Colombo Plan: An example for Africa

At the Commonwealth Conference on Foreign Affairs held in Colombo in January 1950, which was convened to exchange views on the needs of the countries of Asia, a Consultative Committee was established to survey needs, assess available and required resources, focus world attention on the problems involved, and provide a framework within which international cooperation efforts could be promoted to assist the countries of the area to raise their living standards. The Colombo Plan embodies the concept of a collective intergovernmental effort towards the economic and social development of member countries in the Asia-Pacific region. It encourages developing member countries to become donors themselves and to participate in economic and technical cooperation among developing countries. The primary focus of all Colombo Plan activities was human resources development in the Asia-Pacific region.

From the 1950s to the 1970s, the Colombo Plan had the most successful human resource capacity building program for Southeast Asia. Donor countries offered scholarships and fellowships to developing countries in the altruistic spirit that was prevalent after Second World War. Although the program was within the Colombo Plan framework, it was essentially a collection of bilateral programs between specific donor and recipient countries. It was devoid of multilateral bureaucracy and politics. Program implementation was very focused on the needs of the recipient and the matching capabilities of the donor. Without a doubt, nations such as Malaysia, Singapore, Thailand, Indonesia and the Philippines were greatly helped by the technological and professional manpower developed under the Colombo Plan.

The Colombo Plan also contributed significantly to the stable administrative transition from colonial rule in Southeast Asia. It also had very important impact on donor countries, especially Australia. The presence of Colombo Plan students from Asia gradually triggered a flow of students from Southeast Asia to Australia. The Colombo Plan Scholarship and Fellowship Program for Southeast Asia virtually came to an end in the late 1970s before Africa assumed an important position on the world stage. Perhaps that was the reason why the program was not extended to the Commonwealth countries in Africa. However, the Colombo Plan Scholarship and Fellowship Program are worthy of further examination as a model for African technological and professional manpower development.

The wide range of levels of human capacities in science and technology is shown in Appendix H. A composite measure of these capacities, Technology Achievement Index (TAI), gives a broad picture of countries' human resource base, as well as how this base translates into actual technology creation. While there are huge differences between the best and worst performers, largely coinciding with the North-South divide, many developing countries have done well in these areas. In fact, South Korea ranks first overall, reflecting the country's rapid rise in many dimensions of science and technology. Its investment in human skills has translated into full participation in technology creation, and technology diffusion is on par with long-industrialized countries.

6.1 Scientists and engineers in the global economy

The scientific, technological, and engineering community of a country and the associated institutions such as universities, technical institute or all types, and professional associations are among the most critical resources for economic transformation. They deserve special policy attention. There is a disturbing global trend that enrollment in engineering courses in universities and institutions of higher learning is declining. These courses have also persistently remained unattractive to women who constitute half of the world population. This has been particularly evident in developed countries where engineering departments in universities and institutions of higher learning have closed. With regard to enrollment, the situation in science courses is not any better.

While developed countries have always had the alternative of recruiting engineers and scientists from developing countries, the same does not hold for the latter, which desperately need the skilled engineering personnel at home. Developing countries suffer on three counts. First, they do not produce enough engineers and scientists for their own needs as their engineering and scientific education and training infrastructure is inadequate. Second, they expend scarce hard foreign currency in sending their students for expensive engineering and science courses in developed countries. Third, there is constant brain drain of engineers and scientists, usually the best and the brightest, to developed countries. Ironically, developing countries are putting their scarce resources into education and training that are benefiting the developed world.

Even if the developing country's initial absorptive capacity for scientists and engineers is limited due to its low stage of development, the highly educated human resources will be an attraction to foreign firms interested in investing in science and technology in the developing country. Furthermore, as seen in many countries, migrant professionals and workers have contributed to the formation of small and medium enterprises (SMEs) though investment back home, often utilizing technology learned abroad, and are involved in the establishment of joint enterprises in their home countries with firms from the countries of adoption in the developed world.

Nevertheless, "brain drain" remains one of the most hotly debated international issues. The home country's loss of skills—and, thus, of educational investment—needs to be set against the experience gained abroad by scientists and professionals which may be available for use upon return. Temporary labor movements also present an advantage over permanent migration with respect to remittances. The amount of money involved indicates potentially significant effects for such recipient countries as India, Mexico, and Portugal.

Box 19: Kigali Institute of Science, Technology and Management

Rwanda experienced one of the worst human tragedies of the post–World War II period. Its reconstruction efforts have been associated with high-level emphasis on the role of science, technology, and engineering in economic transformation. This is illustrated by the decision by the Rwandan government to convert military barracks into a home for a new university, the Kigali Institute of Science, Technology and Management (KIST). It is the first public technological institute of higher learning in Rwanda.

KIST aims to contribute to Rwanda's economic renewal through the creation of highly skilled manpower. It seeks to become a regional center offering courses in science, technology, and management; carrying out extensive research activities and knowledge dissemination; and in providing technical assistance and services to all sections of the community. KIST was created as a project of the United Nations Development Programme in 1997. It was established with the help the Government of Rwanda as the main stakeholder, UNDP (Rwanda) as the executor of the project, and the German Agency for Technical Cooperation (GTZ) as the implementing agency. The initial funding came from UNDP core funding and a UNDP Trust Fund obtained from the generous contributions by the Governments of Japan and the Netherlands.

The establishment of KIST was part of the Rwandan government's mission to build a strong post-genocide human resource base that is so desperately needed. Government commitment was demonstrated in the handing over of a military academy infrastructure in the city of Kigali, as the start up capital for the institute. KIST opened with major degree programs being offered in engineering and management. Compulsory courses include English or French language and remedial basic sciences. The Institute was officially inaugurated in April 1998. In July 2002, KIST held its inaugural graduation in pomp and ceremony, awarding 403 diplomas and 62 degrees to its 465 proud pioneers in management and computer science disciplines.

Despite many challenges, KIST today boasts of a highly motivated and trilingual student population of 3,247 enrolled in both regular and part-time undergraduate programs, with a wide variety of engineering and management course menus to choose from. In addition, KIST recently introduced a postgraduate diploma in demography and statistics. The institute has highly qualified and diversified staff, more classroom space, and a growing laboratory infrastructure. KIST has also developed thriving income generation activities to offset its otherwise stringent budget.

Source: http://www.kist.ac.rw/

For example, the remittances received by India in 1996 (US$7.6 billion) were almost three times as high as net direct investment inflows in the same year. In terms of foreign currency earnings, they came close to the contribution of the country's entire textiles and clothing industry (US$8.6 billion). Taiwan set the trend for inviting expatriate scientists and engineers home to participate in key R&D projects for national development. Today, these countries are looking at opportunities for R&D partnerships around the world and are not restricted to facilities at home.

The traditional concept of "brain drain" is increasingly being challenged by societies that seek to benefit from the globalization of knowledge rather than rely on nationalistic strategies. International mobility of skills is one of the key mechanisms for the transition of technological capability across nations. The challenge therefore is not necessarily the initial migration of expertise, but the absence of institutions designed to utilize a country's national human resources irrespective of their geographical location. Such institutional arrangements will rely on greater commitment to international cooperation and partnerships and not legislative measures that control the mobility of scientists, technologists, and engineers.

6.2 Higher education and development

Higher education is increasingly being recognized as a critical aspect of the development process, especially with the growing policy awareness over the role of science and technology in economic renewal. While primary and secondary education have been at the focus of donor-community attention for decades, higher education has been viewed as essential to development only in more recent years. Today's economic circumstances make higher education a more compelling need in developing countries than it has ever been. Some key factors are: increased demand for higher education due to improved access to schooling; pressing local and national concerns that require advanced knowledge to address; and a global economy that favors participants with high-technological expertise.

In this respect, vocational institutes and polytechnics in developing countries are very important. Technologists, technicians, and craftsmen are the bedrock on which SMEs (especially in operations and maintenance) are founded. Many developing countries have made the mistake of turning out more university engineering graduates than technicians and technologists when the home demand for engineers is already being fulfilled. In the 1970s, many engineering graduates in India were working as engineering draftsmen, an example of a waste of highly skilled and expensively trained human resources. Yet India then suffered from a critical shortage of skilled tradesmen, such as pattern makers and instrument technicians. Many Indian engineers, however, had already migrated to developed countries.

If anything, the need for training and capability building of technicians and technologists in developing countries is even more acute with the requirement of computer-aided design and drafting in engineering and construction industries. Technicians and technologists are also essential due to the proliferation of sophisticated computer-controlled machineries and instruments for manufacturing in SMEs and heavy industries; as well as in services such as in health care, banking, and recreational and cultural pursuits.

Developing countries should invest and promote institutions that provide recognition and continuing professional development of technologists and technicians like the Institutions of Incorporated Engineers and the Institutions of Technician Engineers in the United Kingdom.

Universities, in particular, have immense potential to promote technological development. However, at present, most universities in developing countries are ill-equipped to handle the challenge. Outdated curricula, under-motivated faculty, poor management, and a continuous struggle for funds have rendered universities ineffective institutions that do not actively promote national development.

Many of the problems that developing countries face today will require scientific, technical, or engineering skills to solve: disease and malnutrition, lack of adequate infrastructure, insufficient agricultural productivity, challenges in diversifying national economies; and managing natural resources in a sustainable manner. Consequently, it is important for developing countries to have indigenous S&T capabilities.

In addition to local forces, global pressure is being exerted on developing countries to move forward in scientific and technological fields. As industries grow more complex and technologically based, greater S&T skills and knowledge are required. The digital revolution has entirely changed communications and knowledge acquisition patterns, while revealing technological disparities between and within nations. Developing countries need to be active partners in international collaborations in research and business collaborations that are being forged across the globe.

6.3 Entrepreneurial universities and technical institutes

A new view that places universities at the center for the development process is starting to emerge. This concept is also being applies at other levels of learning such as colleges, research and technical institutes, and polytechnics. The age when entrepreneurial universities and research institutes (including polytechnics) are integrated into the productive sector has arrived.

Universities are starting to be viewed as a valuable resource for business; the "entrepreneurial university" undertakes entrepreneurial activities with the objective of improving regional or national economic performance, to its own and its faculty's advantage (Etzkowitz 2003). In facilitating firm development, universities can contribute to economic revival and high-tech growth in their surroundings. There are many ways in which the university can be "entrepreneurial"—it can conduct R&D for industry; it can create its own spin-off firms; it can be involved in capital formation projects such as science parks and business incubator facilities; or it can introduce entrepreneurial training into its curricula, encouraging students to play an entrepreneurial role by taking research from the university to firms.

A chief merit of this model, from the perspective of its applicability to the developing world, is its acknowledgement of—in fact, its insistence upon—strong interdependence of three actors: academia, industry, and government. This development was first observed in Latin America, where a triangle of academia-government-industry was seen as an indicator of development.

Industry in the developed world has, by and large, benefited from the activities of entrepreneurial universities, particularly in having state-of-the-art university laboratories carry out cutting-edge research for them. Universities also stand much to gain from the research funds supplied by industry. At present, many developing-country universities serve merely as degree or certificate-awarding institutions, providing the necessary documentation for thousands of young people to apply for jobs. Marginalized in the development process, these universities' goal is often simply to churn out graduates. Universities need to be re-envisioned as potentially powerful partners in the development process.

This adjustment can be implemented in a top-down manner in existing universities, changing existing norms and procedures. It can be done for either all the academic departments of the university or merely certain select ones that are deemed to be of more importance with regard to national development goals. However, the latter process would imply widely different standards regarding student and faculty qualifications for different departments of the same university, and would likely require a separate administrative setup for the departments with higher standards. Also, since the university is already in existence, any newly identified national priority disciplines would have to suit the university location. A benefit of this approach would be working with an established institution with several academic departments already in place. Such an institution also already has libraries, staff, and very likely some links with other research institutes.

Technical institutes are created to serve industry and are by nature more entrepreneurial. Without neglecting their essential and primary roles in capability building for technologists and technicians, some of these institutes could more easily be upgraded to entrepreneurial university status.

New universities may also be created, particularly if a new field of knowledge has been made a national priority in which existing universities have inadequate capability or if student demand has outstripped existing university capacity. These universities can either be entirely new institutes or expansions of industry-based training institutes.

For universities to be able to contribute to S&T-based regional development, appropriate supporting institutions will be necessary. These include both the formulation of enabling policies and the formation of organizations that can increase the pathways of interaction between academia, government, and industry: through tax breaks, venture capital funding, low-interest loans, beneficial changes relating to intellectual property rights, greater returns on inventions, heavy investment in ICTs, fostering business incubation, and creating science parks and centers in or near universities.

The opportunity to form partnerships with other institutions, whether on a national or regional level, is of great benefit for entrepreneurial universities. Many developing-country academics are benefiting from institutional partnerships with universities and R&D institutes abroad. Research partnerships across academic, industry, and government institutions help minimize knowledge gaps across the country, which is particularly useful in the case of SMEs that often lack adequate R&D facilities.

6.4 Reshaping higher education

Reshaping universities to perform development functions will include adjustment in curricula, changes in the schemes of service, modifications in pedagogy, shifting the location of universities, and creating a wider institutional ecology that includes other parts of the development process.

In order to assist the universities in adopting a key development role, national development plans will need to incorporate new links between universities, industry, and government. This is likely to exert effects on the entire national innovation system and have an impact on firms, R&D institutes, and government organizations. Developing countries will not be able to become major economic players unless they can catch up in high-technological fields quickly. Thus, university S&T curricula take on great significance. Today, the S&T curricula in many developing-country universities are outdated or not cross-disciplinary. In certain departments, the research emphasis needs be slanted towards issues of local and national relevance.

University faculties in many developing countries are poorly rewarded and thus under-motivated. Due to either technical difficulties or lack of interest, they are not always conversant with the latest developments in their field. Their teaching methods tend to be old-fashioned—for instance, there is little use of audio-visual equipment during lectures or of advanced apparatus during laboratory sessions. However, the latter is often a case of inadequate funds at the university. Faculty will need to be aware of developments at the frontiers of their research.

Research ability will need to be considered when assessing applications for graduate study in S&T fields. Incentives such as scholarships and low-interest loans should be made available for the most promising students.

Universities that are expected to boost high-tech industry will need to be located near high-tech firm clusters and research institutes, most likely in urban areas. If firm formation is expected to take off after the university is established, the university needs to be located in an area that is conducive to further development. Universities and technical institutes that are expected to play an important role with regard to community development are likely to be more effective in rural areas. Institutions that are involved in research that is very site-specific will need to locate themselves, or some of their laboratories, accordingly. For instance, universities that would like to conduct marine research should be located near the shore, and so on.

Broadly speaking, there are three possible categories of action: reforming existing universities, upgrading existing institutes, or starting up new universities. In all cases, in addition to the suggested changes, supportive policies and regulations will need to be made, and links created between universities, industry, and government.

For universities and technical institutes to adopt their new role as development partners, a new set of management procedures will be required. The recommended changes—requiring drastic revisions in student and faculty selection procedures, new incentives and transparency mechanisms, and revised curricula and teaching methods—are likely to cause upheaval and resentment in various circles of the university. A strong management needs to oversee the new changes to ensure they remain in place.

Universities and technical institutes will very likely be working closely with industry as well as with government in the pursuit of national objectives. Therefore, it is important that the university have mechanisms in place through which it can retain its autonomy.

For universities and technical institutes to be able to contribute to science and technology-based regional development, appropriate supporting institutions will be necessary. These include both the formulation of enabling policies and the formation of organizations that can increase the pathways of interaction between academia, government, and industry.

CONCLUSION

It is now more important than ever for developing countries to make concerted efforts towards moving ahead in scientific and technological development at an advanced level. In so doing, they will be able to build local capacity that can help solve the many science and engineering-related problems they currently face. They will also be positioned to take an active part in the global "knowledge economy" on an equal footing with other countries. Universities are a vastly underutilized and potentially powerful vehicle for development in developing countries, particularly with respect to science and technology. If both universities and industry are encouraged to work actively together, the former will be able to assume an entrepreneurial role—in both senses mentioned earlier in this section—that could accelerate local and national development. However, this will require changes at several levels of university administration to render these institutions more effective as key development partners.

7. GROWING CONCERNS: SCIENCE, TECHNOLOGY, AND BUSINESS

INTRODUCTION

Economic change is largely a process by which knowledge is transformed into goods and services. In this respect, creating links between knowledge generation and business development is the most important challenge facing developing countries. If developing countries are going to promote the development of local technology, they need to investigate their current incentive structures. There are a range of structures that can be used as a means for creating and growing enterprises, from taxation regimes and market-based instruments to consumption policies and sources of change within the national system of innovation. Other policies related to government procurements can be used to promote technological innovation and generate markets for new products in areas such as environmental management. On the whole, the critical element is finding a diversity of measures that help in the creation and expansion of business activities.

Additional measures include business incentives such as support for trade shows, incentives for students to start-up companies, and assisting companies to link with those in advanced industrialized countries through joint ventures are important. With the proliferation of communications technologies such as the World Wide Web and videoconferencing, new ways now exist for cross-national and continental links between companies, or for a local company to branch out overseas. Lastly, the government could act to work with the private sector to generate collaborations across the public-private divide to invest in new technologies.

7.1 Unleashing intellectual capital

Governments need to promote measures that enable society to make effective use of the available intellectual capital through entrepreneurial activities. There are several tools that government can use to ease these barriers and obstacles to encourage entrepreneurship and new small and medium enterprise (SME) creation. Business and technology incubators are one of those tools, and they can take many different forms with different sizes, mandates, sponsorships, goals, and services being offered to participating ventures. The following section introduces the various types of incubators and their best practices for fostering general and long-term economic development through promoting new businesses.

7.1.1 Good practices on technology and small and medium sized business

The small to medium-sized enterprises within a country should be engaged to take a strong role in the development of new opportunities and the use of technology. This goal may be promoted through the establishment and encouragement of regional or

national road shows, technology days, trade shows, advertising, workshops, and online discussions.

There is a particular need to develop, apply, and emphasize the important role of engineering and technology and small enterprise development in poverty reduction, as well as sustainable social and economic development.
Associated recommendations are required regarding the need for capacity building, appropriate financial systems, public awareness campaigns, policy formation and implementation, the development of strategy to promote recommendations in these areas, and the importance of reference to engineering and technology in Poverty Reduction Strategy Papers (PRSPs). The role of government, universities, NGOs and international agencies in the development and implementation of strategy needs to be emphasized.

Small and medium enterprises (SMEs) in developed countries have often been or are still the ones developing innovative and cutting edge technologies (Andreassi 2003). In developing countries, SMEs growing from family-owned and backyard repair enterprises have often been the foundation of industrialization. A good example can be drawn from Taiwan's postwar industrialization experience with SMEs being the engines behind the process of industrial upgrading in the economy. By being suppliers to multinational corporations (MNCs) and foreign buyers in the developed countries, SMEs in Taiwan have gradually learned from their contractors both the process and product technologies that have enabled the economy as a whole to upgrade over the years. However, investments and incentives to grow SMEs have been minimal and often non-existent in most developing countries. Up until now, the focus of governments and foreign investment in developing nations has been on large infrastructure and industrial projects.

However, there are numerous obstacles for new SME venture creation. Many of the obstacles have common characteristics in developing countries and in disadvantaged areas of developed countries: low levels of effective demands in local economies with limited market development; constraints on finance and capital created by low-income and limited savings; lack of access to finance; absence of long-term credits; and high interest rates. Equally debilitating is the lack of support, knowledge, and experience in marketing, finance, and management; shortage of work experience and skilled labor; limited social and business networks; lack of business and trade information; various regulatory barriers; absence of relevant and effective support institutions for entrepreneurship; inconsistency and lack of clarity of government policies for SME support; lack of role models; lack of personal motivation; problems of transition from reliance to benefits; and cultural constraints regarding preference of hardware and to the challenges. Then there is the lack of knowledge on investment; distrust of outsiders; inequity for women in workplaces; and lack of transparency in business dealing.

In developing countries, these problems are further exacerbated by additional obstacles which include: punitive taxes and harassment by officials for SMEs; cumbersome registration and bureaucratic procedures; inconsistent legislation; and weak and slow reforms in protection of intellectual property rights (IPRs), accounting standards, foreign currency transactions, foreign investment, and bankruptcy. On the market side, developing countries suffer from the problems affecting new venture creation in rising inflation and interest rates; declining currency parities, serious disregard for quality of goods and services, and copycat entrepreneurs.

7.1.2 Business incubators

Business incubators play major roles in the creation and facilitation of small- and mid-sized business. Their role ranges from providing affordable space to providing core business support functions, such as business development, financing, marketing, and legal services.

In facilitating the creation of SMEs in developing countries, governments should adapt programs geared towards the creation of business incubators. Incubation comes in many forms, ranging from government-funded initiatives to public-private partnerships. Governments are encouraged to provide grants, low interest rate loans, and tax incentives to private companies that provide incubation resources for SMEs. Governments should consider funding university-based incubators that are focused on a particular science and technology area, as well as funding not-for-profit based incubators that tend to focus on an area of technology.

Technology parks provide environments where SMEs tend to flourish. Governments should have areas throughout their regions that are designated as technology zones. Special incentives should be provided to companies willing to relocate to these zones. Government should also focus on making it fairly simple for a new business to obtain necessary legal documents, facilities, and telecommunications needs (e.g., phone and internet connections).

Business incubation catalyzes the process of starting and growing companies—providing entrepreneurs with the expertise, networks, and tools they need to make their ventures successful (Grimaldi and Grandi 2003). Incubation programs diversify economies, commercialize technologies, create jobs, and build wealth. They are the ventures that promote the development of new and qualified SMEs by providing them with resources (premises, infrastructure, and services) necessary to improve their chances of success. Business incubators first appeared in the late 1950s in the state of New York and became increasingly used as an economic development tool in the United States since the early 1980s. In the beginning of the 1990s, about 200 of them existed, but the number has now expanded to 3,000 today worldwide, of which 900 are in the United States.

