The growth of economies throughout the world since the industrial revolution began has been driven by continual technological innovation through the pursuit of scientific understanding and application of engineering solutions.[1]

U.S. House Committee on Science

STRATEGY WORKING PAPER
SCIENCE AND TECHNOLOGY IN THE WORLD BANK

This paper examines the role of science and technology[2] in development, and considers strategic and tactical issues in World Bank support for science and technology in developing countries.

> For developing countries…. the global explosion of knowledge contains both threats and opportunities. If knowledge gaps widen, the world will be split further, not just by disparities in capital and other resources, but by the disparity in knowledge. Increasingly, capital and other resources will flow to those countries with the stronger knowledge bases, reinforcing inequality. There is also the danger of widening knowledge gaps within countries, especially developing ones, where a fortunate few surf the World Wide Web while others remain illiterate. But threat and opportunity are opposite sides of the same coin. If we can narrow knowledge gaps and address information problems, perhaps in ways suggested by this Report, it may be possible to improve incomes and living standards at a much faster pace than previously imagined.[3]

The World Bank has announced that it seeks to become a world-class knowledge institution. As the Bank focuses on knowledge, specific consideration must be given to scientific and technological knowledge. Because of the epistemological processes embedded in modern scientific and technological institutions, the knowledge which is created, vetted and published by those institutions is quite reliable and accurate. The application of new and of underutilized scientific and technological knowledge is critical to the solution of health, environmental, and economic problems in developing regions.

---

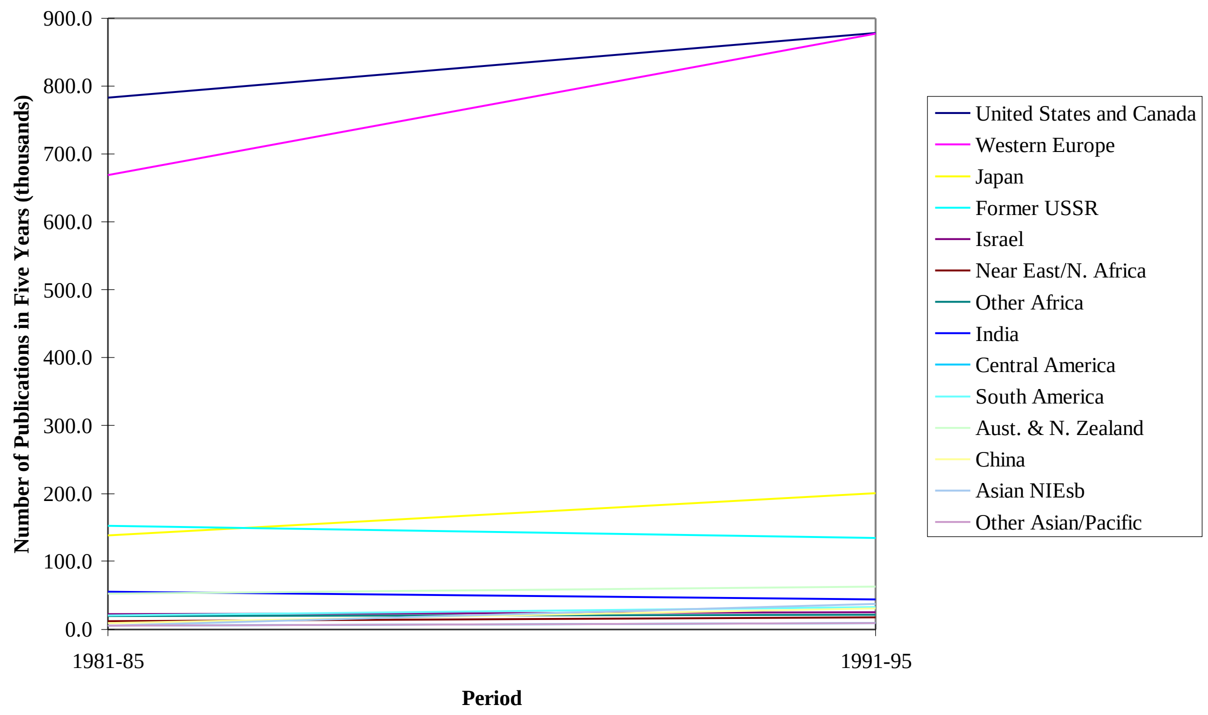
[1] "Unlocking Our Future: Toward a New National Science Policy", A Report to Congress by the U.S. House Committee on Science, September 24, 1998. http://www.house.gov/science/science_policy_study.htm

[2] See attachment 1 for a discussion of the definitions of "science" and "technology" as they affect the World Bank.

[3] World Bank, Summary, Knowledge for Development, World Development Report, Washington, DC, 1998, page 14.

Modern scientific and technological institutions are keystones of modern societies, and they are institutions which developing nations aspire to possess. Figure 1 shows the number of scientific and technical articles published by authors from different regions of the world in two five year periods: 1981-85 and 1991-95.[4] While the numbers of journal articles are only one indicator of scientific and technological activity, the data clearly indicate that the vast majority of scientific and technological knowledge creation is taking place in North America, Europe, and Japan. Not only are developing regions producing far fewer publications, but—as the World Development Report, cited above, cautions—the gap between developed and developing country publications is increasing.[5]

Figure 1. Number of Publications by Region and Five Year Period



As Goldemberg has noted:

> the transition of a country from developing to developed is a complex process that requires facing up to the established interests in society. The impetus for this has to come not only from scientists but from other sectors of society as well. In a world where globalization and competitiveness are the rule, progress requires that developing countries find areas in which they are significantly better than their competitors because of a better trained work force, favorable natural resources, or scientific and technological capabilities. Science and scientists can play an

---

[4] National Science Foundation, Science and Engineering Indicators, 1998, Washington, DC, 1998.