There were estimated to be about 500 incubators in developing countries in 1997, with an average 20 percent annual growth rate. Many types of business incubators have strong real estate components with considerable public investments and proximity to research institutes and technical university environments—for example, science and technology parks or industrial complexes in abandoned buildings.

The past twenty years of business incubator experiences have revealed three critical dimensions of business incubation activities that are important to their success. The first is creation of incubator itself and its management. The second is the incubation process. The third is performance assessment.

Successful business incubator creation depends on careful planning and preparation based on thorough and objective analysis. The preparation and implementation of a business incubator may take one to two years. During this period, a management team of up to ten people needs to define the clear objectives of its activities and clear selection criteria for business to support. It also needs to gather information regarding local or regional conditions to assess the feasibly of the incubator. Four aspects are important for the feasibility assessment: profiles of local entrepreneurs and their needs; potential mobilizing supports; identification of suitable locations; and projection of investment requirements.

Designing the incubator organization and management structure, selection of further staff members (especially recruits of experienced entrepreneurial managers and board members), and definition of resources are all also critical during this period. Initial funds of $500,000 to $1.5 million may be required for launching a business incubator, and securing these funds is a major obstacle in this early phase. Experiences show that business incubators may require three to five years after its launch to become self-sustaining. The best results occur when start-up and existing companies are mixed together to encourage mutual learning and stimulation.

Sustainable business incubators supported by the successful management of the premises are strongly influenced by the second activities of business incubator: the incubation process. A successful incubation process consists of three steps. The first step is entrance of entrepreneurs into the incubator based on clear admission criteria and procedures. Survival rates of the graduates from incubators strongly depend on admission policies.

The second step, development of SMEs in the incubator, is done by provision of a nurturing environment and various value-added services, which include: physical infrastructure (affordable work space); business planning, assistance, resources, and counseling services; advertising and marketing services (provision of lists of potential suppliers, businesses, potential investors, and distributors); financial advice services (advice on funding and investments and daily financial transactions, and providing access to capital and financing); training services (skills and knowledge on management and finance); know-how services (legal processes linked to the use of licenses and know-how); management advisory services (legal, human resources, accounting, and public relations); networking services (links and relationships with other organizations); access to ICT services; industrial infrastructure (roads, water, electricity, ICT, building and industrial machines); secretarial services; security services (especially for intellectual property protection); and aftercare services (post-incubation supports). The objectives of the incubator define the service offered.

The third step, graduation of businesses from the incubator, needs to be based on reasonable graduation policies that determine clear time frames and an agreement on the type, amount, and value of services provided during the incubation process. Overall, success of incubation process clearly depends on the effective policies and management of the incubator itself.

The last activity that is relevant for a successful business incubator is its performance assessment, which needs to be carried out to evaluate the outcome of incubation, management policies and their effectiveness, and services and their value added. Two layers of information are necessary: one is the measurement based on incubator effectiveness versus alternative policy approaches; and another is the measurement of the enabling factors for private sector development and main institutional and structural gaps at the country level.

Besides generating general economic and social development benefits through new venture creation, business incubators provide their own benefits by increasing SMEs' likelihood of survival, encouraging information exchange and mutual benefits, overcoming small business isolation and powerlessness by clustering SMEs, and by itself becoming a role model. Most significantly, the survival rates of new ventures nurtured in business incubators are around 80 to 85 percent in Organization for Economic Cooperation and Development (OECD) countries, compared to 30 to 50 percent of non-incubated business. Survival rates among new ventures that emerge from incubators are as high as 85 percent in developing countries where strong support from government and tight links with the university system are available (e.g., in China and Brazil).

However, business incubators have some downsides as well. They include: limits in the scope of job creation and short-run benefits; limited outreach and "picking winners" problems; the possibility of creating dependency on government support; expensive focused assistance and requirements for external subsidy until incubators themselves become self-sustainable; and the need for good business infrastructure in a good location. Furthermore, it is important to remember that business incubators are not a development panacea. They can address some important development issues, but not all.

In general, several factors that are considered important to determine business incubator success include: public policy to facilitate venture creation and provide business infrastructure; private sector partnerships for mentoring and marketing; community involvement; a knowledge base of university and research; and professional networking.

7.1.3 Technology incubators

Technology incubators are a special type of business incubator that focuses on new ventures with more advanced technologies. Although technology incubators share the same general goals as business incubators, they focus more on technology commercialization and the diffusion of technology by new firms, both of which are often impeded by market and institutional failures and greater uncertainty associated with technology development. The focus of technology incubators on technology commercialization and diffusion is also important to increase returns from public R&D.

Technology incubators are necessary helpful for the creation of high-tech companies. Unlike basic business incubators, technology incubators have the mission of turning innovative ideas into successful business. They provide an environment for prototyping as well as for providing market-tested knowledge on how an idea can be turned into a business. Most technology focused incubators come in the form of private companies. It often consists of a combination of venture capital resources and business support functionality.

Box 20: Good practices in technology incubators

The Organization for Economic Cooperation and Development (OECD) identified good practices based on its member states' experiences (OECD 1997). Several good practices on technology incubators identified in the past share those of general business incubators: clear definition of objectives in the outset and recruitment of experienced entrepreneurial managers. Sharing experiences on what works is also important for both general business and technology incubators. On the other hand, there are good practices that are particularly important for technology incubators. One is the focus on particular cluster-focused technologies, which helps the incubator achieve a critical mass, focus specific needs derived from technology incubation, and enhance synergies between firms, as seen in Salzburg Technology Center.

Selection criteria of technology incubators should also be different from general incubators: it should not depend entirely on business plans, but focus on factors such as marketability of products, entrepreneur experience, and the overall fits with other incubator tenants to foster synergies.

Another good practice for technology incubators is tailoring and leveraging existing services. Since technology incubators are often too small to provide an entire range of services, tailoring services to clients' needs and providing access to existing outside resources through brokering and networking can be helpful, as demonstrated in Regional Technology Centers (RTCs) in South Korea. A related point is building local, regional and international linkages, which can provide not only relevant services, but also integration to local infrastructure and national and international sources of technologies and markets. The German networks of technology and innovation centers connect not only domestically but also internationally including those in Central and Eastern Europe.

Diversification of financial sources for entrepreneurs is also particularly important for technology incubators, because it helps matching entrepreneurs to particular types of capital that support technology activities. Lastly, one very important factor is the effort to integrate technology incubators more closely to the surrounding infrastructure for innovation and the broader national innovation system. Many previous experiences show that real estate management should not be the primary goal for technology incubators, which do have potential for lucrative property ventures.

Technology commercialization has been a main focus of business and technology incubation activities in both developed and developing countries. In newly industrialized and transition countries, technology incubators emerged from central government schemes rather than from local public-private initiatives. They mainly aim to build bridges between academia and industry, promote innovation in SMEs, and encourage investment in technology-based start-up firms. One important feature of technology incubators is that they are not usually stand-alone ventures, but have strong tendency to affiliate with public and private sources of research knowledge—including universities, public research institutions, and large technology-based firms.

Services provided by technology incubators are similar to general business incubators. However, since their main objective is accelerating transfer and diffusion of technological know-how and industrialization, several services hold a particular importance. In OECD countries, technology incubators tend to provide greater assistance than general incubators in such areas as: offering technology consulting and support services that connect enterprises with technology transfer programs, provide access to external technical facilities and resources including university faculty and students, and a link to manufacturing extension services; financing assistance for equity financing including venture capital funds, mutually guaranteed loans, and royalty financing; legal assistance for incorporation, drafting license agreements, and ensuring intellectual property rights; and marketing.

7.1.4 Technology parks

Technology parks have been probably the most kind of popular technology incubators and have proliferated not only in developed countries but also more recently in countries in Southeast Asia and Latin America. The key feature is that they have strong R&D components in their organizational structure. From a structural point of view, technology parks need to be based on the possession of property and to accommodate university and research institutions, which ensure access to research facilities, simplify technology transfer operations, and allow the incubation of spin-off enterprises that can be launched by staffs from university and research institutions.

Thus, Silicon Valley is located near Stanford University and its adjacent Stanford Research Park; the industrial cluster along Route 128 is located near MIT. Taiwan's high-tech Hsinchu Science-based Industrial Park (HSIP) is located near two of the state's best universities, the National Tsing-Hua and the National Chiao Tung universities. Science parks are said to contribute to reindustrialization, regional development, and the creation of synergies.

In Taiwan's case, the HSIP has contributed to a reversal of the state's brain drain and exerted positive spillover effects on its surrounding area. The congregation of high-tech firms also tends to enhance competition between traditional and high-tech industry. Within technology parks, there are numerous variations according to the services offered based on their objectives, which define types and levels of R&D and other technological capabilities required to create and sustain them.

Networking is one of the prominent functions that technology parks can bring to create mutual interaction based on the needs of researchers and entrepreneurs. By encouraging mutual interactions, feedback, and awareness in a close physical proximity, there are two important functions that technology parks are expected to create: facilitation of technology transfer from university and research institutions into business; and stimulation of innovation through the cross-fertilization of ideas between researchers and entrepreneurs.

In terms of stimulation of innovation activities, the clustering of university and research institutions and enterprises is expected to yield more efficient use of innovation resources and link basic research to commercialization through applied research (Link and Scott 2003).

In addition, distinctive possibilities for collective learning and reduced uncertainty and associated risks as a result of innovative behaviors demonstrate the importance of local environment (Branscomb and Auerswald 2001). Such innovation networks favor technology parks. Although technical inputs themselves are obviously necessary for innovation, various experiences inside and outside of technology parks have shown that business skills to bring contacts and interactions into products and services that support such business skills are the essential ingredient in order to allow technology create and sustain such environments.

7.1.5 Export processing zone (EPZ)

Export Processing Zones (EPZs) are an important mechanism for acquiring technology and diffusing it in the local economy. But achieving this requires that strategies to promote the establishment of such zones are designed with long-term technological development in mind. EPZs are areas in developing countries that permit participating firms to acquire their imported inputs duty-free in exchange for an obligation to export 100 percent of their products. This scheme works when selling manufactured goods at world prices is profitable given the low wages of developing countries. The concept has been most widely used in Asia, where they have quickly spread as a policy tool, from South Korea and Taiwan to Malaysia, Indonesia, Thailand, and China.

EPZs can be used as business incubators and be very useful for development of enterprises with export and foreign trade potential. In general, EPZs have better linkages with the international community and bring little potential to strengthen the local economy due to their limited backward linkages or technological spillovers. This is because the focus of EPZs is attracting foreign direct investment (FDI) through facilitating business services and providing access to infrastructure and tax incentives. FDI in turn can lead to an increase in productivity in the host country through technology diffusion to participating domestic firms as well as backward and forward linkages.

However, experience shows that such linkage formations are difficult because most of FDI to developing countries is vertical FDI that has a much lower level of technology transfer than market-seeking horizontal FDI. In vertical FDI, the investing foreign firms fragment their production chain into stages, matching factor intensities of their activities with factor endorsements of host countries. EPZs can match demand and supply between foreign firms and local factories and help incubate new ventures within the zones.

South Korea and Taiwan have been the most successful users of EPZs. Most of their rapid growth rates were attributed to the export orientation and EPZs were the starting point of export-oriented performance standards. In those countries, EPZs and the performance of export by the participating firms were tied to subsidies. In South Korea, higher exporters were given access to cheaper and longer-term investment capital and tariff protection for their sales in the domestic market. Taiwan also gave permission to sell products in several industries in the highly protected domestic market only to high export performers.

7.1.6 Production networks and clusters

Networking is a very important factor to create successful incubation activities, because it fosters SMEs to access skills and highly educated labor, as well as pooled business services. While networking has always been an important component for any incubators, greater attention will be paid to groups of firms, teams, and inter-firm networks than individual firms in the rapidly changing technological and global business environment and this makes networking an even more important tool in incubation activities (Chen, Liu, and Shih 2003).

Networking within the incubator is a critical element to connect needs of participants. Industrial clustering is considered an effective tool for networking, because it brings actors into close proximity. This has been an important assumption behind property-based incubation activities. However, some of the past experiences of technology parks show that effective networks do not occur just by bringing actors such as business entrepreneurs and researchers together. Networks are formed on the basis of mutual needs: cooperation happens when one has a need for goods or services and another can deliver such needs. Therefore, connecting needs, rather than just bringing actors together in close proximity, is the most important role that incubators play.

Costs are an important, often prohibitive, determinant for services offered by incubators. Costs are especially large for technology incubators, which are usually facilities-based. From this reason, so-called incubators without walls or virtual incubators are created. Most of them are in fact technology incubators, often hosted by a university or a research institution. These incubators are non–property-based ventures that require lower fixed investments and have succeeded in serving SMEs in areas where a sufficient critical mass of tenants is lacking. The important characteristics of these incubators are their capability to operate both within and outside of walls. When they operate outside of walls, they serve new ventures without housing them within the incubator facilities by linking via computer and telecommunications networks. Successful examples of this kind of incubator can be found in Brazil, Russia, and Australia.

Networking can also extend to existing and established firms outside the incubator facilities. Both general business and technology incubators can provide their services to existing outside firms (known as affiliate clients) and large or established firms (known as anchor firms). These firms can provide a boost in incubator revenue, serve as a marketing tool, and bring experiences to tenant firms in cooperation with outside firms.

7.2 Unlocking financial capital

7.2.1 Banks and finance institutions

Banks and financial institutions can play an important role in fostering technological innovation. However, their record in this field in developing countries has been poor. There is a need to reform some banking and financial institutions so they can play a greater role in promoting technological innovation. Sustainable development type investment is creating capital opportunities, with investment from superannuation and pension funds making up a large portion of the trillions of dollars currently invested internationally.

Box 21: Availing local capital

A variety of methods can be used to promote the creation of capital markets. These include:

Create sound monetary policies. Reducing cost inhibitors, allowing loans to be secured with intellectual property, and providing insurance and indemnity protection on loans to SMEs.

Provide additional capital incentives for specific technologies. This could be geared towards privately backed VCs and lending institutions in order to create specific policies for supporting SMEs engaged in developing technologies of particular interest. These incentives could include differential rates of borrowing, access to domain experts, or preferential access to new R&D from local or foreign government or university research institutions.

Establish a government-funded venture type investment strategy. Capital markets do not automatically exist for all sectors or technologies. Indeed, part of the very process of development is the creation of such institutions to stimulate interest in a particular type of technology that the government or public deem to be a priority for development, but for which private sector funding is not forthcoming.

Help government initiate capital to become professionally managed. In India, for instance, government funds for R&D and SMEs exist, but the management of these funds often face difficulties with assessing new technologies due to lack of domain expertise or other shortcomings. The "graduation" of such traditional investors to more professional and technological management requires not only government support, but ideally international learning exposure as well.

Support micro-finance. Such schemes are emerging as a key way to help poor entrepreneurs to help themselves. The technological components of such enterprises can be substantial, ranging from food processing to auto repair to solar energy or other initiatives. Micro-finance also provides an opportunity for very small firms to build links and scale, and also facilitates simple technology transfer and the consideration of export opportunities.

There are at least four stock market indexes that track "sustainable businesses": the Domini 400 Social Index in the USA, the National Provident Institution (NPI) Social Index in Britain, the Janizi Social Index in Canada, and the Dow Jones Sustainability Group Index for international shares. Three of these indexes—the Domini 400, the NPI, and the Dow Jones Sustainability Group—have all been around long enough to now have a track record that can be compared to the main markets. In each case, they have all out performed their sustainability-neutral counterparts.

There are also a number of market-based instruments (MBIs) being developed that use trading mechanisms, auctions, and price signals to change corporate behavior. Rather than prescribing behavior or technology use, MBIs allow for more flexibility in the sustainable use and management of natural resources, while providing market mechanisms for development. Many countries, from Poland to the Netherlands, have created rolling funds to provide credit schemes to give companies additional incentives to do the right thing. Thus far, these measures have been seen largely as a feature of developed economies, but they hold considerable potential for less developed countries as well. The government needs to take the lead in this effort, but there should also be substantial inputs from both private sector and non-profit organizations as well.

7.2.2 Venture capital and angel investors

Promote the creation of venture capital and encourage the emergence of angel investors as sources of finance for technological innovation. SMEs have flourished in most developed nations because of the critical role that the capital markets have played in creating that business, especially the role that the venture capitalist market has played (Bruton, Ahlstrom, and Yeh 2003). Venture capitalists (VC) do not just bring money to the table; they help groom these start-ups into multinational institutions. Another advantage of bringing venture capital markets into developing nations may be to ensure the sustainability of the companies in which they invest.

Studies have also shown that companies in developing nations rarely survive beyond the lifetime of the initial founder and owner. In order words, people in developing nations tend to go to their graves with the knowledge, expertise, and assets of the company. On the other hand, more than one person usually owns a VC-funded company and the VC ensure that their investment is safe by always having a succession plan in place.

Individual or angel investors who supplement shortfalls in the funding for new technology ventures provide a large portion of funding for new technology ventures in industrialized countries. Their contributions, however, remain poorly documented. This is mainly because angel markets are associated with transactions in private equity securities that are subjected to the strict disclosure requirements similar to those in public equities. In addition, there is no institutional mechanism that supports this market, which is fragmented and highly localized.

7.2.3 Government procurement

Government technology procurement (GTP) can be an important tool in low-income countries, which are characterized by weak productive sectors and a weak technological demand. While there is an ideological debate the role of public support for procurement—and in fact WTO members have agreed to look into public procurement in the context of trade liberalization—the fact remains that a multitude of countries have created and nurtured entire new industries or lagging old ones on this basis. In so doing, there have been many examples of gradual technological capability being built and of firms becoming competitive globally over time. The critical issues are less whether public procurement is needed and for what purpose, than when it ceases and how it assists firms in competing on their own.

For instance, in the drive to make nationally owned firms globally competitive, the Chinese government promotes domestic computer hardware firms through both direct and indirect support—including favored treatment in government procurement as well as access to technologies developed in state R&D institutions. The Indian government does gives similar support to the country's pharmaceutical industry for public health's "essential" drugs, and other sectors have seen such policies in the past at critical stages of their development.

The Nordic countries show fairly high success rate of public procurement in promoting industrial development, specifically in the telecommunications sector. This has been widely accepted by the general public and various important representative organizations. The GTP lessons these countries learned from its industrial development process are now being extended to other fields such as environmental management and could be used to stimulate technological innovation that is relevant to developing countries.

GTP is currently used the most (and is perhaps ideologically the least contested) in building public health infrastructure and access to medicine. This experience can be used to develop GTP with strict guidelines for the selection of local partners and in the evaluation of the products and services delivered. This is the only way to foster a real learning process. Equally important is to assure that participation is inclusive.

7.2.4 Technology and international trade

International trade is one of the most important sources of impetus for rapid technological innovation. Until recently, the trading system, dominated by the agenda of the WTO, has addressed development only in a piecemeal fashion. Debates on trade at the WTO have been conducted with little reference to a broader vision for how trade fits into development. Concerns over the agreement on Trade-related Aspects of Intellectual Property Rights (TRIPS) have taken center stage. For instance, patent law changes have occupied much of the WTO's time and created inordinate pressures on developing countries to harmonize their systems with those of the advanced industrialized countries.

However, there has been relatively little appreciation for the amount of time institutional reform may take, even when learning from the histories of now industrialized countries. A second important issue that is being neglected is trade-related investment measures (TRIMs), which have important implications on learning supports for enterprises and timelines for institutional reform.

The 2000 WTO Ministerial Meeting recognized that the links between trade and technological development needed to be better understood. They agreed to set up a Working Group on Trade and Transfer of Technology to examine these links and make recommendations on how to accelerate the technology flows to developing countries. The WTO also agreed to put development at the heart of the WTO Work Programme. This agreement, together with the establishment of the Working Group on Trade and Transfer of Technology, has opened a window of opportunity to make the multilateral trading system more technology-oriented. This will be very difficult. There are strong interests working against it, and expectations for significant change are low. But the potential rewards are worth the effort.

7.2.5 Managing intellectual property rights

Protecting intellectual property rights is a critical aspect of technological innovation. However, overly protective systems could have a negative impact on creativity. It is therefore important to design intellectual property protections systems that take the special needs of developing countries into account. Provisions in international intellectual property agreements that provide for technology cooperation with developing countries need to be identified and implemented without further delay.

To encourage innovation and to unlock local capital, individuals and corporations will need to feel that their hard earned research is protected, and in cases where there has been a violation of their intellectual property, that adequate compensation is provided. However, most countries appear to have developed over time without these benefits being structured across the economy in any clear way. Indeed, institutional development of patent regimes usually occurred after a country's firms achieved a significant level of innovation capability and then desired to protect their investments.

Thus, less developed countries may need to work together to think of how to: (1) create an avenue for emulation of products and technology without the infringement of intellectual property rights; (2) use regional and zonal patent right protection; (3) create a loyalty system to facilitate revenue sharing between the patent owner and the local user where the local can only use such a patent within an approved zone; and (4) establish a tiered system of protections that is contingent on the GDP per capita of a country that uses the technology and where the patent was issued.

For example, one scenario could be that the highest level of protection (provisions of TRIPS, level A) needs to be accepted by developing countries with, say, a GDP of more than US$5,000 or perhaps an export criterion; a lesser level B for those with a GDP US$1,000 to US$5,000; and a still lower level C for those with a GDP of less than US$1,000. The C level will meet most of the demands made by the developing countries regarding amendments to TRIPS, while the B level will afford intermediate levels of protection. Applications for intellectual property rights need be made at the highest level taking into consideration the countries of residence, citizenship, or incorporation of the inventors or assignees.

Thus, if one of the applicants or the assignee is from a developed country, the initial application needs to be made in a country with A-level protection. If all the applicants are from a least developed country, they can apply for protection in their own country where the laws may provide C-level protection. However, if these applicants wish to extend their rights to cover a developed country, they would only be able to obtain C-level protection for their invention, even in the developed country that has provision for A-level protection.

Lesser developed countries could be permitted to allow process patents and use these patented methods to make drugs for their own market and for markets in other countries offering C-level protection, but they would not be able to compete in markets with A-level protection. Successful developing countries with C-level protection may become industrialized and in time meet the GDP criteria to reach the intermediate level, and they would then have to amend their laws to afford B-level protection. These might facilitate the eventual adoption of patent regimes desirable to both advanced industrialized and developing countries, while still allowing the latter to frame their own laws.

The TRIPS agreement represented important step in efforts to harmonize intellectual property rules and establish minimum standards for national laws. Most of the key elements of the intellectual property systems of the United States, the European Union, and Japan were similar and could be harmonized. These regions are the largest sources of inventions. Areas of divergence between their systems include first-to-invent system, scope of patentable subject matter, treatment of plants and animals, geographical indications, and the degree to which moral values should influence the granting of intellectual property rights.

For example, the Berne Convention for the Protection of Literary and Artistic Works was substantially revised in 1971 to include an annex on "Special Provisions Regarding Developing Countries." The annex allows a country to "grant non-exclusive, nontransferable licenses to its nationals for the reproduction or translation of foreign-owned copyright works for educational or research purposes." These revisions were justified on the basis of national public interest. Similar revisions were attempted in other intellectual property regimes, but were stalled by the onset of the Uruguay Round of negotiations. It is notable that there have been no major efforts by developing countries to invoke the special provisions of the Berne Convention to grant copyright works to their citizens. This is mainly because of the difficulties associated with the use of compulsory licensing as a development policy instrument.

The need to balance between enforcement of intellectual property rights and meeting the technological needs of developing countries became a key theme in the Uruguay Round of negotiations. The TRIPS agreement reflects this point. In Article 8, TRIPS states that countries "may, in formulating or amending their laws and regulations, adopt measures necessary to protect public health and nutrition, and to promote the public interest in sectors of vital importance to their socioeconomic and technological development, provided that such measures are consistent with the provisions of this Agreement." The agreement (in Article 8.2) provides countries with freedom to adopt measures that "may be needed to prevent the abuse of intellectual property rights by right holders or the resort to practices which unreasonably restrain trade or adversely affect the international transfer of technology." This prevention of abuse clause deals primarily with measures that undermine competition.

But the existence of such flexibility suggests that developing countries will need to formulate their interests through national policy and legislation. The successful use of the flexibility granted in the TRIPS agreement will also depend on the relationship between a country and its major trading partners in the industrialized world. This is because most of the inventions that are likely to be affected by national laws belong to rights holders in the industrialized world.

Another interesting feature of the TRIPS agreement is Article 66.2, which states that "developed country Members shall provide incentives to enterprises and institutions in their territories for the purpose of promoting and encouraging technology transfer to least-developed country Members in order to enable them to create a sound and viable technological base." This provision has received little attention in policy circles despite a 2003 decision of the TRIPS Council that called for annual reports on its implementation. The reports required by the decision will include information on the type of incentive and the government agency or other entity providing it, as well as information on practical functioning of the incentives.

7.3 Energizing human capital

7.3.1 Technological entrepreneurship

It is important for a developing country to create an institutional environment that encourages entrepreneurship. The motivation and encouragement of graduate students to consider entrepreneurship as a valid means of livelihood through creation, extension, and innovation of new and existing technology is essential to this.

In genomics, for example, nurturing entrepreneurship entails certain challenges. The development of marketable health products relies, to a large extent, on a system that supports intellectual property rights through, for example, patents. The use of patents is not inherently antithetical to the notion of global public goods—in fact, one of the aims of the patent system is to disseminate information (and therefore make knowledge public) and discourage "trade secrets."

Patents can also provide incentives for innovation by granting inventors a temporary monopoly on the commercialization of their discoveries, and enabling them to recoup their research and development costs. However, genomics knowledge itself remains non-rival as a global public good, but to ensure its development, genomics-based products (such as diagnostic tests, drugs, or vaccines) are made excludable. This may promote entrepreneurship and market competition.

Promoting technological entrepreneurship improves both the competitiveness of SMEs within a country and stimulates employment. For example, a program at the Swinburne University of Technology in Australia was successful in developing a technological entrepreneurship program in which, in a given year, 87 percent of participants started their own ventures.

A critical issue in providing relevant courses in business schools would be the provision of highly qualified and effective presenters. Business schools may also focus on communicating with industry associations. As most industries obtain their information from these associations, it is important to encourage linkages between these universities and industry. Finally, any entrepreneurial activities should be linked with the building of human capability.

7.3.2 Industry extension services

Knowledge extension can be applied to help meet the MDGs using science, engineering, and technology in many ways. This is a case where ICTs could be effectively applied to help. The person with the knowledge and the person with the problem could be effectively matched using ICTs, and they would not need to be co-located in time or place in order to discuss how to solve a specific problem.

Establishing a virtual center, one that ties into the many existing extension and engineering centers around the world, is an exciting prospect that could bring knowledge to places that badly need it. Training extension officers in pilot projects has been attempted, and an examination of how, where, why, and when this process works, and accumulating the best practices into freely accessible databases, would be another way to use ICTs to effectively and efficiently to diffuse technology and encourage its appropriate adoption in developing countries.

7.3.3 Technological innovation as social learning

There are three important elements to institutionalizing technological learning in any economy: government, enterprise, and research-based academia. These elements are embedded in a wider social setting where civil society plays an important role in shaping the direction and pace of technological learning. While the enterprise acts as a locus of learning, the government acts to facilitate this process. A simple example is when companies use Digital Subscriber Line (DSL) technology to speed up communications, and the government acts to change regulations to drop the price of DSL or other such services within the country. Another example is when a company develops software that demonstrably enhances productivity through better inventory tracking. The government then spurs this innovation by using this software in public procurement for government supply agencies, or assists the company through well-structured trade shows or export incentives to find new foreign markets. In sum, technological change such as the widespread application of ICTs does not occur in a vacuum; it is driven by vastly different structural and institutional elements of different countries.

The United Kingdom and other countries have aggressively pursued the development of ICTs for distance learning at the national level, and some Nordic countries, Germany, and Japan have all used ICTs extensively in tracking enterprise productivity. The technological elements of such expansion of the use of a technology are less interesting than the policy environment and the enterprise capabilities that generated the innovations in the first place. The rest is left to human ingenuity and the ever-present seeking of entrepreneurial opportunities. It is not that citizens of some developing countries lack entrepreneurs; they lack an institutional environment that rewards innovation that takes them from being simply traders to full-fledged entrepreneurs.

Furthermore, the environment that retains skills is as critical as that which generates them. Developing economies are notorious for being unable to stop a "brain drain," although those with some pockets of prosperity are able to attract members of the diaspora back or act to actively facilitate this process (Taiwan did this aggressively in developing its semiconductor industry and the basis for its own information technology revolution, and India's software hubs are seeing a slow but increasing return rate of expatriates). A policy environment that prevents deskilling is vital.

This loss of skill sets may come about through many different processes, from letting universities languish, to eroding the confidence of local individuals to participate in global innovation due to lack of funds or a track record of innovation, to introducing new technologies too rapidly and eroding the infrastructure necessary to sustain previously-made gains, to importing technologies that require foreign technicians to service them without creating a local technical capability.

7.3.4 Form international linkages

International partnerships and linkages are an important aspect of technological development in poor countries. There is a need to provide incentives that encourage such partnerships. These include the diffusion of hardware technologies from centers such as Silicon Valley and Route 128 through diaspora channels to countries like Israel, India, and Ireland. In addition, the potential exists for the establishment of private-public partnerships to invest in new technologies. An often neglected development is the link established between open-source material (often declassified, sometimes from the U.S. Defense Department) from public sector institutes in all these countries and the private sector.

CONCLUSION

If a developing country is to unlock the potential that it has in turning science and technology into business opportunities, it needs to undertake a number of core activities. These include providing broader incentive structures to all firms, while creating an institutional environment that encourages entrepreneurship, rewards innovation, fosters start-ups, and sustains existing firms with injections of capital.

PART III. GOVERNING THE FUTURE

8. IMPROVING THE POLICY ENVIRONMENT

INTRODUCTION

Government policies play a critical role in creating a suitable environment for the application of science and technology to development. More specifically, government policies towards science and technology have a critical role to play in economic transformation. One of the key areas requiring policy adjustment in most developing countries is the way that governments receive advice on issues related to the role of science and technology in development. There is a need for science, technology, and innovation (STI) advice to reach policymakers. The first necessary step is to provide the institutional framework and commit to support such a framework. Among the most successful institutions are the Office of Science Advisor to top political leaders at the president or prime minister level and national scientific and engineering academies.

8.1 Structure and principles of science and technology advice

Science and technology applications can provide significant pointers to aid development, but in order to be effective, governance structures need accommodate them. Governments need technical advice in order to use STI effectively and to assess where to make strategic investments. Drawing upon lessons learned in countries that have used science and technology advising to good effect, this section makes suggestions for activities related to the Millennium Development Goals (MDG).

8.1.1 Structure of science and technology advice

Advising structures differ among countries, depending on their governance structures. For example, in Japan the advising structure is a standing committee that serves the prime minister. In Malaysia, the structure includes a publicly chartered corporation within the Science Advisor's Office that serves the prime minister. In the United States, the office has statutory position within the Executive Office of the President. In many cases, academies also provide advice. The Royal Society of London, on behalf of the InterAcademy Panel (IAP) that consists of ninety national scientific academies, conducted a survey on science advice by academies to governments. It was found that science advice to government is one of the most important functions of a national scientific academy.

The structure of advising may follow a number of models and still be effective, including: (a) the corporate non-profit model; (b) the independent advisory model; and (c) the embedded advisory model. Nevertheless, in each case, certain elements will greatly increase their effectiveness.

First, the advising function should have some statutory, legislative, or jurisdictional mandate to provide advising to the highest levels of government. This protects the advisor from being unduly influenced by political pressures, and it provides credibility and regularity to interactions between the advising and the decision-making roles of government. The advisor should have a trusted and regular link to those making decisions at the highest levels. This trusted link should have some privilege attached to it, so that the science advisor can offer frank advice without fear of later being penalized by interest groups. However, the Office of Science Advisor needs to strike a delicate balance between advice given in confidence to policymakers and some accountability to the public sector, or else the science advisor could be seen as a "mouthpiece" for those in power and lose the ability to interact with the STI community and the public at large.

Second, the structure should have its own operating budget and a budget to fund policy research. This helps the advising structure to create an institutional memory of how decisions are made effectively and how they can be improved in the future. It also assists with coordination of decision-making across government agencies and with outside groups as well.

Third, the science advisor should have access to good and credible scientific or technical information, either from within its own government, from the STI community through national academies, or through international networks. This network of advice should be readily available, so that when decisions need to be made, technical advice is immediately at hand.

Finally, the advisory processes should have some accountability to the public, and some method of obtaining public opinion. This may involve some outreach through tools such as foresight exercises or regular interaction with legislative bodies.

The science advisor should work with those in power to establish a national science and technology vision, one that encompasses specific missions and targets for the sustainable use and enhancement of national capabilities. Examples of these types of mission statements exist in many countries. These offer some guidelines that can be used by countries seeking to implement this type of strategic planning.

Advising takes place at all government levels, and advice can be sought in a variety of ways. It differs in: (1) the level at which scientific input is received; (2) how formal or flexible the advisory process is; (3) the relative use of science advice in different branches of government (executive or legislative); and (4) the degree of decision-making involvement by advisors.

The taxonomy of advising bodies and the circumstances under which they are established are also complex. Some committees are *ad hoc* and flexible, while their counterparts in other countries may be more permanent. In many countries, a single person serves as chief scientific advisor to the head of state and chairs a panel of prominent scientists advising the executive branch. This is true both of the U.K.'s Chief Scientific Advisor and Council for Science and Technology (CST), and the U.S. President's Scientific

Adviser and President's Council of Advisors on Science and Technology (PCAST). Malaysia's prime minister also has a single Science Advisor's Office (SAO).

In contrast to the United States, where input in the executive's decision-making is limited to an intimate circle of task forces and councils, government ministries and departments in many countries are offered more opportunity for participation. In France, for example, responsibility for much of the advising process has been tasked to issue-specific agencies, along the lines of the U.K.'s Non-departmental Public Bodies (NDPBs).

Box 22: National science advice: The case of Malaysia

The Academy of Sciences, Malaysia (ASM) assists the office of the Science Advisor to the Prime Minister. The Science Advisor' Office has instituted a series of far-reaching innovations to the structure of science advice to government at the very top, including establishing institutions within the office for technology prospecting and matching and for venture capital.

A fundamental feature of the ASM model was that a decision was made early on that the academy should first and foremost serve national development objectives. ASM not only integrates the national science and engineering experts, but also the institutions that support scientific, technological and engineering enterprises. ASM has sustained its financial well-being through an initial grant from the government that has underwritten a substantial part of its annual operating and maintenance cost by investment income. This has enabled ASM to have a competent full time staff.

This ASM financial principle has served as a model for existing and new academies in Africa. Nigeria and South Africa have adopted the ASM financial model, while Zimbabwe and Tunisia intend to integrate scientists and engineers in their proposed academies. Another important element of the success of ASM is its vigorous cultivation of international scientific, technological, and engineering linkages through regional and international organizations such as the Inter-Academy Council, Inter-Academy Panel, International Council for Science, the Third World Academy of Sciences, the Association of Southeast Asian Nations (ASEAN) Council of Academics of Science and Engineering, and the Science Council of Asia. This has enabled ASM to freely tap into the vast pool of international scientific, technological, and engineering knowledge, experience, and expertise.

ASM is much less successful in providing scientific, technological, and engineering advice to industry. A particular characteristic of developing countries is the isolation of scientific, technological, and engineering academic organizations from the industrial community. The contacts are minimal and crossover of personnel from one to the other is limited. In addition, the forms of certification and validation of merit are entirely different. There is a need to construct means by which the applied and engineering sciences are brought closer to academia. One way to do this is to encourage scientific, technological, and engineering academies and associations to take on more functional activities such as training and certification of professionals and paraprofessionals working in industry. Member institutions of the World Federation of Engineering Organizations (WFEO) are already doing this.

In some instances, in both France and the United Kingdom, these agencies also have the executive responsibility for legislative implementation. Some Swedish policy-oriented agencies also implement government policies, relying on internally employed researchers to provide scientific expertise for their decisions. In contrast to Sweden, however, expertise of the pluralistic U.K. system's NDPBs constitutes only a fraction of the overall scientific advice given to the executive branch.

Sectoral agencies also rely on a mix of sources for advice. Particularly in Sweden, sectoral agencies run on internal expertise capacity, and often overlap with executive science advisors. In other countries such as France, Italy, and the United Kingdom, sectoral ministries and departments tend to rely on a variety of committees for their information. The United Kingdom in particular has a relatively devolved mechanism for informing decision-makers about scientific matters and challenges, with sources including: the Royal Society, the Royal Academy of Engineering, the Council for Science and Technology, the Office of Science and Technology, the prime minister's science advisors, individual departmental science advisors, a Parliamentary Committee on Science and Technology, and an Association for the Advancement of Science.

As to the independence of sectoral agencies, both the U.K. and German systems are prime examples of ministerial sovereignty over science advice. Ministries tend to have their own permanent committees, although in Italy, a common response to emerging problems seems to be rather *ad hoc*, issue-based committee formation. In countries such as the Newly Independent States (NIS), sources of STI advice to sectoral agencies have included: national scientific, technical, and engineering academies; autonomous research councils and organizations to which work has been outsourced; non-governmental organizations (NGOs); and agencies of other governments.

Looking at the different science advisory mechanisms for legislatures: each U.S. Congressional office and committee has a number of staff experts, while U.K. science advisors only provide expert oversight for the executive branch of government. In even greater contrast, the China People's Political Consultative Conference (CPPCC) functions as an explicitly in-house advisory group of policy experts trained in scientific disciplines for the National People's Congress (NPC) and State Council, China's two primary legislative bodies. These differences extend beyond organizational characteristics to financial and political lines as well; in this case, the CPPCC is fully funded by the Chinese central government.

Such funding issues are at the heart of debates over how to establish STI advice mechanisms, ranging from national academies to global commissions. Notably, the robustness of China's science advisory mechanisms and their span across organizations seems due in large part to their healthy funding from government. Government support, and how it shapes (or does not shape) the nature of a science advisory institution, institutional procedures, and institutional capacity (e.g. human resources) is a recurring theme for budding STI advice groups in developing countries.

8.1.2 Functions of science and technology advice

The functions of advising follow the same basic principles of trust, credibility, and accountability that appear in the discussion above, but these functions are the ones that are common to most science advising activities:

- Advising should seek to create a **coordination** function across government—one that takes the different needs and missions of various agencies into account.

- Efforts should be made to seek a **consensus** or a process of **deliberation** of views about investments and applications of science and technology. This can involve representatives from government, business, and the public.

- **Adjudication mechanisms** should be explored to see how to discuss and make decisions on highly contentious issues. The process should be as transparent as possible.

- The advisor should work with experts to determine how to **measure the effectiveness** of science and technology investments within government.

- Advisors should work towards collecting internationally recognized **indicators** of science and technology operations.

- **Policy research** should be nurtured, and best practices from other countries should be imported.

- A process of identifying **emerging issues** should be put in place, so that contentious issues can be anticipated and possibly mitigated by open discussion and research.

- A process of "**prospecting**" for best practices and good technologies should be undertaken.

8.1.3 Quality of science and technology advice

Maintaining quality of expert advice depends on a variety of conditions, including: early and appropriate identification of issues; recognition and appropriate treatment of scientific uncertainty and risk; and diversity of opinion and cross-disciplinary approaches. In this respect, academies of developed countries generally strive for independence and disinterestedness in outcomes of academy analysis. Academies of developing countries, on the contrary, increasingly work towards improving engagement with government.[4] In general, they all aim towards a broader, overarching accountability to the public.

Early and appropriate identification of issues is a primary factor in the quality of science advice at high levels of government. Anticipation of hazards and salient issues for STI policy has become increasingly important. Responsiveness of science advisory

[4]. Science advisors of developing countries have emphasized disinterestedness and academy independence from government as principles currently feasible only for developed countries. They have highlighted that engagement, conversely, should be the ideal to which academies in developing countries strive. This argument is based on the relative availability of resources to countries for the creation and maintenance of independent academies—that is, an academy of a developing country cannot afford to be financially disengaged from government.

mechanisms to emerging issues has also proven to be particularly important in building and maintaining trust between science advisors and the public, politicians, and the wider scientific community. Proactive, rather than reactive, science advice has been invaluable in past experiences with such crises, as reflected in comparisons of how different national governments coped—or failed to cope—with the spread of the recent Severe Acute Respiratory Syndrome (SARS) epidemic.

Recognition and appropriate treatment of scientific uncertainty and risk are important elements of science advice. In environmental policymaking based on scientific analysis, the precautionary principle has been advocated, such that reasonable concern would override some scientific uncertainty when policymakers are considering steps to prevent environmental destruction or environmental risks to public health. Science advisors and policymakers receiving science advice, most notably in the European Commission, have argued that this principle should also be applied to other issues, such as biosafety (e.g., genetically modified organisms' impact on consumer health).

Diversity of opinion and cross-disciplinary approaches in response to scientific questions are also essential to robust science advice. A variety of perspectives improves the accuracy of scientific evidence, analysis, and conclusions, and can boost public faith in the science advisory system. Developing countries with a small technological base may find a challenge in gathering a diversity of appropriately qualified STI advisors, and even greater difficulty in assembling groups of experts from across disciplines. It is therefore important they conserve and build on the small critical mass in one multi-disciplinary academy. For example, the Academy of Sciences, Malaysia (ASM) was first mooted as an academy of engineering. Its founders had the wisdom to engage the whole Malaysian technological community such that ASM is now an organization embracing the whole range of sciences, engineering, and technology in government, academia and industry.

Independence and disinterestedness in outcomes on the part of science advisors are also key principles that govern many science advisory processes. Public trust in STI advice and resulting policies depend to a great extent on whether or not a given advice mechanism relies on information sources that are independent from government and industry. Major factors in public perceptions of disinterestedness include: individual advisors' organizational separation from advice recipients in government, freedom from political influence, and financial independence from government.

In developing countries with a small STI base, advisors are often of necessity chosen even though they have governmental connections and ties with industry, such that full independence may simply be infeasible. In developed countries, such situations will be viewed as posing conflicts of interest (e.g., in the U.S. climate change debate), but in developing countries, such trade-offs may be unavoidable.

Accountability to the public is a crucial element of successful science advice. This typically requires some method of obtaining public opinion and may involve outreach through tools such as foresight activities or legislative processes. But such accountability should be promoted in ways that reduce transactions costs while enhancing the quality of advice provided. For example, subjecting every stage of the advisory process to public scrutiny may increase the level of oversight, but not necessarily the quality of advice.

8.1.4 Inclusiveness and openness

Increasing the inclusiveness and openness of STI advice processes can strengthen public trust, while also improving the robustness of the final advice and product. Gathering a diversity of STI perspectives from across disciplines, sectors, institutional boundaries, and stakeholder interests has been said not only to spark public dialogue and accountability, but also to check accuracy of facts and opinions. Such proactive work in the early stages of science advice can help to avert or at least minimize controversy in the long term.

In some countries, however, inclusiveness and openness are perhaps the most controversial principles of STI advice. While they have taken quick root in the open climate of the U.S. advisory process and have recently become more prevalent in scientific advisory systems of other countries, such democratically influenced guidelines may not be appropriate for the traditionally closed political systems. Science advisory mechanisms should still be informed to a good extent by domestic political traditions, financial circumstances, and organizational history.

National responses to recent public health crises provide a good illustration of this reality. Based on recent scandals, damaged public trust and growing concern about the failures of governments to account for scientific analyses have bred increasing expectations that science advisory processes should be inclusive and transparent. In established democracies, these sentiments have been the primary force for changes in STI advice mechanisms: in the United Kingdom, the practice has been that top leaders acquire a breadth of advice from top sources, especially in cases of scientific uncertainty, and openly publish advice and related documents.

Scandals regarding contaminated blood and mad cow disease that rocked the French and British systems respectively, have spurred concerted efforts towards even greater transparency and interactivity in science advice. As a result, even more meetings of the U.K. science advisory committees are open to the public, and in France, all science advice related to food and drug safety is published online.

The international media raised the question of whether China would open up its public health advice system during the initial stage of the SARS epidemic. Subsequently, China demonstrated its openness about SARS from its top leadership downwards. China has also made moves in the area of environmental policy to open up rule making for some public input, and has modified both national and local laws to accommodate WTO requirements. But China’s tradition of government control over information is still strong, representing a political perspective on information access fundamentally different from that of the United Kingdom and France.

An example of a highly successful science advisory system that has decided not to adhere strictly to "established" principles is that of the Academy of Sciences, Malaysia (ASM). ASM founders were well aware that developed countries had lauded independence from government as an important principle of science advice, but recognized, even more importantly, that financial wherewithal of the academy depended on significant support from the Malaysian government. Academies and science advisory organizations of developing countries face such trade-offs regularly, and their experiences suggest that governments should not accept the above "established" science advice principles religiously, but instead select those guidelines that are reasonable for their own circumstances.

8.1.5 Review and feedback mechanism

Governments use a range of different methods to review S&T decisions and obtain feedback from within the system, in order to ensure that S&T advice is serving the interests of government and the public good. Most of these review mechanisms focus primarily on the robustness of the discussion process rather than on any estimated value of a given policy's outcome. Three models derived from an analysis of existing review and feedback systems help to illustrate how such review and feedback can work: agency outreach; independent advice; and convened advice. The trade-offs of each model differ according to country circumstances.

Agency outreach. In developed countries, many research agencies often seek input from the scientific establishment to assist in the priority-setting process. This priority-setting model involves establishing workshops that bring together leading scientists and technologists from government, industry, and academia. Discussions and debate identify common themes for research within each field of science, which then compete at the program and directorate levels as budget priorities are set. Application of this framework would work especially well in countries that already have an established S&T advisory system, in which advice recipients are accustomed to inclusiveness and openness in their decision-making processes. Moreover, because the primary goal of this agency outreach would be for the decision-makers to draw on a diversity of perspectives, it might also work more effectively in large countries with established S&T communities. In other words, the agency outreach may require more human and financial wealth than developing countries with scarce finances or new S&T communities can afford.

Independent advice. An independent advisory model offers more maneuvering room for developing countries. This model of priority setting is one in which the science agency turns to an objective group for input. From there, a task group might be formed, which in turn could convene workshops and panels to provide themes for priority setting in astronomy and astrophysics. This board could: concentrate on scientific objectives rather than the methods by which the objectives are implemented; prioritize scientific questions of significance; and account for costs and technical feasibility. This kind of independent advisory group would also add credibility to the advisory process. This independent advisory model, in which an S&T academy would be an ideal leader, is a more promising option than the agency outreach model for small countries with developing S&T

communities. This model is more realistic for developing countries, as it allows for success with a range of institutional variation and financial circumstances. As long as the public and concerned actors feel confident that the advisor can in fact provide objective advice, it may not even matter whether such an institution is supported by government funds.

Convened advice. A third model for input from experts is the convened science advisory board model. These advisory committees can have members with several-year terms and can be convened to advise on scientific and technical issues. Such a science board would offer external advice, and would have a greater stake in outcomes than workshop panels. Similar to the advisory board model, the convened board model provides more flexibility for small and developing countries to tailor their own review and feedback systems.

All three of these sample processes for review and feedback bring the views of scientists and stakeholders to bear on government decision-making about science. While the agency outreach model may be too taxing for small countries with few S&T-related resources, the independent advisory and convened board models assume less about the pre-existing S&T base and therefore give developing countries greater room for adaptation and individual tailoring. Realistically, the successful selection and implementation of any institutional arrangement and principles will ultimately depend on a given country's bottom line: whether the national economic circumstances, S&T community size, and other conditions permit the luxury of an STI advice group's financial and organizational independence from government.

The past evolution of these guidelines reflects the political philosophy and mood of the country at the time they arose; the financial wherewithal of the organizations involved; national economic conditions; public perception of science and government, respectively; and other circumstances that influenced the ability of an STI advice mechanism to function successfully. Realistically, financial solvency, organizational capacity, and political credibility are the "bottom line" in determining the feasibility of establishing science academies and similar advice mechanisms; they are limiting factors in the process of institutional innovation in science advice. As such, countries should select their own science advice principles based on an assessment of these domestic conditions.

8.1.6 Involving the wider society

Science and technology is applied to innovation within a social and economic context. STI has no intrinsic moral or ethical value—ethics emerges as knowledge and its application merges with culture. There may be cases where a local culture understands, but simply decides not to adopt, a technology. In other cases, local knowledge can greatly enhance the effective application of knowledge. This process works best when stakeholders (citizens, knowledge workers, and politicians) take part in the decision-making process.

Citizen councils have been used quite effectively in Europe. The mechanism of "consensus councils" has a long tradition of settling contentious matters in science and technology. In the late 1980s, for example, the Danish Board of Technology defined consensus councils as bodies of lay citizens that would be convened to consider the evidence on a particular science or technology issue, participate in public debate, and ultimately provide a consensus report of their findings and policy recommendations. The purpose of the process was not to dictate policy, but instead to help the legislature understand where an educated population might stand on an issue before considering specific policies. This success led to the engagement of similar processes in the Netherlands, the United Kingdom, and France.

However, the councils would need to be identified, constituted, and convened at the local and regional levels and around specific issues (e.g., genetically modified foods) in order to be effective. In addition, the councils need to have a real part to play in recommending policy changes that stick.

An especially interesting exercise is related to public opinion about science and technology. This type of public opinion polling has been performed in Europe, the United States, and through some grass-roots organizations in India, showing people's hopes and fears related to STI. In Uruguay, an exercise of this type was done in the late 1990s, showing that 57 percent of the population was in favor of doing R&D with the country's own budgetary resources, given their belief that this would enhance the country's development prospects.

However, when asked about the relationships between STI and dependency, the less educated members of society answered that STI deepened the country's dependency on external factors, while the best educated members of society answered the exact opposite. One could interpret this to suggest that those with less formal education knew less about the country's indigenous capabilities in STI, believing the solution of various developmental problems to have been exclusively foreign, while the best educated knew well the local achievements in solving-problems through R&D. From this interpretation one might suggest that an important media effort is required to present STI not only as "world achievements" but also as local ones, using and benefiting from local skills and local learning institutions at increasingly higher levels of good practice.

8.1.7 Foresight

A significant need in developing countries is the consistent identification of core technologies, combined with prioritization and targeted funding. While foresight activities have a role in identifying new technologies, it remains highly relevant for developing the entire innovation system. The process of technological innovation requires the dedication of resources to identifying core technologies. In ICTs, the challenge is not only to identify emerging trends, but also to give weights to mature technologies within realms such as semiconductors, cellular technology, or even landline telephones. In genomics, on the other hand, the challenge is how forecasting activities similar to the Biotechnology Prioritization Study by the University of Toronto can be encouraged and tailored to the specific needs of each country, taking into account the availability of resources and local technological capability.

However, if the focus is only on new technologies, critical infrastructure supporting the manufacture and services of existing technologies often fall prey to neglect. With new technologies comes the risk of deskilling of populations associated with mature technologies. When cellular telephony replaced landlines in some countries, labor pools trained in equipping and maintaining key landline technologies were at risk. These types of workers should be considered an important resource to sustain or retrain in those countries considering the newer technologies.

Foresight, a method of establishing priorities in STI funding and policy based on analysis of current trends and expectations of future developments, is a prime example of innovative STI advice activities dependent on finances, capacity, and political mandate. In practice, foresight is a collection of participatory exercises that seeks to obtain the views of different parties, identify trends, create networks, and inform decision-makers and the public about scientific developments. When wisely designed, these exercises can provide an important source of advice to the STI decision-making process, and can change trends in developing countries. The long-term nature of development and the time frames associated with the implementation of the MDGs provide an opportunity to include foresight activities as a central theme in the application of STI to development.

Notably, foresight methods were developed and have evolved to meet the needs of advanced industrialized countries. This is not to say that developing countries cannot benefit from foresight: in fact, in some ways, they can take even greater advantage of it, particularly in regards to the networks created by participatory exercises. A recent study issued by the International Council for Science (ICSU), for example, found that developing have used foresight even more than developed countries in order to focus on both technological areas as well as developments needed to solve more immediate problems.

Box 23: The benefits and costs of foresight: Japan's "Visions"

Japan's pre-1990s foresight activity offers an example of success with the most recent wave of innovation, information technology. Through a participatory process of establishing "Visions" for STI progress in Japan, representatives from both government and the STI community collaborated successfully on ways to stimulate industry R&D and, in turn, socioeconomic development. In more recent years, however, the deterioration of the Japanese economy has demonstrated the limitations of "Visions" and similar foresight approaches. STI foresight is neither a failsafe predictor of future issues nor a cure-all for economic woes. Moreover, in times of economic difficulty, finding the resources to maintain formerly high-priority programs becomes extremely difficult. As the Japanese example conveys, while foresight can be important for strategizing how to use STI for future growth, at the same time dire economic conditions can cut off the possibility of financial support for such activities. Developing countries often face this circumstance.

Source: Watanabe, 2000.

The increasingly global nature of R&D also challenges national concepts of STI foresight and the resulting support for science. Foresight continues to use traditional political borders and disciplinary structures as the parameters for discussion. This makes sense, given the need to define and bound any problem for intelligent discussion. Nevertheless, trends towards the globalization of science mean that national foresight efforts may miss some of the very important global and cross-disciplinary trends that are emerging outside the bounds of their exercises.

While many economists and policymakers see STI as a contributing factor for economic growth and development, the ways in which science advice is applied towards this end depends upon the capacity of the country to follow through on this advice. Foresight exercises for developing countries should be tailored to the needs and capacities of the country sponsoring the foresight. This will increase the chances that foresight will successfully provide more than mere advice to the decision-making process, but have the greatest chance for successful development and commercialization.

8.2 Institutions for science and technology advice

The establishment and maintenance of STI advisory institutions in developing countries is an essential component of development planning. These activities are often considered expensive and so their cost-effectiveness is often discussed. But a number of countries have devised methods that not only increased the effectiveness of these activities, but also reduced their costs relative to their strategic importance.

The experience of Malaysia provides an example of academy innovation that has transcended these constraints, an innovation driven by its founders' mantra of "the 3 M's": money, manpower and mandate. Before ASM's inception in 1995, the STI bodies positioned to support the provision of STI advice through the Science Advisor's Office were government-*cum*-industry–funded research institutes. These institutes were primarily focused on major agricultural and plantation-based industries like natural rubber, palm oil, and forestry, and typically engaged in applied research; they did not pursue holistic research in new technologies like information and communications technologies (ICTs), biotechnology, nanotechnology, and space technology that Malaysia has needed in order to meet its economic growth challenges.

Since then, ASM has progressed a great deal in achieving its mission of national development. Its activities range widely from promoting science education to providing consultancy studies to the Malaysian government, and its international affiliations include InterAcademy Panel (IAP), the ICSU, the Third World Academy of Science (TWAS), and the Science Council of Asia (SCA).

The seemingly constant expansion of these activities reflects a thriving institutional innovation, the definition of which is increasingly growing to include such expansion of responsibilities as: science education and popularization; international networking, as ASM in Malaysia and Academia Sinica have done through participation in a constellation of different international associations; and general pursuit of the public good, as ASM has done in assisting the development of STI in Islamic countries worldwide. This expansion of STI advice activities to include new and creative roles on the international scene has become an important element of academy innovation.

As the ASM mantra suggests, funding, capacity building, and political capital have been vital in enabling the organization to pursue new and creative roles. To be highly relevant to national development, ASM founders consciously established ASM by act of parliament, emulating the U.S. National Academy of Sciences that was established by act of congress and signed into law by President Abraham Lincoln. In other countries, this strong connection to government might have led critics to challenge the academy's independence and disinterestedness, but ASM has risen above that issue by building its political credibility through participating in international partnerships and eliciting widespread participation from medical doctors, engineers, architects, surveyors, and town planners in professional practice, and technologists in industries and from the academic scientific community. Such activities have also proven to be valuable in building the necessary organizational capacity for ASM to pursue its range of new responsibilities. In the final analysis ASM has also used this success in its application of the principles of inclusiveness and openness to maintain its reputation of active participation and contribution to national development through STI.

Such institutional evolution is increasingly demanding that academies find creative ways for acquiring necessary funding and capacity, not to mention political capital and sources of credibility. ASM is a good example of an academy that has met these challenges.

Most academies now function in an advisory capacity, though they vary in origin, structure, and mission, all of which are to some extent determined by their sources of funding. While some academies have grown from the STI community, independently of the government, others have been formed through efforts on the part of government ministers. Some academy leaders pride themselves on taking no money from government, while others find that they need to accept government grants to pursue necessary expansions or simply to maintain the capacity to stay afloat.

As academies' credibility in the eyes of the public depends on their image of disinterestedness and independence, the political implication of government support is often a hot-button issue: academies seem to either pride themselves on financial (and assumed political) independence from government, or defend their government connections passionately. Funding conditions also bear on academies' choice between pursuit of basic ("pure or "fundamental") science and of applied science. Governments and STI advisors of developing countries may well view the practice of basic science research as a luxury, given the urgency with which more obviously pressing, practical problems demand attention and applied science from the STI community.

All academies tend to defend their independence from political influence, but national academies actually vary a great deal in their degree of financial reliance on government. In contrast to the Science Council of Japan (SCJ), which is an organ of the Prime Minister's Department, the fully government-funded Chinese Academy of Sciences (CAS) or the government-supported ASM, the Engineering Academy of Japan (EAJ) resists any government funding, relying instead on membership fees (US $1,000 per year). Notably, academy leaders internationally have agreed that financial jumpstarts and even ongoing support from government can be vital for young academies in developing countries with small scientific, technical, and engineering communities, as neither the private sector (through endowment) nor prospective members (through fees) can provide sufficient funds to initiate and run a successful academy.

For example, in Malaysia, STI foresight is entrusted to the Science Advisor's Office (SAO) in the entity called the Malaysia Industry-Government Partnership for High Technology (MIGHT). With the active participation of industry and the assistance of ASM, results of this foresight exercise can reach the top echelon of political leadership. Thus far, Malaysian foresight focus has been on the establishment of indigenous SMEs in high-tech sectors and STI innovations in traditional industries such as agriculture and construction. At present, it is not preoccupied with reaching a level world-class science that its leaders consider "beyond the capacity of most small developing countries."

But one major factor in the choice to pursue foresight activities, as with other STI advice choices, is that of financial feasibility. Scenario planning across a range of technologies or national goals, for example, can be a lengthy and expensive effort, costing more than $500,000. Road-mapping efforts that focus on a single technology could cost less, although their outcome would be more targeted. In this way, the budget available to conduct a foresight initiative can affect the choice of method, and the choice of method in turn affects the exercise outcome. Needless to say, cost and budget also impact whether a given country opts to undertake foresight activities at all.

Another important consideration is that many developing countries need to improve the management of data collection and preparation so that it is reliable, consistent and meaningful. Again, this issue is primarily one of human resources and organizational capacity.

8.3 Building science and technology advisory capacity

8.3.1 Training decision-makers in science and technology policy

The successful implementation of STI policy requires the existence of appropriate capacity in policy analysis in the civil service, which in turn presupposes the existence of training facilities for policy analysis in local universities and research institutions. In many countries, a large number of civil servants are not technically trained and it can considerably aid the process of integrating STI advice into decision-making if these individuals receive training in technology management, science policy, and foresight techniques. For example, the Commonwealth Partnership for Technology Management has been successful in training civil servants from African countries towards this end.

Another example comes from China where scientists and engineers are regularly invited to make presentations to the high-level central government officials, including the prime minister and the president. These events take place several times a year, and government officials give them a high priority. Additionally, a factor sometimes cited as propelling STI in China is the fact that many political leaders are trained engineers. Another example worth further investigation in the context of technology management is Singapore, where many civil servants have a university degree in engineering. This integration of technicians within the decision-making process can be an effective way to integrate STI into national strategies.

Box 24: Strengthening the capacity of policymakers

While science, technology, and innovation are increasingly recognized as important factors in the economic transformation of developing countries, their prominence in development policy is generally understated. To address this issue, the Belfer Center for Science and International Affairs at Harvard University's John F. Kennedy School of Government has launched a short-term training program on Science, Technology, and Innovation Policy. The program provides high-level leaders from government, academia, industry, and civil society with a unique opportunity to learn from others' experiences and strengthen their ability to integrate science and technology into national development policy.

The program is designed for high-level decision-makers (ministers, deputy ministers, senior civil servants, diplomats, development leaders, university presidents, and chief executive officers) from both developing and industrialized countries. Participation is also open to senior advisors to heads of state and government. Participants are drawn from a diversity of leadership positions including: finance; economic and development planning; industry; trade; science and technology; education; health; agriculture; energy; environment and natural resources; information and communications; and foreign affairs. Participants attend five days of classes that will rely largely upon collective approaches to problem-solving using case studies. Emphasis is placed on interactive learning involving participants from a diversity of backgrounds and interests.

These sessions assess developing countries science and technology policies. Attention is given to examining the emerging role of science, technology, and innovation in meeting basic human needs, strengthening the capacity of developing countries to participate in the global economy, and enhancing the ability of nations to make the transition towards sustainability. The sessions address specific policy themes related to biotechnology, information and communications technologies, and environmentally sound technologies. They explore issues like science and technology advice, human capacity, enterprise development, and investment in research and development. The curriculum covers: innovation systems; international technology cooperation; technology and foreign direct investment; intellectual property rights; and managing new technologies.

8.3.2 Science and technology policy fellows

Science and technology policy fellows attached to various branches of government help to improve the quality of decision-making by providing decision-makers with the best available information on trends in science and technology. In addition to formal training, developing countries could develop a system of science and technology fellows that could be attached to the various branches of government. The American Association for the Advancement of Science (AAAS), for example, administers a science and diplomacy fellows program that allows scientists to be attached to the various branches of government. The fellows help government officials to have access to timely and accurate scientific and technological information needed for decision-making.

To complement these efforts, the U.S. Government announced the creation of the Jefferson Science Fellows (JSF) program at the U.S. Department of State. The fellows will be tenured academic scientists and engineers from U.S. institutions of higher learning. This program will promote closer engagement of the scientific, technological, and engineering community in the formulation and implementation of U.S. foreign policy.

8.3.4 Building science and technology capacity among negotiators

Strengthening the capacity of negotiators to engage in technological issues is an essential aspect of international relations. The United Nations Conference on Trade and Development (UNCTAD) Science and Technology Initiative aims to equip key diplomats from developing countries with the ability to address science and technology issues related to trade, especially intellectual property, biodiversity, energy, and climate negotiations. The aim of the program is to have collective learning occur from examples across the globe, while allowing diplomats to represent their countries through the analysis of complex issues. The WTO's priority in capacity building is training of trade negotiators from developing countries, which should include training in science and technology issues.

The term "STI diplomacy" applies to activities of international cooperation and compromise on issues of STI policy, just as the term "biodiplomacy" has described the process of international negotiations related to ecological resources and ecosystem services. In recent years, the importance of this field has grown in tandem with STI advances on issues ranging from infectious diseases and biotechnology to sustainability and information technology. In all of these areas, international public servants and diplomats increasingly depend on STI expertise to make their policy decisions, although many currently do not receive systematic advice.

Most issues of STI now cross lines of national sovereignty. Science and technology had already become a truly international activity in the twentieth century, with a great rise in transnational collaboration on STI issues. In the past few decades, existing and new institutions have taken on the mantle of providing international science advice in innovative ways. International scientific assessments, for example, have contributed a great deal to both national and international policy formulation, as well as private-sector decision-making, on issues of stratospheric ozone depletion, biodiversity loss, and climate change. In cases such as these, although the two respective communities of STI and international relations remain very different, they have begun to recognize the urgency of improving their communications and collaboration. According to many experts, the input from this broad range of stakeholders and disciplines has been vital to progress on otherwise intractable trans-boundary conflicts.

The activities of STI diplomacy and resulting networks offer excellent opportunities for a variety of resource-sharing: exchanging lessons from past experiences, opening countries up to better funding opportunities from international sources, and sharing organizational capacity and STI expertise. Notably, participation in international networks can also help to build the domestic political and scientific credibility of academies and analogous science advisory institutions, especially in developing countries.

But STI diplomacy still presents challenges, particularly due to its relative lack of formal procedures and systematization. First, the right people to "cross over" and serve in informative, science advisory roles need to be identified; then, relationship-brokering on both formal and informal levels is the next step for improved institutional coordination. More coordination along these lines is needed to improve decision-making regarding controversial issues; both science and policymaking communities need to work to forge better channels and methods for both formal and informal communication; discussion of foreign policy issues need to be infused with scientific and technical knowledge that reflects high technical standards; and scientists need to understand the global governance structures that may impinge on the conduct or reporting of their research.[5]

8.3.5 Strengthening scientific and technical academies

Scientific and technical academies of all types (including science, technology, engineering, medicine, and agriculture) can play an important role in providing advice to government. They need to be strengthened or reformed to play this function. And where they do not exist, efforts should be made to promote their creation. Scientific and technical academies will need to cooperate with other institutions—especially judicial academies—whose activities influence scientific and technological development through court rulings.

Other examples of creative institutional responses to these challenges are sprouting up around the world, due in large part to individual "connectors" who work to plug home organizations into the growing constellation of international alliances. In addition, innovative relationship building is occurring in groups such as the Global Science Forum of the OECD and within UNESCO, the International Council for Science (ICSU), and academy groups such as the InterAcademy Panel (IAP) and its offshoot, the InterAcademy Council (IAC).

Scientific and technical academies will need to cooperate with other academies whose work affects scientific and technological development. For example, judicial systems around the world are increasingly dealing with scientific issues. For example, the Philippine Judicial Academy is engaged in educating its membership on the linkages between law and science. It is therefore important to create linkages between scientific and technical academies and judicial academies.

[5] One example of this phenomenon is the recent debates about whether scientific journals should withhold publication of articles that editors judge to have national security implications.

CONCLUSION

In summary, the diversity of political experience, resources, and constraints in both developed and developing countries means that the creation of STI advice mechanisms cannot be guided by a "one-size-fits-all" mentality. Tailoring of advice principles and institutional innovation needs take place according to domestic circumstances. In order to create and implement successful science advisory policies and mechanisms, it is imperative to understand the broader political context of an existing system. Funding, capacity, and political credibility are the greatest factors limiting science advisory mechanisms; these three parameters limit and even shape the degree to which budding science advisory organizations can actually adhere to science advice "principles" that have been recommended by established science advisory groups. It is thus vital that science advisory system founders not only tailor underpinning principles and processes to domestic circumstances, but also prioritize the above structural and institutional elements of a proposed science advisory system according to the realities of costs and available government resources.

9. GLOBAL TECHNOLOGY GOVERNANCE

INTRODUCTION

International organizations can play a critical role in promoting the application of science and technology to the implementation of the Millennium Development Goals (MDGs). These organizations—especially United Nations organs and allied intergovernmental bodies—have extensive influence on the development agenda through their normative and operational activities. Efforts to bring these organizations in line with the requirements of the MDGs will require that these organizations focus their attention on their functions and competencies, and not on their jurisdictional mandates.

9.1 Normative activities

9.1.1 Guidance and advocacy

The five-year review of the implementation of the Millennium Development Goals to be held in 2005 should be used to generate fresh guidance and advocacy that is based on a deeper understanding of the role of technological innovation in economic growth. Policy guidance and advocacy are central functions of many international organizations. The guidance and advocacy are either provided through universal bodies such as the UN General Assembly or the decisions of the conferences of parties to various international agreements. The Millennium Declaration is an example of a guidance and advocacy statement. The effectiveness of the declaration will depend largely on the extent to which its elements are translated into the governmental and non-governmental programs. The relevance that governments place on technology for development can be discerned from such guidance and advocacy documents.

Currently, the general attitude in a number of international agencies towards technology is skeptical or even hostile. This is partly because technology challenges traditional views about human progress. Another source of disenchantment with technology is the view that technological risk has had a negative impact on culture and the environment. Those who hold this view argue that slowing down technological advancement contributes to environmental and cultural protection. The United Nations, through its guidance bodies, will need to take a more active role in articulating the importance of technology in economic transformation.

9.1.2 Rule-making and standards-setting

International rule-making and standards-setting institutions such as the World Trade Organization (WTO), the International Organisation of Standards (ISO), and the Bretton Woods institutions set a wide range of rules that affect the capacity of developing countries to build domestic scientific and technological capabilities.

Much of the debate on international rules and standards has revolved around issues such as intellectual property rights. Indeed, it is generally assumed that the WTO Agreement on Trade-related Aspects of Intellectual Property Rights (TRIPS) is the most important international treaty affecting technological innovation in developing countries. This view is indeed a misrepresentation. There is a need to review other rule-making and standard-setting activities to determine the extent to which they can be adjusted to suit the interests of developing countries.

The trade-related investment measures (TRIMs) agreement under WTO, for example, may have more serious implications for technological innovation in developing countries that compound the concerns raised by the TRIPS agreement. This treaty, however, receives little policy attention. Equally important are standards relating to environmental management and other economic activities.

9.1.3 Scientific and technical advice

The United Nations system should strengthen its capacity to advise nations on the linkages between technological innovation and development. This will entail building competence in science and technology advice in the executive offices of United Nations.

In his report to the Millennium General Assembly entitled, "We the Peoples," the United Nations Secretary-General Kofi Annan says that the UN "is the only body of its kind with universal membership and comprehensive scope, and encompassing so many areas of human endeavor. These features make it a uniquely useful forum—for sharing information, conducting negotiations, elaborating norms and voicing expectations, coordinating the behavior of states and other actors, and pursuing common plans of action."

The United Nations, especially those organs that address international peace and security issues such as the Office of the Secretary-General and the Security Council, will increasingly address technological issues associated with development. It is therefore imperative that they equip themselves with the capacity to address technological issues. The United Nations secretary-general, for example, could provide leadership in this area by strengthening the UN's capacity for science and technology advice and by encouraging the creation of such facilities in other United Nations agencies.

9.2 Operational activities

9.2.1 Working multilateral and bilateral institutions

Multilateral financial institutions led by the World Bank and the regional development banks should play a leading role in promoting technological innovation in developing countries. Similarly, bilateral institutions should place science and technology at the core of their development assistance programs. This process will

involve creating and strengthening institutions of science and technology advice in multilateral and bilateral agencies.

Multilateral financial institutions are already involved in extensive lending and operational activities that significantly influence technological innovation in developing countries (Watson, Crawford, and Farley 2003). Multilateral financial institutions can play two important roles involving leadership as well as funding. The first task is particularly important because the World Bank has only had modest activities on the role of technological innovation in development.

The first step would be for the World Bank to integrate technological considerations into their operations. For example, their support to infrastructure could be pursued as classical lending projects. But the same activities could be structured as a foundation for technological innovation and linked to domestic research and entrepreneurial activities. Such leadership would not necessarily require additional funding, but it would require these institutions to upgrade their internal capacity to address technological issues. They would need to create technology-related performance standards for their investment activities and demand that their partners use complementary standards.

Providing such leadership may also entail strengthening the internal advisory capabilities of these institutions. For example, offices of chief scientists in these institutions would need to be strengthened to take on additional technological advisory functions to ensure that there is sustained advice to the leadership of these institutions and complementary integration of technological issues into their operational programs. In other words, these institutions would need to strengthen their internal capacity for reformulating their activities in terms of technological innovation.

The second activity would involve providing additional funding or refocusing existing financial support. Multilateral financial institutions have a wide range of facilities that can be deployed to provide additional financial support that can serve as incentives for innovation. The lessons of the Global Environment Facility (GEF) in providing incremental funding to investment projects to ensure that they provide global environmental goods could be applied to technological innovation. The challenge would be to create mechanisms that can help to leverage additional investment to innovation activities in lending projects. This does not necessarily need to be a new fund, but a commitment to devote a certain share of investment funding to supporting innovation-related activities. There are several incentives that are used in various countries to promote innovation that can be adapted to the needs of multilateral financial institutions.

Bilateral assistance institutions play a critical role in promoting cooperation between industrialized and developed countries. Over the decades, these agencies have made significant contributions in fields such as capacity building (with a focus on human resources and to some degree institutional development). They are also engaged in a wide range of specific projects around the world. Much of the work of these agencies is guided by changes in a host country and often reflects foreign policy objectives. Indeed, development assistance is more of an exercise in "development diplomacy" than economic transformation. Many of these agencies distinguish programs on "poverty eradication" from "economic growth." The scope of the projects tends to be limited and often de-linked from long-term economic activities that involve private sector activities, which is where the impetus for growth actually lies.

A few bilateral development agencies have a strong focus on science and technology. But even where such programs exist, they do not have strong links with domestic scientific institutions in donor countries. Improving this situation will require a review of the purpose of development assistance in light of the MDGs. More critically, aid programs will need to reflect the obvious view that the best way to address poverty is to stimulate economic growth. This in turn will require a focus on science, technology, and innovation. This approach would create new opportunities for greater international partnerships involving government, universities, civil society, and the private sector. It would also provide opportunities for shifting from the current focus on development advocacy towards more practical programs that involve developing technical competence in poor countries.

Reforms will be needed in bilateral development agencies to promote such partnerships. The agencies will need regular science and technology advice and would better served by creating internal offices that provide guidance on the role of science and technology in international development. This approach will deepen international cooperation by creating close linkages between economic institutions in donor and recipient countries.

9.2.2 Research, development, and capacity development

United Nations agencies have a wide range of activities related to research and development. These activities are modest in scope. The strength of the United Nations, however, lies in advocacy for research in areas of relevance to development. In addition, the United Nations could also contribute to capacity building in developing countries in the engineering sciences and technical education. United Nations Educational, Scientific and Cultural Organization (UNESCO), in cooperation with other agencies such as the United Nations Industrial Development Organization (UNIDO), could create an inter-agency consortium (in partnership with universities, the private sector, and professional associations) to strengthen engineering and technical institutions in developing countries.

The United Nations system (defined broadly to included allied international organizations) undertakes a wide range of research activities, including basic, applied, and policy research. Indeed, the diversity of these activities is a reflection of the complex nature of the global system (NRC 2002). This diversity exists both between as well as within organizations.

A large share of this research aims at addressing developing country challenges. The specialized agencies of the United Nations—such as UNESCO, the International Atomic Energy Agency (IAEA), World Meteorological Organization (WMO), the World Health Organization (WHO), the Food and Agriculture Organization (FAO), and the United

Nations Industrial Development Organization (UNIDO)—are engaged in a variety of scientific research activities in their areas of expertise and jurisdiction. Similar activities are reflected in the activities of programs of the United Nations as well as regional economic commissions. Much of this work is carried out through partnerships and alliances with other research institutions around the world.

Examples of research include the activities of the International Centre for Genetic Engineering and Biotechnology (ICGEB), located in Trieste, Italy and New Delhi. ICGEB conducts research, provides services to member states, and leads training activities. The centers research includes both basic and applied research challenges and places an emphasis on developing country problems. More than 300 people from thirty different countries work in its laboratories.

The United Nations is also involved in R&D activities through its support of the Consultative Group on International Agricultural Research (CGIAR), created in 1971. The aim of the CGIAR is to contribute to food security and eradicate poverty in developing countries through the use of research, partnerships, capacity building, and policy support. The CGIAR, as a consortium of public and private members, supports a network of sixteen centers with activities in more than 100 countries to leverage scientific research to address hunger and poverty, improve human nutrition and health, and protect the environment. It operates on an annual budget of $320 million contributed by a consortium of donors, which supports more than 8,500 CGIAR scientists and scientific staff. The CGIAR manages one of the world's largest *ex situ* collections of plant genetic resources in trust for the world community. It holds over 500,000 accessions of over 3,000 crop, forage, and agroforestry species. The collection includes farmers' varieties, improved varieties, and the wild species from which those varieties were initially derived. These collections have been placed under FAO administration.

A large portion of United Nations' research is devoted to social issues. Agencies such as the United Nations University, the United Nations Research Institute for Social Development (UNRISD), and the United Nations Institute for Training and Research (UNITAR) have been at the forefront of such work. Some United Nations organs have made important contributions to the understanding of the role of technology in development over the years. For example, the United Nations Conference on Trade and Development (UNCTAD) has been a leading supporter of policy research related to the role of technology in development. The United Nations University, through its research centers, has also been a major player in policy research.

Although many of the R&D activities of the United Nations system attempt to address the needs of the poor, the UN often does not have the requisite institutional arrangements that would help to translate research knowledge into goods and services. In other words, links with other institutions such as the private sector are generally weak. The CGIAR, for example, has not been able to establish effective and durable links with sections of the private sector that hold the key technologies needed to advance agricultural production. The problem is not simply the lack of interest to foster such partnerships, but much of the challenge lies in differences in research cultures as well the character of public sector funding upon which the system relies. Solving these challenges will require a greater emphasis on designing institutional arrangements that allow for greater linkages between United Nations research and private sector activities.

Most UN agencies focus their S&T-related activities on human and institutional capacity building, education, and training. UNESCO is the technical agency of the UN with a specific mandate for science and technology. It is active in the basic and applied sciences in such areas as mathematics, physics, chemistry, life sciences, applied sciences such as water and earth sciences, engineering and technology, and in science analysis and policy. UNESCO is host to four of the five intergovernmental programs in science—the Intergovernmental Oceanographic Commission (IOC), the Intergovernmental Geological Correlation Programme (IGCP), the Intergovernmental Hydrological Programme (IHP), Man and the Biosphere Programme (MAB), and the Management of Social Transformations Programme (MOST). UNESCO is also working on the ethics of science and technology, hosts the Commission on the Ethics of Scientific Knowledge and Technology (COMEST), and the Universal Declaration on the Human Genome and Human Rights.

The focus in the basic and engineering sciences is on capacity building. In the basic sciences, UNESCO has programs in mathematics, physics (and the International Centre for Theoretical Physics in Trieste, Italy), chemistry, and the life sciences. There is a proposal for an international program in the basic sciences focusing on networking and the support of centers of excellence. Activities in the engineering and technology program include engineering education, accreditation, standards, and a specific program on engineering, technology and poverty eradication.

UNESCO is also in close cooperation with the International Council for Science (ICSU) and World Federation of Engineering Organisations (WFEO). The Water Sciences division hosts the Intergovernmental Hydrological Programme. In the earth sciences, the focus is on geoscience, space science, and disasters. Science analysis and policy focuses on the development of science policies and application to national development. In engineering and technology, science analysis and policy also includes a focus on innovation, university-industry cooperation, the commercialization of R&D, and the role of innovation in development (Carayannis, Alexander, and Ioannidis 2000; Looy, Debackere, and Andries 2003).

9.2.3 Open access to scientific and technical information

The United Nations has been at the forefront of championing the need to promote open access to information and technology. It can therefore play a critical role in promoting the concept of "open access," especially in the field of scientific and technical journals (PLoS 2003). This is a role that the United Nations could champion as it continues to redefine its focus.

The Internet has made it possible to share scientific and medical knowledge more widely than ever before. Despite the potential for cost-effective and virtually instantaneous dissemination of new research, however, widespread access to scientific and medical literature has yet to be realized. "Open access" publishing is an exciting departure from the traditional subscription-based model of scientific publishing, a system that often frustrates the attempts of scientists, clinicians, and other interested users to search, read about, and share important scientific discoveries. While the prospect of freely available, comprehensive Internet archives of scientific literature is certainly a compelling vision, the financial logistics of open access remain a source of uncertainty for some stakeholders in scientific publishing.

Box 25: A model "open access" venture: The Public Library of Science

The Public Library of Science (PLoS) is a non-profit organization of scientists and physicians committed to making the world's scientific and medical literature a freely available public resource. The venture is led by Harold Varmus, former director of the National Institutes of Health (NIH) and co-recipient of a Nobel Prize for studies of the genetic basis of cancer, who currently serves as the president and chief executive officer of the Memorial Sloan-Kettering Cancer Center in New York City.

The Internet and electronic publishing enable the creation of public libraries of science containing the full text and data of any published research article, available free of charge to anyone, anywhere in the world. Immediate unrestricted access to scientific ideas, methods, results, and conclusions will speed the progress of science and medicine, and will more directly bring the benefits of research to the public.

To realize this potential, a new business model for scientific publishing is required that treats the costs of publication as the final integral step of the funding of a research project. To demonstrate that this publishing model will be successful for the publication of the very best research, PLoS will publish its own journals. *PLoS Biology* launched its first issue on October 13, 2003, in print and online. *PLoS Medicine* will follow in 2004.

PLoS is working with scientists, their societies, funding agencies, and other publishers to pursue its broader goal of ensuring an open-access home for every published article and to develop tools to make the literature useful to scientists and the public.

The Bethesda Principles, developed during an April 2003 meeting convened by the Howard Hughes Medical Institute, provide a definition of an open-access publication. First, the author(s) and copyright holder(s) grant(s) to all users a free, irrevocable, worldwide, perpetual right of access to, and a license to copy, use, distribute, transmit and display the work publicly and to make and distribute derivative works, in any digital medium for any responsible purpose, subject to proper attribution of authorship, as well as the right to make small numbers of printed copies for their personal use. Second, a complete version of the work and all supplemental materials, including a copy of the permission as stated above, in a suitable standard electronic format is deposited immediately upon initial publication in at least one online repository that is supported by an academic institution, scholarly society, government agency, or other well-established organization that seeks to enable open access, unrestricted distribution, interoperability, and long-term archiving.

Source: http://www.plos.org/index.html

Open access to scientific and medical literature allows anyone, anywhere, with a connection to the Internet to find and read published research articles online, and to use their contents in the course of scholarship, teaching, and personal inquiry. With open access, published material is expediently archived in a public digital repository which enhances the utility of all deposited papers by allowing sophisticated searching, manipulation, and mining of the literature using existing and emerging tools. Storing works in a public repository ensures the long-term preservation of the literature as a freely accessible resource, irrespective of the fate of the depositing entity or of any change in its policies regarding open access. A complete version of the work and all supplemental materials, including a copy of the permission as stated above in a suitable standard electronic format, is deposited immediately upon initial publication in at least one online repository that is supported by an academic institution, scholarly society, government agency, or other well-established organization that seeks to enable open access, unrestricted distribution, interoperability, and long-term archiving.

The dissemination of scientific discoveries and ideas provides the foundation for progress in science and medicine. The more widely and freely accessible it is, the greater the value of peer-reviewed research. For authors, open-access literature maximizes the potential impact of their work. Anyone can access their manuscripts, increasing the likelihood that their works will be read, cited, and used as the basis for future discoveries.

For the scientific community, open access unleashes full-text literature into a single information space. Unrestricted access to scientific data, such as genetic and molecular information, has revolutionized life science research over recent years; open access to the treasury of scientific and medical literature will have similarly profound benefits for research. For research libraries, open access will help contain the spiraling costs of subscriptions to scientific serials. Mergers and market concentration within the publishing industry are placing increasing pressures on the budgets of university science libraries and other archives of research, and open access to peer-reviewed journals is a long-term solution to the problem that has become known as the “serials crisis.” Beyond the research community, open access will make scientific knowledge available to others who cannot afford access to subscription-based journals—clinicians and other health professionals, educators, students, and the general public. Open access to the literature will benefit research, education, and health.

Open access requires a systemic change in the way that scientific publishing is funded. Scientists have historically relied on print as the most effective medium for sharing and promoting their work. When information was encoded as ink on paper and distributed using trains, trucks and boats, a large portion of publishing costs was in printing and distribution, and each additional copy entailed an expense for the publisher. In this context, the subscription-based business model for scientific publication was sensible, relatively efficient, and served science well.

Today, however, the costs involved in scientific publishing are almost entirely in the steps leading to production of a final electronic document, and the costs to produce and distribute each additional copy electronically are infinitesimal. If revenue can be generated to completely cover the costs of producing an electronic document, the document can then be made freely available to anyone with an Internet connection.

Open access is intended increase the amount of information available, especially those researchers who cannot pay because of limited funding in the fields or in the regions of the world in which they work. The Public Library of Science (PLoS), a pioneer in this field, acknowledges that publication charges are a burden for some potential authors. PLoS and BioMed Central (BMC), the U.K.-based open access publisher, offer fee waivers or discounts for authors who cannot pay in full. BMC has received support from the Open Society Institute (OSI) through its Budapest Open Access Initiative to offset publication charges for authors from particular countries, the majority with economies in transition. One can imagine similar arrangements where grants support publication in particular disciplines or with urgent policy implications, as the OSI arrangement with BMC does for these geographic regions.

In the long run, this open access model will thrive when there is a redistribution of the money that exists within the scholarly publication system. Costly individual and institutional subscriptions can be eliminated, thus freeing up funds from libraries, universities, and ultimately from research grants—funds that can then be used to pay for publication charges. Many research-funding agencies—particularly those that invest in health, the environment, and other areas of particular concern to developing countries—already acknowledge that the dissemination and sharing of information and data is crucial to the advancement of their goals. These agencies can do more to assert that open access publishing is an important mechanism to facilitate this global sharing of knowledge.

Open-access publishing advocates recognize that not everyone has affordable, reliable, or uninhibited access to the Internet. The "digital divide" between the developed and developing world is a problem that must be addressed with creative solutions (Quibra et al. 2003). But we should not let the digital divide prevent the international community from finding creative ways to promote access to knowledge. In fact, the existence of open access facilities such as PLoS should serve as a signal of the urgency to provide the infrastructure needed to link the developing world to the global fund of knowledge. Open-access publishing is already addressing the knowledge divide—with explicit support from publishers, funders, and other stakeholders. For the full participation of all researchers in the publishing enterprise, the international community can ensure that the divide is replaced by a multidirectional global flow of information and knowledge. The leadership of the United Nations, especially through its agencies dealing with science, education, and research can play a critical role in promoting measures that allow for the full use of PLoS-like facilities by developing countries.

The emergence of an open access regime for academic journals raises interesting possibilities for extending the concept to technological fields. Every year large quantities or patents expire, bringing into the public domain new knowledge that had hitherto been available only upon royalty payment. This knowledge represents an important reservoir of ideas that can be directly utilized in meeting development needs. However, little attention has been paid to this fund of knowledge. In addition to expired patents, inventors are increasingly interested in making their ideas available free of royalty for use in meeting the needs of poor nations. But there are only a handful of mechanisms designed to promote such activities. Extending the open access model to technological information would be a natural extension of current efforts to broaden the space for human creativity.

CONCLUSION

This section has emphasized the urgent need to realign the activities of international institutions to reflect the technological requirements for implementing the MDGs. This effort will not only help deploy available financial and other resources to meet the MDGs, but such a process will also help in the identification of gaps in available resources. These efforts need to be undertaken in the context of a better understanding of the sources of economic growth. The five-year review of the implementation of the MDGs in 2005 offers a unique opportunity to start this re-conceptualization process.

10. CONCLUSION

Many of the options for action in this report are already part of the development strategies in most countries. These strategies may, however, not have been formulated with the sense of urgency and priority that has informed this report. Indeed, most of the options for action will be implemented over the long run or are contingent on complementary adjustments in other countries, regions, or the international economic system. There are, however, a few strategic measures that need to be taken at the national and international levels in the short-run. These measures include the options related to creating and strengthening institutions of science and technology advice at the national and international levels. National efforts to establish and strengthen institutions of science and technology advice need to be accompanies by similar activities at the global level. Of particular importance are multilateral and bilateral institutions as well as various organs of the United Nations.

In addition to these measures, developing countries should initiate reviews of their educational systems to examine the degree to which they address development challenges. More specifically, the review process should focus on the role of higher education in development and the place accorded to training in science, technology, and engineering. Finally, developing countries should review and strengthen national programs designed to promote business development. These measures can be achieved in the next five years and will pave the way for more systematic implementation of additional measures aimed at achieving the MDGs in particular and sustainable development in general.

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Appendix A: Technology performance index

			Technology creation			Diffusion of recent innovations		Diffusion of old innovations				Human skills			
TAI rank		**Technology achievement index (TAI) value**	**Patents granted to residents** (per million people) 2001[a]	**Receipts of royalty and license fees** (US$ per capita) 2001[b]		**Internet users** (per 1,000 people) 2001	**High- and medium-technology exports** (as % of total goods exports) 2001	**Telephones** (mainlines and cellular, per 1,000 people) 2001		**Electricity consumption** (kilowatt-hours per capita) 2000		**Mean years of schooling** (age 15 and above) 2000	**Gross tertiary science enrolment ratio** (%) 1995-97[c]		**Old TAI rank**
1	Korea, Rep. of	0.428	461	14.6		521	31.5	1,106	d	5,607		10.8	23.1		5
2	United States	0.409	307	135.5		501	32.6	1,118	d	12,331	e	12.1	13.8	f	2
3	Japan	0.405	861	82.4		384	29.1	1,174	d	7,628	e	9.5	10.3	g	4
4	Singapore	0.390	0	97.0	h,i	412	56.5	1,196	d	6,948		7.1	27.2	i	8
5	Finland	0.377	16	112.5		430	26.6	1,351	d	14,588	e	10.0	27.3		1
6	Sweden	0.364	54	160.5		516	21.7	1,529	d	14,471	e	11.4	16.0		3
7	Netherlands	0.322	184	107.5		491	26.5	1,388	d	6,152		9.4	9.9		6
8	United Kingdom	0.321	68	134.5		330	30.1	1,358	d	5,601		9.4	15.4		7
9	Ireland	0.317	109	90.1		233	46.5	1,258	d	5,324		9.4	12.7		13
10	Australia	0.312	66	15.4		371	6.9	1,115	d	9,006	e	10.9	25.2		10
11	Germany	0.312	234	38.3		374	20.1	1,317	d	5,963		10.2	14.7		11
12	Canada	0.298	39	48.2		467	11.4	1,038		15,620	e	11.6	14.0	f	9
13	Israel	0.283	55	68.0		277	31.9	1,373	d	6,188		9.6	12.3	f	18

14	Norway	0.282	111	34.3	464	4.5		1,547	d	24,422	e	11.9	11.6		12
15	New Zealand	0.275	67	16.0	461	4.1		1,076	d	8,813	e	11.7	13.0		15
16	Belgium	0.269	83	86.3	310	13.5		1,244	d	7,564	e	9.3	14.2	f	14
17	Hong Kong, China (SAR)	0.266	3	16.0	387	32.2		1,439	d	5,447		9.4	9.8	f, g	24
18	Austria	0.263	165	16.9	387	14.4		1,285	d	6,457		8.4	13.8		16
19	France	0.261	186	42.3	264	24.0		1,179	d	6,539		7.9	12.8		17
20	Philippines	0.241	0	(.)	26	66.6		192		477		8.2	6.5	f	44
21	Iceland	0.224	18	0.0	599	2.3		1,529	d	24,779	e	8.8	7.6		0
22	Russian Federation	0.220	95	0.4	29	3.2		296		4,181		10.0	20.4	g	0
23	Malaysia	0.219	..	0.9	273	50.8		512		2,628		6.8	3.1	f	30
24	Hungary	0.210	18	9.4	148	27.3		873		2,909		9.1	8.4		22
25	Slovenia	0.208	97	7.2	301	14.1		1,139	d	5,290		7.1	10.6		23
26	Italy	0.201	15	7.6	269	11.7		1,355	d	4,732		7.2	13.6		20
27	Greece	0.201	1	1.3	132	7.5		1,281	d	4,086		8.7	17.1	f	26
28	Spain	0.200	43	8.9	183	10.5		1,167	d	4,653		7.3	15.7		19
29	Czech Republic	0.191	24	3.6	147	15.9		1,057		4,807		9.5	8.2		21
30	Slovakia	0.178	16	3.0	125	7.5		689		4,075		9.3	10.4		25
31	Portugal	0.173	5	2.5	281	9.3		1,199	d	3,834		5.9	12.0		27
32	Bulgaria	0.169	16	0.3	75	4.8	j	551		2,962		9.5	10.9		28
33	Chile	0.169	..	0.3	201	0.8		575		2,406		7.6	13.4		37
34	Argentina	0.166	..	0.6	101	3.2		416		2,038		8.8	12.0	g	34
35	Poland	0.164	22	1.2	98	8.6		554		2,511		9.8	6.3	f	29
36	Croatia	0.157	26	24.3	111	11.0		760		2,695		6.3	10.5		31
37	Romania	0.157	30	0.7	45	7.2		356		1,513		9.5	7.7		35
38	Mexico	0.154	1	0.4	36	28.5	j	354		1,655		7.2	5.2		32
39	Thailand	0.150	..	0.1	58	28.9		222		1,448		6.5	5.3		40
40	Costa Rica	0.146	0	0.2	93	25.7		305		1,630		6.1	5.7	g	36
41	Panama	0.136	..	0.0	41	2.0		294		1,331		8.6	8.8		42

42	Uruguay	0.130	..	(.)	119	1.8		438	1,924		7.6	7.3		38
43	China	0.126	4	0.1	26	24.2		248	827		6.4	3.2		45
44	Peru	0.122	..	0.0	77	0.6		137	668		7.6	7.4	f	48
45	Bahrain	0.121	..	..	203	(.)		728	8,507	e	6.1	6.7	f	0
46	Trinidad and Tobago	0.109	0	..	92	1.5		437	3,692		7.8	3.4		41
47	Bolivia	0.097	..	0.2	22	3.0		158	387		5.6	7.7	f, g	46
48	Ecuador	0.095	0	..	26	0.9		170	624		6.4	6.0	f, g	53
49	South Africa	0.095	0	1.2	65	3.8		353	3,745		6.1	4.0		39
50	Kuwait	0.095	..	0.0	88	0.5	k	594	13,995	e	6.2	4.5		0
51	Turkey	0.093	1	0.0	60	7.0		581	1,468		5.3	4.7		0
52	Brazil	0.091	4	0.6	47	12.5		385	1,878		4.9	3.3		43
53	Iran, Islamic Rep. Of	0.088	8	0.0	16	0.2		201	1,474		5.3	7.6		50
54	Algeria	0.086	0	..	6	0.1	j	64	612		5.4	7.5		58
55	Dominican Republic	0.085	..	..	21	5.7		257	788		4.9	5.7		55
56	Colombia	0.085	(.)	(.)	27	3.4		249	788		5.3	5.5		47
57	Sri Lanka	0.085	0	..	8	5.1		80	293		6.9	1.5		62
58	Indonesia	0.083	0	..	19	10.4		66	384		5.0	3.2		60
59	Paraguay	0.081	..	32.0	11	0.9		255	838		6.2	2.2		52
60	Tunisia	0.080	0	1.6	41	4.8		149	939		5.0	3.9		51
61	El Salvador	0.080	..	0.2	23	6.7		236	587		5.2	3.4		54
62	Syrian Arab Republic	0.077	2	..	4	0.1	j	115	900		5.8	4.6	g	56
63	Egypt	0.073	1	0.7	9	1.8		147	976		5.5	3.7		57
64	India	0.066	0	0.1	7	5.5		44	355		5.1	1.8		63
65	Jamaica	0.065	1	2.3	38	1.1	j	449	2,328		5.3	1.7		49
66	Nicaragua	0.062	..	..	14	0.6		59	267		4.6	3.7		64
67	Honduras	0.061	1	0.0	14	0.5		84	499		4.8	3.0	g	61

68	Zimbabwe	0.060	0	..	9	0.9	j	51		845		5.4	1.6		59
69	Kenya	0.045	0	0.2	16	2.2	j	30		106		4.2	0.3	f	68
70	Pakistan	0.042	(.)	(.)	3	0.8		29		352		3.9	1.4	f, g	65
71	Ghana	0.036	0	..	2	0.3	j	21		288		3.9	0.4	f, g	67
72	Mozambique	0.027	0	..	2	12.2		14		53		1.1	0.2		72
73	Senegal	0.025	..	0.2	10	1.7		56		121		2.6	0.4	f, g	66
74	Tanzania, U. Rep. Of	0.023	0	(.)	3	0.7		17		56		2.7	0.2		70
75	Nepal	0.023	..	..	3	1.3	j	14		56		2.4	0.7		69
	Afghanistan	..	..	..	..	..		1		..	e	1.7	..		0
	Albania	..	0	..	3	1.2		149		1,073		..	2.4		0
	Andorra	..	..	..	..	14.1			d	..	e	..	..		0
	Angola	..	..	1.2	1	..		12		88		..	..		0
	Antigua and Barbuda	..	0	0.0	90	26.0	k	804		..	e	..	..		0
	Armenia	..	41	..	18	4.1	j	147		944		..	4.0		0
	Azerbaijan	..	0	..	3	0.5		214		1,852		..	7.4	f	0
	Bahamas	..	..	..	55	4.0		597		..	e	..	..		0
	Bangladesh	..	..	(.)	1	2.9		8		96		2.6	..		0
	Barbados	..	0	0.9	56	12.5		679		..	e	8.7	6.5		0
	Belarus	..	38	0.1	42	5.4		302		2,678		..	14.8		0
	Belize	..	0	..	73	0.7	j	302		..	e	..	..		0
	Bhutan	..	..	..	7	..		26		..	e	..	..		0
	Bosnia and Herzegovina	..	0	..	11	..		171		1,473		..	..		0
	Botswana	..	0	(.)	30	0.5		273		..	e	6.3	1.7		0
	Brunei Darussalam	..	..	..	102	..		659		7,263		..	0.4		0
	Burkina Faso	..	..	..	2	1.7		11		..	e	..	0.2		0
	Burundi	..	..	0.0	1	0.1		7		..	e	..	..		0
	Cambodia	..	..	..	1	..		19		..	e	..	0.3		0

Cameroon	..	..	..	3	0.1		27		183		3.5	..	0
Cape Verde	..	..	0.1	27	3.2		215		..	e	..	..	0
Central African Republic	..	..	..	1	13.6		5		..	e	2.5	..	0
Chad	..	..	..	1	..		4		..	e	..	0.1	0
Comoros	..	..	..	3	0.3	j	12		..	e	..	..	0
Congo	..	..	..	0	..		55		86		5.1	..	0
Congo, Dem. Rep. of the	..	..	..	0	..		3		40		3.0	..	0
Côte d'Ivoire	..	..	(.)	4	0.2	j	63		..	e	..	..	0
Cuba	..	0	..	11	..		52		1,049		7.7	2.8	0
Cyprus	..	0	..	218	9.4		1,087	d	3,958		9.2	..	33
Denmark	..	64	..	429	20.0		1,461	d	6,079		9.7	9.6	0
Djibouti	..	..	..	5	..		20		..	e	..	..	0
Dominica	..	0	0.0	116	1.0		398		..	e	..	..	0
Equatorial Guinea	..	..	..	2	..		47		..	e	..	..	0
Eritrea	..	..	..	2	..		8		..	e	..	..	0
Estonia	..	10	1.5	300	24.5		809		3,628		..	13.4	0
Ethiopia	..	..	..	0	0.4		5		22		..	0.3	0
Fiji	..	..	..	18	1.3		211		..	e	8.3	..	0
Gabon	..	..	..	13	0.2	j	234		697		..	..	0
Gambia	..	0	..	13	..		67		..	e	2.3	..	0
Georgia	..	30	..	9	14.6		235		1,212		..	21.1	0
Grenada	..	0	0.0	52	14.6		392		..	e	..	..	0
Guatemala	..	(.)	..	17	4.2		162		335		3.5	..	0
Guinea	..	..	0.0	2	0.2		11		..	e	..	0.5	0
Guinea-Bissau	..	..	..	3	..		10		..	e	0.8	..	0
Guyana	..	..	..	109	..		178		..	e	6.3	2.8	0
Haiti	..	..	..	4	3.2		21		37		2.8	..	0
Iraq	..	..	..	..	..		29		1,450		4.0	..	0

Jordan	..	..	..	45	12.5		296		1,236		6.9	..		0
Kazakhstan	..	75	0.0	9	2.5	j	157		2,622		..	13.7		0
Kiribati	..	..	..	23	..		48		..	e	..	..		0
Korea, Dem. Rep.	..	0	..	0	..		21		..	e	..	..		0
Kyrgyzstan	..	9	0.2	30	3.9	k	83		1,606		..	3.3	f	0
Lao People's Dem. Rep.	..	..	..	2	..		15		..	e	..	..		0
Latvia	..	41	1.1	72	6.1		586		1,887		..	10.7		0
Lebanon	..	..	..	78	6.4		416		1,814		..	4.6		0
Lesotho	..	0	5.6	2	..		37		..	e	4.2	0.3		0
Liberia	..	0	..	0	..		3		..	e	2.5	..		0
Libyan Arab Jamahiriya	..	..	..	4	1.8		118		3,921		..	..		0
Liechtenstein	..	..	..	447	..		1,062	d	..	e	..	..		0
Lithuania	..	21	0.1	68	7.9		589		1,768		..	13.2		0
Luxembourg	..	188	459.1	360	15.6		1,700	d	13,050	e	..	..		0
Macedonia, TFYR	..	13	1.6	34	2.8		373		..	e	..	7.7		0
Madagascar	..	(.)	(.)	2	1.9	k	13		..	e	..	0.4		0
Malawi	..	0	..	2	0.3		11		..	e	3.2	..		0
Maldives	..	..	12.8	36	..		168		..	e	..	..		0
Mali	..	..	..	3	..		9		..	e	0.9	..		0
Malta	..	48	1.7	253	56.5		1,141	d	4,018		..	4.2		0
Marshall Islands	..	..	..	16	..		86		..	e	..	..		0
Mauritania	..	..	..	3	..		53		..	e	..	..		0
Mauritius	..	..	(.)	132	4.3		483		..	e	6.0	1.1		0
Micronesia, Fed. Sts.	..	..	..	43	..		87		..	e	..	..		0
Moldova, Rep. of	..	46	0.3	14	3.8		197		720		..	12.4		0
Monaco	..	433	..	466	..		1,529	d	..	e	..	..		0
Mongolia	..	36	0.0	17	0.9		133		..	e	..	4.7		0
Morocco	..	0	0.8	14	6.6		204		447		..	3.2		0

Myanmar	..	..	(.)	0	..		6		69		2.8	2.3	0
Namibia	..	..	..	25	1.1		119		..	e	..	0.4	0
Nauru	..	..	..	..	..		290		..	e	..	..	0
Niger	..	..	..	1	0.4		2		..	e	1.0	..	0
Nigeria	..	..	..	1	(.)	j	8		81		..	1.8	0
Oman	..	0	..	46	1.1		213		2,952		..	2.4	0
Palau	..	..	..	..	..		..	d	..	e	..	..	0
Papua New Guinea	..	..	..	9	0.5	j	14		..	e	2.9	..	0
Qatar	..	..	..	66	(.)		568		14,994	e	..	..	0
Rwanda	..	..	0.0	3	(.)		11		..	e	2.6	..	0
Saint Kitts and Nevis	..	..	0.0	79	7.8		537		..	e	..	..	0
Saint Lucia	..	0	0.0	82	2.6		334		..	e	..	..	0
Saint Vincent and the Grenadines	..	..	0.0	48	1.7	j	292		..	e	..	..	0
Samoa (Western)	..	..	..	17	..		72		..	e	..	..	0
San Marino	..	..	..	513	..		1,347	d	..	e	..	..	0
Sao Tome and Principe	..	..	5.1	60	..		36		..	e	..	..	0
Saudi Arabia	..	0	0.0	13	0.7		258		4,912		..	2.8	0
Serbia and Montenegro	..	13	..	56	5.8	j	416		..	e	..	9.9	0
Seychelles	..	..	..	110	(.)		800		..	e	..	..	0
Sierra Leone	..	0	..	1	..		10		..	e	2.4	..	0
Solomon Islands	..	..	0.2	5	..		19		..	e	..	..	0
Somalia	..	..	..	0	..			d	..	e	..	..	0
Suriname	..	..	0.0	33	0.5	j	374		..	e	..	..	0
Swaziland	..	0	0.2	14	0.7		85		..	e	6.0	1.3	0
Switzerland	..	257	..	307	27.2		1,460	d	7,294		10.5	10.7	0
Tajikistan	..	0	..	1	..		36		2,137		..	4.8	0
Timor-Leste	..	..	..	..	..		..	d	..	e	..	..	0

Togo	..	..	0.0	32	0.2		36	..	e	3.3	0.4	0
Tonga	..	..	..	28	..		112	..	e	..	..	0
Turkmenistan	..	0	..	2	0.5	j	82	1,071		..	..	0
Tuvalu	..	..	..	100	..		65	..	e	..	..	0
Uganda	..	0	..	3	1.0		14	..	e	3.5	0.3	0
Ukraine	..	212	0.1	12	4.8	j	256	2,293		..	..	0
United Arab Emirates	..	0	..	315	..		956	10,725	e	..	3.5	0
Uzbekistan	..	18	..	6	..		69	1,612		..	..	0
Vanuatu	..	..	..	27	..		35	..	e	..	..	0
Venezuela	..	..	0.0	47	0.6		373	2,533		6.6	..	0
Viet Nam	..	0	..	12	..		53	286		..	..	0
Yemen	..	..	..	1	..		31	107		..	0.2	0
Zambia	..	0	..	2	1.2		20	556		5.5	..	0

Note: The technology achievement index was first presented in Human Development Report 2001 (United Nations Development Programme. 2001. Human Development Report 2001. New York: Oxford University Press.). For technical details please refer to this report, available online at http://hdr.undp.org/.

a. For purposes of calculating the TAI, a value of zero was used for countries for which no data were available.
b. For purposes of calculating the TAI, a value of zero was used for OECD countries for which no data were available.
c. Data refer to the most recent year available during the period specified.
d. For purposes of calculating the TAI, the weighted average value for OECD countries (1,062) was used.
e. For purposes of calculating the TAI ,the weighted average value for OECD countries (7,336) was used.
f. Data on the share of tertiary students in science refer to the most recent year available during the period 1989-1994.
g. Data are based on preliminary UNESCO estimates of the tertiary gross enrolment ratio.
h. Data refer to 1998.
i. Data are from national sources.
j. Data refer to 2000.
k. Data refer to 1999.

Source:
Column 1: Calculated on the basis of data in columns 2-9; see Human Development Report 2001 for details.
Column 2: WIPO (World Intellectual Property Organization). 2001. Intellectual Property Statistics. Publication A. Geneva.
Column 3: World Bank. 2003. World Development Indicators 2003. CD-ROM. Washington, DC.
Column 4: UN (United Nations). 2003. Millennium Indicators. Database. Statistics Division, New York. [http://millenniumindicators.un.org/]. August 2003.
Column 5: Calculated on the basis of data on exports from Lall, Sanjaya. 2000. "The Technological Structure and Performance of Developing Country Manufactured Exports, 1985-98." Oxford Development Studies 28(3): 337-69, and UN (United Nations). 2003. Comtrade Database. Statistics Division, New York. August 2003.
Column 6: UN (United Nations). 2003. Millennium Indicators. Database. Statistics Division, New York. [http://millenniumindicators.un.org/]. August 2003.
Column 7: World Bank. 2003. World Development Indicators 2003. CD-ROM. Washington, DC.
Column 8: Barro, Robert J. and Jong-Hwa Lee. 2000. "International Data on Education Attainment: Updates and Implications." NBER Working Paper 7911. National Bureau of Economic Research, Cambridge, Mass.
Column 9: Calculated on the basis of data on gross tertiary and science enrolment from UNESCO (United Nations Education, Scientific and Cultural Organization). 1998. Statistical Yearbook 1998. Paris, UNESCO. 1999. Statistical Yearbook 1999. Paris, and UNESCO. 2001a. Correspondence on gross enrolment ratios. 21 March. Paris.

Appendix B: Co-authorship index

Country	2001
United Kingdom	2948.178
France	2146.830
Switzerland	1457.549
United States	1402.592
Netherlands	1313.244
Canada	1204.615
Russian Federation	1170.521
Sweden	1019.885
Spain	947.311
Belgium	947.099
Senegal	819.474
Italy	778.273
Denmark	749.617
Australia	690.982
Japan	640.435
Poland	631.499
Austria	582.645
China	455.885
Israel	447.726
Finland	440.909
Norway	381.662
Brazil	347.030
Hungary	322.082
West Bank and Gaza	317.717
Czech Republic	279.495
Greece	253.565
India	252.834
Korea, Rep	234.475
Mexico	233.406
Ukraine	209.076
Portugal	199.473
Ireland	186.879
New Zealand	183.985
Romania	169.289
Argentina	164.778
Slovak Republic	158.516
South Africa	158.064
Chile	157.048
Bulgaria	122.253
Slovenia	96.498
Turkey	87.894
Singapore	86.936
Colombia	75.321
Thailand	72.268
Indonesia	65.190
Egypt, Arab Rep.	62.789
Croatia	61.242
Belarus	60.062

Country	2001
Estonia	59.993
Morocco	58.976
Kenya	57.685
Venezuela	57.333
Malaysia	53.606
Armenia	48.082
Iceland	45.094
Lithuania	44.005
Latvia	42.062
Saudi Arabia	41.469
Cuba	41.131
Philippines	40.610
Uruguay	37.436
Vietnam	35.597
Algeria	32.237
Iran	31.059
Yugoslavia, FR	25.371
Tanzania	25.310
Cameroon	25.055
Georgia	24.248
Ethiopia	24.101
Moldova	23.381
Côte d’Ivoire	23.312
Peru	23.008
Costa Rica	22.384
Tunisia	21.790
Zimbabwe	20.921
Nigeria	20.526
Pakistan	19.949
Uzbekistan	18.860
Kazakhstan	18.549
Ghana	18.339
Bangladesh	17.012
Macedonia	16.095
Nepal	15.198
Zambia	15.087
Uganda	15.051
Gambia	14.926
Kuwait	14.657
Lebanon	14.483
Sri Lanka	14.145
Malawi	13.931
Panama	13.891
Jordan	13.448
Guatemala	12.520
United Arab Emirates	12.212
Papua New Guinea	11.746
Oman	11.100
Burkina Faso	10.787

Country	2001
Bolivia	10.530
Sudan	9.586
Mali	9.100
Benin	8.941
Madagascar	8.373
Jamaica	7.648
Mongolia	7.314
Trinidad Tobago	6.881
Azerbaijan	6.111
Niger	5.667
Honduras	5.595
Congo, Rep.	5.195
Nicaragua	4.600
Dominican Republic	4.247
Mozambique	4.081
Togo	3.867
Yemen	3.700
Mauritius	3.600
Mauritania	3.433
Luxembourg	3.374
Kyrgyz Republic	3.000
Botswana	2.957
Central African Republic	2.735
Tajikistan	2.667
Namibia	2.600
Angola	2.500
Paraguay	2.475
Haiti	2.459
Syrian Arab Republic	2.300
Albania	2.167
Ecuador	1.889
Turkmenistan	1.767
Iraq	1.762
Cambodia	1.695
Guinea-Bissau	1.595
Myanmar	1.567
Eritrea	1.564
El Salvador	1.050
Sierra Leone	1.000
Libya	1.000
Guinea	0.933
Lesotho	0.833
Rwanda	0.721
Burundi	0.600
Chad	0.200
Laos	0.181
Bosnia and Herzegovina	0.096
Korea, Dem. Rep.	0.071

Appendix C: Research-related institutions index

(Per million inhabitants)

Country	2000	Country	2000	Country	2000
Canada	91.75	Lithuania	2.43	Egypt, Arab Rep.	0.64
United States	63.65	Argentina	2.22	Sri Lanka	0.64
Finland	30.58	Cuba	2.16	Philippines	0.63
Israel	30.17	Bolivia	2.15	Rwanda	0.62
Australia	24.79	Macedonia	2	Ukraine	0.58
Austria	22.47	Malawi	2	Central African Republic	0.57
Denmark	21.89	Papua New Guinea	1.96	Mali	0.57
New Zealand	20	Senegal	1.89	Colombia	0.56
Norway	16.36	Zambia	1.86	Mexico	0.56
Switzerland	15.92	Yugoslavia, FR	1.79	Saudi Arabia	0.53
Slovenia	13.5	Namibia	1.76	El Salvador	0.49
Estonia	12.86	Japan	1.74	Dominican Republic	0.48
Belgium	12.35	Russian Federation	1.74	Syrian Arab Republic	0.46
Slovak Republic	11.11	Lebanon	1.67	Iraq	0.45
Hungary	10.99	Tunisia	1.51	Oman	0.43
Netherlands	10.57	Hong Kong, China (D)	1.49	Pakistan	0.43
Sweden	9.78	Venezuela	1.34	Sierra Leone	0.41
Bulgaria	9.64	Ecuador	1.31	Mauritania	0.4
Ireland	9.46	Turkmenistan	1.28	Iran	0.39
Latvia	9.17	Azerbaijan	1.27	United Arab Emirates	0.37
Czech Republic	8.54	Guinea	1.27	Benin	0.34
Guinea-Bissau	7.5	Belarus	1.18	Ethiopia	0.33
Mauritius	7.5	Luxembourg	1.11	Morocco	0.32
Greece	7.43	Panama	1.07	Indonesia	0.31
France	7.28	Armenia	1.05	China	0.3
United Kingdom	6.9	Kenya	1.02	Niger	0.3
Germany	6.59	Peru	1.01	Burkina Faso	0.28
Poland	5.76	Tajikistan	0.98	Madagascar	0.27
Singapore	5.31	Ghana	0.97	Haiti	0.26
Italy	4.51	Korea, Rep	0.97	Vietnam	0.25
Jordan	4.35	Lesotho	0.95	India	0.24
Iceland	4.34	Moldova	0.93	Uganda	0.24
Portugal	4.2	Cameroon	0.91	Nepal	0.22
South Africa	4.2	Malaysia	0.9	Nigeria	0.22
Costa Rica	4	Thailand	0.9	Bangladesh	0.21
Croatia	4	Côte d'Ivoire	0.83	Nicaragua	0.21
Botswana	3.75	Gambia	0.83	Paraguay	0.19
Uruguay	3.64	Guatemala	0.83	Mozambique	0.18
Mongolia	3.46	Honduras	0.81	Burundi	0.15
Georgia	3.33	Tanzania	0.75	Sudan	0.14
Jamaica	3.08	Congo, Rep.	0.71	Algeria	0.1
Spain	3.07	Kazakhstan	0.71	Cambodia	0.09
Chile	2.91	Togo	0.67	Angola	0.08
Zimbabwe	2.91	Turkey	0.66	Congo, Dem. Rep.	0.04
Romania	2.67	Brazil	0.65	Myanmar	0.02
Kuwait	2.63				

Appendix D: S&T journal article index

Country	S&T Journal Articles per Million Inhabitants 1997	S&T Journal Articles 1997
Switzerland	954.9221659	6935
Sweden	926.2878207	8219
Israel	910.7474359	5321
Finland	754.1384728	3897
Denmark	740.2002176	3950
Netherlands	692.6652302	11008
United Kingdom	647.318589	38530
Canada	636.5476774	19910
Australia	615.3526655	11793
New Zealand	604.2261272	2308
United States	590.8826554	166829
Norway	558.1141677	2501
Belgium	460.5767941	4717
France	446.4175351	26509
Germany	440.8556008	36233
Austria	422.082542	3432
Japan	346.417323	43891
Ireland	294.4230533	1118
Hong Kong, China	292.3146542	2080
Italy	284.2201739	16405
Singapore	280.3657279	1164
Spain	280.1373778	11210
Slovenia	268.210146	517
Greece	200.2541709	2123
Czech Republic	197.0370649	2024
Slovak Republic	175.6671097	950
Hungary	169.348695	1717
Estonia	155.0852235	222
Croatia	127.0370294	544
Russian Federation	117.4442595	17147
Bulgaria	114.9205035	896
Portugal	107.9791947	1085
Poland	103.9951769	4019
Korea, Rep	97.73327567	4619
Kuwait	87.658317	173
Latvia	58.62966262	141
Argentina	56.51009042	2119
Chile	56.0915525	850
Lithuania	54.68471225	198
United Arab Emirates	53.60565569	127
Armenia	53.22431717	178
Belarus	52.86146948	548
Yugoslavia, FR	46.14200333	492
South Africa	45.5003259	1927
Ukraine	44.00542819	2163

Country	S&T Journal Articles per Million Inhabitants 1997	S&T Journal Articles 1997
Uruguay	32.99266903	110
Turkey	32.22334518	2116
Saudi Arabia	27.83389711	613
Georgia	25.50035481	128
Moldova	25.05273488	111
Macedonia	24.00234733	49
Lebanon	22.63811767	81
Brazil	22.26111259	3908
Oman	20.92059293	53
Botswana	20.91600702	33
Costa Rica	19.67359087	73
Tunisia	19.59680205	188
Mexico	19.08325327	1915
Jamaica	18.47182237	49
Gambia	18.28656362	25
Venezuela	18.22224848	429
Egypt, Arab Rep.	15.71801941	1108
Malaysia	13.94924576	304
Cuba	13.28307663	148
Panama	13.04517367	37
Uzbekistan	10.54310354	261
Azerbaijan	9.163462359	71
Morocco	8.996642028	271
India	8.416206464	8439
Zimbabwe	8.206183983	100
Kenya	7.753156648	235
China	7.193017706	9081
Kazakhstan	7.111598976	119
Papua New Guinea	6.291881605	31
Senegal	5.927848881	58
Thailand	5.709516206	356
Congo, Dem. Rep.	5.339073906	15
Colombia	5.241188535	208
Iran	5.029855526	332
Mongolia	4.998394746	13
Cameroon	4.935223835	73
Tajikistan	4.502593805	29
Algeria	4.455996982	139
Ghana	3.998105513	78
Namibia	3.832930237	7
Syria	3.495718879	57
Malawi	3.494705659	38
Bolivia	3.311818777	27
Nigeria	3.272738142	405
Sri Lanka	3.170713008	61

Country	S&T Journal Articles per Million Inhabitants 1997	S&T Journal Articles 1997
Tanzania	2.635665164	89
Niger	2.457325834	25
Zambia	2.347291109	23
Guinea-Bissau	2.346942208	3
Libya	2.345834677	12
Peru	2.332219137	63
Nicaragua	2.285681514	11
Bosnia/Herzegovina	2.08562698	8
Philippines	1.993984812	159
Uganda	1.957786464	46
Côte d'Ivoire	1.953912745	31
Burundi	1.925193626	11
Kyrgyz Republic	1.920930242	9
Mauritius	1.695823526	2
Ethiopia	1.644017584	103
Pakistan	1.638953112	232
Burkina Faso	1.637014469	20
Honduras	1.612669649	10
Turkmenistan	1.549266223	7
Iraq	1.543508166	35
Sierra Leone	1.537675254	8
Central African Repub.	1.427963932	5
Nepal	1.416882495	35
Togo	1.390880553	7
Vietnam	1.350016102	106
Sudan	1.225776169	43
Guatemala	1.170019787	15
Mali	1.125135403	12
Lesotho	1.082938467	2
Bangladesh	0.996882106	130
Mauritania	0.749664806	2
Dominican Republic	0.718259657	6
Paraguay	0.716097954	4
Rwanda	0.675246529	5
Yemen	0.572108367	10
Indonesia	0.54876799	123
Mozambique	0.531465127	9
El Salvador	0.489994716	3
Laos	0.36378631	2
Guinea	0.347143271	3
Haiti	0.278663502	2
Cambodia	0.241295875	3
Chad	0.237561742	2
Angola	0.197387069	2
Congo, Rep.	0.154410852	8

Trinidad Tobago	36.4423065	41	Ecuador	3.018554357	39	Myanmar	0.071819033	3
Jordan	35.4101698	177	Benin	2.955636212	19			
Romania	33.51014882	751	Albania	2.864972417	10			

Appendix E: Patent index

Country	Number of External Patents per Million Inhabitants
Monaco	473.291
United States	343.609
Japan	259.858
Cayman Islands (D)	208.279
Switzerland	200.761
Sweden	195.874
Israel	143.091
Germany	131.674
Luxembourg	125.746
Finland	125.593
Canada	125.487
Denmark	95.383
Netherlands	88.723
Hong Kong, China (D)	77.014
Belgium	73.817
Korea, Rep	73.464
France	70.274
United Kingdom	68.714
Austria	66.043
Iceland	65.131
Norway	59.360
Singapore	58.289
Turks and Caicos (D)	57.136
Palau	53.288
Bahamas	48.263
Australia	44.822
Ireland	36.605
Gibraltar (D)	36.261
New Zealand	35.604
Italy	34.079
Bermuda (D)	31.761
Aruba (D)	28.761
Saint Kitts and Nevis	25.761
Dominica	13.978
Netherlands Antilles (D)	9.518
Slovenia	9.338
Spain	7.947
Malta	5.106
Czech Republic	4.868
Kuwait	4.054
Hungary	3.748
South Africa	2.952
Estonia	2.794
Malaysia	2.157
Costa Rica	2.156
Greece	1.698

Country	Number of External Patents per Million Inhabitants
Venezuela	1.359
Qatar	1.343
Cyprus	1.319
Russian Federation	1.274
Portugal	1.194
Lebanon	1.118
Chile	1.056
Mexico	0.997
Slovak Republic	0.925
Saudi Arabia	0.863
United Arab Emirates	0.844
Jamaica	0.754
Panama	0.705
Brazil	0.644
Dominican Republic	0.599
Lithuania	0.552
Namibia	0.548
Thailand	0.481
Latvia	0.416
Yugoslavia, FR	0.375
Ukraine	0.346
Poland	0.336
Uruguay	0.300
Belarus	0.289
Colombia	0.277
Cuba	0.269
Sri Lanka	0.260
Bolivia	0.245
Syrian Arab Republic	0.245
Kazakhstan	0.239
Kyrgyz Republic	0.213
Romania	0.178
Honduras	0.161
Guatemala	0.156
Philippines	0.150
India	0.131
China	0.129
Azerbaijan	0.129
Bulgaria	0.128
Guinea	0.116
Egypt, Arab Rep.	0.113
Peru	0.111
Kenya	0.099
Turkey	0.091
Uzbekistan	0.081
Morocco	0.066

Argentina	1.680	Indonesia	0.062
Bahrain	1.577	Pakistan	0.035
Croatia	1.401	Nigeria	0.016

Appendix F: R&D expenditure index

Country	R&D expenditure as a %of GDP 1989-2000
Sweden	3.80
Israel	3.62
Finland	3.37
Japan	2.98
United States	2.69
Korea, Rep	2.68
Switzerland	2.64
Germany	2.48
France	2.15
Denmark	2.09
Netherlands	2.02
Belgium	1.96
Singapore	1.88
United Kingdom	1.87
Canada	1.84
Austria	1.80
Norway	1.70
Australia	1.51
Slovenia	1.48
Czech Republic	1.35
India	1.23
Ireland	1.21
New Zealand	1.11
Italy	1.04
China	1.00
Russian Federation	1.00
Croatia	0.98
Ukraine	0.95
Spain	0.94
Hungary	0.82
Brazil	0.77
Estonia	0.76
Uganda	0.75
Portugal	0.71
Poland	0.70

Country	R&D expenditure as a % of GDP 1989-2000
Slovak Republic	0.69
Greece	0.67
Turkey	0.63
Bulgaria	0.57
Chile	0.54
Cuba	0.49
Argentina	0.45
Tunisia	0.45
Hong Kong, China (D)	0.44
Mexico	0.43
Latvia	0.40
Malaysia	0.40
Romania	0.37
Panama	0.35
Venezuela	0.34
Georgia	0.33
Bolivia	0.29
Kazakhstan	0.29
Mauritius	0.28
Uruguay	0.26
Colombia	0.25
Azerbaijan	0.24
Costa Rica	0.20
Kuwait	0.20
Burkina Faso	0.19
Egypt, Arab Rep.	0.19
Kyrgyz Republic	0.19
Sri Lanka	0.18
Syrian Arab Republic	0.18
Nicaragua	0.15
Trinidad Tobago	0.14
Thailand	0.10
Ecuador	0.09
Peru	0.08
Senegal	0.01

Appendix G: Scientist and engineer index

(Number of scientists and engineers per million inhabitants)

Country	1990-2000
Iceland	5686
Japan	4960
Sweden	4507
United States	4103
Norway	4095
Russian Federation	3397
Australia	3320
Denmark	3240
Switzerland	3058
Canada	3009
Germany	2873
Finland	2799
Azerbaijan	2735
France	2686
United Kingdom	2678
Netherlands	2490
Belgium	2307
Belarus	2296
New Zealand	2197
Singapore	2182
Estonia	2164
Slovenia	2161
Korea, Rep	2139
Ireland	2132
Ukraine	2121
Lithuania	2031
Uzbekistan	1754
Slovak Republic	1706
Cuba	1611
Austria	1605
Portugal	1583
Israel	1570
Spain	1562
Croatia	1494
Poland	1460
Romania	1393
Italy	1322
Czech Republic	1317
Armenia	1308
Bulgaria	1289
Hungary	1249
Yugoslavia, FR	1099
Latvia	1090
Greece	1045
South Africa	992
Kazakhstan	716
Argentina	711
Tajikistan	660
Iran	590

Country	1990-2000
Kyrgyz Republic	574
Costa Rica	533
Egypt, Arab Rep.	493
Mongolia	468
China	459
Macedonia	387
Chile	370
Cyprus	369
Libya	361
Mauritius	360
Moldova	334
Turkey	303
Vietnam	274
Peru	229
Kuwait	214
Mexico	213
Nicaragua	203
Venezuela	194
Sri Lanka	188
Indonesia	182
Benin	174
Bolivia	171
Brazil	168
India	158
Philippines	156
Malaysia	154
Trinidad Tobago	145
Ecuador	140
Tunisia	124
Guatemala	103
Thailand	102
Togo	102
Malta	96
Jordan	94
Hong Kong, China (D)	93
Pakistan	78
Bangladesh	51
Central African Republic	47
Rwanda	35
Congo, Dem. Rep.	34
Syrian Arab Republic	29
Uganda	25
Burundi	21
El Salvador	19
Burkina Faso	17
Nigeria	15
Madagascar	12
Oman	4
Senegal	2

Appendix H: Tertiary science enrolment index

Country	Gross Tertiary Science Enrolment Ratio in % 1995-1997
Finland	27.4
Australia	25.3
Jordan	25.3
Singapore	24.2
Korea, Rep	23.2
Georgia	20.2
Russian Federation	19.7
Macedonia	18.4
Greece	17.2
Cuba	16.7
Spain	15.6
Sweden	15.3
United Kingdom	14.9
Belarus	14.4
Germany	14.4
Canada	14.2
United States	13.9
Kazakhstan	13.7
Austria	13.6
Belgium	13.6
Estonia	13.4
Chile	13.2
New Zealand	13.1
Italy	13
France	12.6
Ireland	12.3
Argentina	12
Moldova	12
Portugal	12
Lithuania	11.7
Bangladesh	11.2
Norway	11.2
Israel	11
Croatia	10.6
Slovenia	10.6
Bulgaria	10.3
Switzerland	10.3
Denmark	10.1

Country	Gross Tertiary Science Enrolment Ratio in % 1995-1997
Japan	10
Hong Kong, China (D)	9.8
Latvia	9.5
Netherlands	9.5
Slovak Republic	9.5
Panama	8.5
Czech Republic	8.2
Bolivia	7.7
Hungary	7.7
Peru	7.5
Iceland	7.4
Azerbaijan	7.3
Uruguay	7.3
Romania	7.2
Poland	6.6
Iran	6.5
Algeria	6
Ecuador	6
Costa Rica	5.7
Dominican Republic	5.7
Colombia	5.2
Philippines	5.2
Congo, Rep.	5.1
Mexico	5
Tajikistan	4.7
Turkey	4.7
Syrian Arab Republic	4.6
Thailand	4.6
Lebanon	4.5
Kuwait	4.4
Armenia	4
Nicaragua	3.8
Tunisia	3.8
El Salvador	3.6
Cameroon	3.5
Uganda	3.5
Brazil	3.4
South Africa	3.4

Country	Gross Tertiary Science Enrolment Ratio in % 1995-1997
Kyrgyz Republic	3.3
Malaysia	3.3
Trinidad Tobago	3.3
China	3.2
United Arab Emirates	3.2
Indonesia	3.1
Honduras	3
Egypt, Arab Rep.	2.9
Haiti	2.8
Albania	2.7
Central African Republic	2.5
Oman	2.4
Myanmar	2.3
Paraguay	2.2
Nigeria	1.8
India	1.7
Botswana	1.6
Jamaica	1.6
Zimbabwe	1.6
Pakistan	1.4
Sri Lanka	1.4
Mauritius	1
Nepal	0.7
Sudan	0.7
Benin	0.5
Senegal	0.5
Ghana	0.4
Guinea	0.4
Togo	0.4
Ethiopia	0.3
Kenya	0.3
Lesotho	0.3
Burkina Faso	0.2
Cambodia	0.2
Mozambique	0.2
Tanzania	0.2
Yemen	0.2
Chad	0.1

Appendix I: Biographies

Task force members

Calestous Juma (Coordinator) is professor of the Practice of International Development and director of the Science, Technology and Globalization Project at Harvard University's John F. Kennedy School of Government. He is a former executive secretary of the United Nations Convention on Biological Diversity and Founding Director of the African Centre for Technology Studies in Nairobi, and served as chancellor of the University of Guyana. He is a fellow of the New York Academy of Sciences and the World Academy of Art and Science, and a member of the Kenya National Academy of Sciences. Professor Juma is visiting professor at the United Nations University (Tokyo). Juma has won several international awards, including the Pew Scholars Award in Conservation and the Environment (1991), the United Nations Global 500 Award (1993), and the Henry Shaw Medal (2001). He has served on several committees of the U.S. National Academy of Sciences on science advice for sustainable development, geographical information sciences, and biotechnology. He holds a Ph.D. in science and technology policy studies, and has written widely on science, technology and environment. He is founding editor of the *International Journal of Technology and Globalisation*.

Dato' Ir Lee Yee-Cheong (Coordinator) is president of the World Federation of Engineering Organizations (WFEO), former vice president of the Academy of Sciences of Malaysia (ASM), and chairman of the board of the ASEAN Council of Academies of Science, Engineering and Technology and Similar National Organizations (ASEAN-CASE). He is a member of the Board of the InterAcademy Council of World Science Academies and was a member of the Academic Council of the World Economic Forum. Dato Lee led WFEO in the ICSU/WFEO joint initiative as the Organizing Partners for the Science & Technology Community for the World Summit for Sustainable Development (WSSD) Johannesburg, 2002. He was managing director of Tenaga Ewbank Preece and Partner in the UK holding company, overseeing the expansion of the group in the Asia Pacific region. He served with the National Electricity Board Malaysia. He was CEO of KTA Tenaga Sdn Bhd, a top engineering consultancy companies in Malaysia. He is a non-executive director of UMW Holdings. He received several Malaysian and Australian State awards and is an honorary fellow of several national engineering institutions of Malaysia, Mauritius, U.K. and Australia. He is a foreign fellow of the Australian Academy of Technological Sciences and Engineering.

James Bradfield Moody (Executive Secretary) is the outgoing president of the International Young Professionals Foundation. He was formerly managing director at Natural Resource Intelligence (NRI), Australia's first publicly listed environmental spatial information company, providing environmental, social, and economic intelligence to assist organizations in monitoring and evaluating natural resources. In the last five years, James has been heavily involved with the United Nations, and was co-facilitator and Australian representative of the forty-strong youth advisory council to the UN Environment Programme (UNEP). He was also a member of the Science and Technology delegation to the UN World Summit on Sustainable Development earlier this year and attended the World Economic Forum as a Global Leader of Tomorrow in 2003. In 2000, James was named Australian Young Professional Engineer of the Year. While holding this title, he promoted the engineering profession and his particular brand of "socially conscious engineering." In 2000 James was also awarded Young Queenslander of the Year and in 2001 was awarded Young Australian of the Year in Science and Technology. James is passionate about the supporting role that young socially conscious businesspeople can play in society and works actively towards communicating these views to the general community.

Kamel Ayadi was appointed by presidential decree in May of 2001 as president of the Tunisian National Authority of Regulation of Telecommunications. He is the president-elect of the World Federation of Engineering Organizations (WFEO) and president of WFEO's Committee on Information and Communication. He is an expert in information and communications technologies (ICT) and in particular, the regulatory issues of ICT. He has wide experience in the design, management, and realization of large-scale wastewater projects. He has organized, and lectured in, many congresses and conferences on ICT and environment issues. Ayadi was formerly head of the International Cooperation Department at the Waste Water Department (ONAS) and director of Technical Cooperation at ONAS. He served as president of the Tunisian Order of Engineers from 1998-2002 and as secretary-general from 1990-1998. Appointed by presidential decree to the Tunisian Social and Economic Council, he was also awarded by the president the status of "Engineer General" in 2001 in recognition of his outstanding professional experience. He received his civil and environmental engineering degree from the National Institute of Engineers and his post-graduate degree from the Tunis University of Law.

Susan Brandwayn joined the United Nations in 1988. She is in charge of the New York Office of the UN Conference on Trade and Development (UNCTAD, with headquarters in Geneva). Before that, Susan was Regional Coordinator at UNCTAD, managing a program aimed at increasing the competitiveness of developing countries and countries in transition in world markets through foreign trade, investment, and technology development. Before joining the UN, Susan held various posts in New York, dealing with foreign investment, trade, and multinational corporations (MNCs): At Citibank's Economics Department, where she did research on economic and business conditions; at Chase Bank's International Treasury, where she advised Latin American central banks, MNCs, and private banks on foreign exchange risk management; and at The Economist Group, where she was responsible for forecasting and consulting services for MNCs with operations in Latin America. Susan holds degrees from the University of Chicago and The Johns Hopkins University.

Norman Clark is vice chancellor of Kabarak University, Nakuru, Kenya and professor of Environmental Studies and director of the Graduate School of Environmental Studies at the University of Strathclyde. He is a development economist specializing in science, technology, and environmental policy issues with particular relevance to Third World problems. He has lived and worked in many countries, with particular concentration on Kenya, Nigeria, and India. Previously he held academic posts at the Universities of Glasgow and Sussex. While at Sussex he acted as the founding director of graduate studies at the Science Policy Research Unit (SPRU) where he worked for some fifteen years and now holds the post of honorary professor. He has also acted as founding director of the Technology Planning and Development Unit, University of Ife, Nigeria; visiting professor, Institute for Advanced Studies, University of Sao Paulo, Brazil; and director of the Capacity Development Programme at the African Centre for Technology Studies (ACTS), Nairobi, Kenya. In addition to normal academic activities, he has had some twenty-five years of experience as an adviser and consultant to governments, international agencies, and NGOs. He acted also as an adviser to the U.K. House of Commons Select Committee on Overseas Development.

Sakiko Fukuda-Parr is director of the *Human Development Report (HDR)* at the United Nations Development Programme, New York. She has been lead author of this annual publication since 1995 including the 2001 HDR "Making New Technologies Work for Human Development". Other themes have included democracy, human rights, globalization and poverty. She has written and spoken widely on development policy from the human development perspective, including *Readings in Human Development).* Sakiko has also worked on issues of capacity development and technical cooperation, and is co-editor of *Capacity for Development: Old Problems, New Solutions.* She is editor of the *Journal of Human Development*. Earlier, Sakiko worked in the Africa Bureau and Policy Bureau of UNDP, as well as in the Agriculture Division of the World Bank. She was educated at the University of Cambridge, University of Sussex, and the Fletcher School of Law and Diplomacy. She is a Japanese national.

Denis Gilhooly is senior adviser to the administrator and director of Information & Communication Technology (ICT) for Development at the United Nations Development Programme (UNDP). Prior to joining UNDP he was information infrastructure adviser at the World Bank. He was also previously vice president, business development at Teledesic, media & technology director of The Wall Street Journal-Dow Jones, and founding publisher and editor of *Communications Week International*. He is a founding commissioner of the Global Information Infrastructure Commission (GIIC), a visiting fellow at Harvard University's John F. Kennedy School of Government, and a member of the Irish Governments Advisory Committee on ICT.

Professor Qiheng Hu graduated from Industrial Automation Specialty of Moscow Institute for Chemistry Mechanics in 1959 and obtained Doctor's Degree in 1963. She has devoted her research work on automatic control for production processes and pattern recognition in the Institute of Automation, Chinese Academy of Sciences. Her project, the Recognizer of Handwritten Numerals for Automatic Mail-Sorter, was awarded a prize from 1st China's National Congress of Science in 1977. She led the construction of the first National Laboratory on Pattern Recognition in China in1986. From 1980 to 1982 she was a visiting research professor at Case Western Reserve University, US. From 1983 to 1989 she was director of Institute of Automation, CAS and from 1988 to 1996 vice president of CAS. She was elected president of China Computer Federation, 1985-1994; president of China Association for Automation, 1984-1993; and member of CAE in 1994. She has been vice president of China Association for Science and Technology since 1996. In 2001, she was elected president of the Internet Society of China and is a member of ICANN IDN Committee, and of the Working Group for Ethics in Research Training set up by COMEST, UNESCO.

Vijaya Kumar is senior professor of Chemistry and dean of the Faculty of Science at the University of Peradeniya, Sri Lanka. He was educated at the University of Ceylon and at Magdalene College, University of Oxford, where he worked for his Ph.D. He is a fellow of the National Academy of Sciences, Sri Lanka and a recipient of the Presidential Award for Scientific Achievement. He is the Sri Lankan representative and vice-chairperson of the UN Commission on Science and Technology for Development (UNCSTD) and was the chairperson of the Commission at its last session. He is a member of the Board of Management of the Postgraduate Institute of Science and formerly of the National Science Foundation, the Council for Information Technology, and Chairman of its Committee on Computer Education. He has worked in universities and research institutes in Canada, Sweden, Germany, Thailand, and India. He has published widely in his areas of research interest: natural products chemistry, chemical ecology, agricultural biotechnology, and aspects of science policy concerning developing countries.

Sanjaya Lall is professor of Development Economics at the University of Oxford and a fellow of Green College. He is based at the International Development Centre in Queen Elizabeth House, the university department specializing in research and graduate teaching on development. He is the managing editor of *Oxford Development Studies* and the course director for the MSc. in Economics for Development at Oxford University. He worked at the World Bank during 1965-1968 and 1985-1987, and has acted as advisor and consultant to many international organizations. His research covers South Asia, East Asia, the Middle East, Africa, Eastern Europe, and Latin America. He is principal consultant to UNCTAD on its *World Investment Report* and to UNIDO on its *Industrial Development Report*. Professor Lall has published widely on international investment, technology transfer and indigenous technology development, trade and industrial strategy, and other aspects of industrialization. His recent books include *Alternative Development Strategies in Sub-Saharan Africa*, with Frances Stewart and Samuel Wangwe (1993), *Technology and Enterprise Development: Ghana Under Structural Adjustment* (1994), *The Technological Response to Import Liberalization in Sub-Saharan Africa* (1999), *Competitiveness, Technology and Skills* (2001) and *Failing to Compete: Technology Systems and Technology Development in Africa* (2002), with C. Pietrobelli.

Tony Marjoram is responsible for Engineering Sciences and Technology in the Division of Basic and Engineering Sciences of UNESCO in Paris. Dr. Marjoram has over twenty-five years of international research experience in engineering, science, and technology. Before UNESCO, he was senior research fellow at the International Development Technologies Centre at the University of Melbourne. He also worked at the Centre for Applied Studies in Development and Institute for Rural Development at the University of the South Pacific, the Programme for Policy Research in Engineering Science and Technology (PREST), and the Department for S&T Policy of the University of Manchester. He has a BSc in mechanical engineering from the University of Manchester Institute of Science and Technology (UMIST), an MSc in science and technology policy from the University of Manchester and a Ph.D. on technology for development from the University of Melbourne. He is a chartered professional engineer, fellow of the Institution of Engineers Australia, and member of the Institution of Mechanical Engineers (U.K.), and is on the editorial boards of the *European Journal of Engineering Education* (of SEFI) and *Technology Analysis and Strategic Management*. He received the Industry Canada Award for the Promotion of Gender, Science, and Technology in 1997.

Kenneth Nwabueze is a strong leader with exceptional business, political, and diplomatic capabilities and a passion for technology and foreign affairs. As founder and CEO of SageMetrics, a leading outsourced business intelligence provider, Nwabueze has a demonstrated a reputation as a developer and entrepreneur of innovative technologies across various high-tech industries. Prior to SageMetrics, Nwabueze conducted advanced research for Lawrence Berkeley Lab, created patented software technology for the Walt Disney Company, and developed business-critical software systems for Buena Vista Pictures and Television. Currently, his company, with headquarters in Los Angeles and London, is providing data integration and analysis for companies including Philips Electronics, L'Oreal, Cox Interactive, the *Washington Post*, and *Forbes*. Mr. Nwabueze is an engineer by profession, with emphasis in Industrial and Manufacturing Engineering. He is a member of the President's Council of Advisors on Science and Technology for President George W. Bush. He attended California State University at Northridge, School of Engineering and Computer Sciences, and Pepperdine University School of Management and Business Administration.

Teresa Shuk-Ching Poon is assistant professor of Business and Administration at the Open University of Hong Kong (OUHK). She received her undergraduate and postgraduate education in Hong Kong, the U.K. and Australia. Prior to her joining the OUHK, Teresa has taught in Australia. In 1999, Teresa received an external collaboration contract offered by the International Labor Office to deliver a paper for the International Conference on "Responding to the Challenges of Globalization: Local and Regional Initiatives to Promote Quality Employment through Social Cohesion" held in Bologna, Italy. In 1998 and 2001, Teresa received two awards in the Regional Case Writing Competitions organized by the American Chamber of Commerce and the Management Development Center of Hong Kong, respectively. Her current research interest focuses on firm networks and industrial development, particularly in East Asian countries including the People's Republic of China. Teresa has recently published a book *Competition and Cooperation in Taiwan's Information Technology Industry* (Quorum Books, 2002), examining how inter-firm networks contributed to the upgrading of the information technology industry in Taiwan, using the global commodity chains perspective.

Tony Ridley is a civil engineer who worked for the Greater London Council in its early years. He has held managing director/chairman/board member roles with the Tyne and Wear Passenger Transport Executive, Hong Kong Mass Transit Railway Corporation, London Transport, London Underground, Docklands Light Railway, and Eurotunnel. He was the professor (now emeritus professor) of Transport Engineering at Imperial College London 1991-1999, during which time he was the director of the University of London Centre for Transport Studies. He was head of the Dept of Civil and Environmental Engineering 1997-1999. His higher education was at the University of Newcastle, Northwestern University, University of California (Berkeley), and Stanford University. He was president of the Institution of Civil Engineers (1995-1996), international president of the Chartered Institute of Logistics and Transport 1999-2001 and president of the Association for Project Management 1999-2003. He is president of the Commonwealth Engineers Council, and a member of the Executive Council of the World Federation of Engineering Organizations.

Dr. Francisco Sercovich is currently senior policy advisor to the director-general of the United Nations Industrial Development Organization, Vienna, Austria. He was formerly visiting scholar at the Harvard Institute for International Development; visiting professor at the Université de Québèc a Montréal; consultant and advisor international organizations and Latin American governments on technological policy, industrialization and trade integration. He has published books and over 100 articles and reports on technology, trade, and industrialization, with focus on technological policy and dynamic comparative advantage, including *China in the WTO-The Birth of a New Catching Up Strategy.* He graduated in economics at Buenos Aires University; received his Ph.D. in Development Economics at Sussex University, and published early reports on international technology diffusion and related policies (including *The Channels and Mechanisms for the Transfer of Technology from Developed to Developing Countries* with C. Cooper). He has managed research programs and published on trade integration, technology exports from developing countries, and biotechnology policy in developing countries. He contributed to the fields of competitiveness policy benchmarking (*Competition and the World Economy—Comparing Developing Policies in the Developing and Transition Economies*), multilateral technical cooperation (*Reforming the United Nations*), and development (*Gearing Up for The New Development Agenda*).

Professor Judith Sutz has done research related with science, technology, and development during the last twenty years, working in academic centers of Venezuela, France, and Uruguay, and receiving academic awards. Currently she is full professor and academic coordinator of the Scientific Research Council of the University de la República, Uruguay, where she inaugurated the teaching of Science, Technology and Society. She has written extensively on social aspects of informatics, technical change, innovation systems, competitiveness, higher education, and underdevelopment. In Latin America and France, she participated in several research projects and was coordinator of the "Uruguay: The Electronic Complex of a Small Country," "Possibilities and Risks of an Active Insertion in the World Market: The Case of Uruguay," and "Systemic Competitiveness and Innovation in Uruguay" projects. From 1991 to 1997, she was the secretary of Science, Technology and Development of the Latin American Commission of Social Sciences (CLACSO). She has worked as a consultant for several national and international organizations. At the Central University of Venezuela, she received a degree in electrical engineering (1979) and obtained her Master's in Development Planning (1982). At the University of the Paris-Sorbonne, she received a "Doctorat de Troisième Cycle" in Socio-Economi'a of the Development (1984).

Brendan Tuohy is secretary general of the Department of Communications, Marine and Natural Resources, having been appointed in June 2002 on the establishment of the department. The department is responsible for a number of sectors of the economy including telecommunications, broadcasting, postal, e-commerce, marine, fisheries, aquaculture, ports, exploration, mining, forestry, energy, and renewable resources. Tuohy was previously secretary general of the Department of Public Enterprise and prior to that was assistant secretary in that department and its predecessor, the Department of Transport, Energy and Communications. He currently serves as a member of the National Economic and Social Council and the United Nations Task Force on Information and Communications Technology for Development. He holds a degree in civil engineering from University College Cork and post-graduate qualifications in environmental engineering and management from Trinity College, Dublin.

Caroline S. Wagner specializes in science and technology and its relationship to innovation, policy, and society. She is a research leader at RAND Europe in Leiden, Netherlands. She is a doctoral fellow at the University of Amsterdam working on a book on the global network of science. Caroline serves on the Advisory Board of Research on Knowledge Systems, a program of the International Development Research Centre. She is on the editorial board of the *International Journal for Technology and Globalization*. She is a founding member of the Washington Science Policy Alliance. Caroline has also worked at RAND's offices in Washington, D.C. for the Science & Technology Policy Institute. Caroline was a professional staff member for the United States Congress Committee on Science, Space, and Technology and worked in the Congressional Office of Technology Assessment. She has also served as an analyst for the United States federal government specializing in comparative analysis of global developments in science and technology, which included a two-year stint at the U.S. Embassy in South Korea. She has consulted for several national and international organizations She holds degrees in science, technology, and public policy, and in philosophy and has authored more than twenty reports on science, technology, and innovation.

Genomics working group members

Tara Acharya is a research associate for the Canadian Program on Genomics and Global Health. She has a Ph.D. in bioinorganic chemistry and a Master's in Public Health, with a focus on international health, both from Yale University. Following this, she worked at the interface of science and epidemiology at Genaissance Pharmaceuticals and at Celera Genomics in their proteomics initiative. Her interest in science policy research brought her to the University of Toronto's Joint Centre for Bioethics in January 2003. Here she has had the opportunity to use her training in science and public health to explore the application of biotechnology to global health. In a recent project, she supported the analytical process that led to the identification of the "Grand Challenges in Global Health," a $200 million initiative by the Bill & Melinda Gates Foundation. Her current work involves research, analysis, writing, and execution of a report on biotechnology solutions for the United Nations Millennium Development Goals.

Abdallah S. Daar is professor of Public Health Sciences Surgery at the University of Toronto, and director of the Program in Applied Ethics and Biotechnology at the University of Toronto Joint Centre for Bioethics. He studied medicine in London, followed by postgraduate clinical training in surgery and internal medicine, and a doctorate in transplant immunology/immunogenetics in Oxford. He lectured in Oxford before going to the Middle East to help start two medical schools. He took up the foundation chair of Surgery in Oman in 1988. He has published two books and over 250 publications in immunology, immunogenetics, transplantation, surgery, and bioethics. He chaired the WHO Consultation on Xenotransplantation and wrote the WHO Draft Guiding Principles on Medical Genetics and Biotechnology. He has been an expert advisor to the WHO and OECD. He is a fellow of the New York Academy of Sciences and is on the Ethics Committee of the (International) Transplantation Society and of the Human Genome Organization. He is also a member of the Institute Advisory Board, Institute of Infection and Immunity of the Canadian Institutes of Health Research. His current research focuses on how genomics and other biotechnologies can be used to ameliorate global health inequities.

Elizabeth Dowdeswell is president of the Nuclear Waste Management Organization; visiting professor in Global Health, Genomics and Ethics at the University of Toronto; commissioner of the Commission on Globalization; and associate fellow of the European Centre for Public Affairs. She has had an extensive career in government, education, and international affairs. She has served as executive director of the United Nations Environment Program, permanent representative to the World Meteorological Organization, principal delegate to the Intergovernmental Panel on Climate Change, and Canadian chair of the Great Lakes Water Quality Board. Throughout, her focus has been on bringing the public into policymaking. A former assistant deputy minister of environment for Canada, Ms. Dowdeswell has been a member of numerous Canadian and international boards, advisory panels, and commissions.

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Halla Thorsteinsdóttir is a senior research associate in the Program in Applied Ethics and Biotechnology and the Canadian Program on Genomics and Global Health. She completed her doctoral studies in Science and Technology Policy in 1998 at SPRU—Science and Technology Policy Research, University of Sussex, Britain. Prior to that she completed a Master's degree in Development Economics from the Norman Paterson School of International Affairs at Carleton University in Ottawa, Canada as well as a Master's degree in Psychology from the same university. Dr Thorsteinsdóttir has worked in science policy research in Canada, Iceland, and in Britain. Her research interests span various topics from research collaboration and the organizations of science in small countries, to examining genomics and health biotechnologies in developing countries. Currently she is involved in a multi-country research collaboration comparing the factors that encourage innovation and the development of health biotechnologies in developing nations.

Staff members

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Elizabeth Willmott (Researcher) is a 1999 graduate of Williams College, where she majored in biology and Chinese language. As a Williams-in-China Teaching Fellow (1999-2001) at the Chinese University of Hong Kong, she taught ecology and researched southern China's water policy issues for the Hong Kong Legislative Council. After returning to the United States from Asia, Elizabeth received a Master's in public policy degree from the John F. Kennedy School of Government at Harvard University, writing her thesis on government-steel firm energy agreements in mainland China. Elizabeth is currently a 2003-2004 fellow in Asia-Pacific studies at the East-West Center in Honolulu, Hawaii.