[5] Indeed, the production of scientific papers actually decreased from 1990 to 1995 in the Ex-Soviet republics, Central and Eastern Europe, Sub-Saharan Africa, North America, India and Central Asia, and Southeast Asia. "World Conference on Science: A Second Chance to Make a Difference in the Third World," Science, Vol. 284, No. 5421, June 11, 1999, pages 1760-61.

important role in determining those choices and implementing development strategies.[6]

In the following pages, this paper will deal with eight issues for the World Bank:

- Should the World Bank increase its emphasis on science and technology?
- Should the Bank stimulate new public-private partnerships in science and technology?
- Should the World Bank modify the way it supports science and technology in countries with small economies?
- Should the World Bank increase emphasis on global S&T approaches to solving global problems?
- Should the World Bank develop a "Centers of Excellence" program?
- What should be the role of the World Bank *vis a vis* other international organizations in the field of Science and Technology?
- How should the World Bank strategy vary from sector to sector?
- How should the World Bank change its organization to better deal with the challenges of Science and Technology?

SHOULD THE WORLD BANK INCREASE ITS EMPHASIS ON SCIENCE AND TECHNOLOGY?

Technology development is central to the three primary objectives of the Bank economic growth, poverty alleviation, and environmental sustainability. The main advantage of the Bank over other institutions is that it can provide comprehensive packages to countries packages of policy action, technical assistance, and finance for institutional and human resource development.

Carl Dahlman[7]

Rates of Return to Investments in Science and Technology.

In the United States, according to Laura D'Andrea Tyson, "the average rate of return from investment (in research and development) by private industry is in the 20 to 30 percent

[6] Goldemberg, José, "What Is the Role of Science in Developing Countries?", Science, Volume 279, Number 5354 Issue of 20 Feb 1998, pp. 1140 - 1141.

[7] Dahlman, Carl, "Technology, Development, And The Role Of The World Bank", Human Capital Development and Operations Working Paper, The World Bank, Washington, DC, no date specified. http://www.worldbank.org/html/extdr/hnp/hddflash/workp/wp_00053.html

range. The average rate of return from investment by the Federal Government in research and development is probably greater than 50 percent." [8] In the U.S. it has been noted that:

> Dozens of studies over 30-odd years through 1990 show social returns on the government's investment in agricultural R&D averaging 35 to 50 percent, with a substantial number showing returns of 50 to more than 100 percent. Landmark studies led by Mansfield and Tewkesbury of a heterogeneous sample of private-sector investments in both product and process innovation showed high social returns (private benefits to the investing firm, profits to imitators, and benefits to buyers) -- 56 and 99 percent respectively (both figures are medians).[9]

The efficiency of R&D depends on the intrinsic power of research methods (see below) and the existence of appropriate institutions, but also on science and technology policies, and their effects on the efficiency of research. It may be noted, for example, that over the period from 1981 to 1991 the U.S. GDP deflator for academic R&D grew at 6.6 percent per year while the overall national U.S. GDP deflator grew at 4.1 percent per year. This inflation of R&D costs was consistent with trends which saw the cost of R&D per publication increase.[10] While the results described are preliminary, they would appear to indicate that the productivity of academic research in the U.S. was reduced as a result of economic and financial policies of the universities. Of course, other explanations might be possible, such as major shifts in the research portfolio from low cost to high cost projects or fields of research.[11]

It is difficult to assess the productivity of developing country science and technology quantitatively. Still, there is evidence to support the conclusions that developing countries have been inefficient in the generation and acquisition of scientific and technological knowledge, and they have been inefficient in the utilization of the knowledge once

---

[8] "Meeting the Challenge: A Research Agenda for America's Health, Safety, and Food," National Science and Technology Council, Committee on Health, Safety, and Food, February 1996 http://www.whitehouse.gov/WH/EOP/OSTP/NSTC/html/challenge/challenge.html

[9] "Strategic Planning Document - Civilian Industrial Technology

Research and Development," The Committee on Civilian Industrial Technology (CCIT) of the U.S. National Science and Technology Council, March 6, 1995.

http://www.whitehouse.gov/WH/EOP/OSTP/NSTC/html/cit/cit-plan.html

[10] Adams, James and Zvi Griliches, "Measuring Science: An Exploration", in National Academy of Sciences Colloquium: Science, Technology and the Economy, National Academy Press, Washington, DC, 1996.

[11] Indeed, in the U.S. the shares of funding for academic research in the social sciences, environmental sciences and agricultural sciences were greatly reduced in the 1980swhile the shares were greatly increased for medical, engineering and computer sciences. Rapoport, Alan I., "How Has The Field Mix of Academic R&D Changed?", National Science Foundation, Directorate for Social, Behavioral and Economic Sciences, NSF 99-309, December 2, 1998. http://www.nsf.gov/sbe/srs/issuebrf/sib99309.htm

acquired.[12] To the degree that research and development in developing countries is concentrated in universities, and to the degree that the higher education system in these countries is seriously inefficient, one may suggest that the general inefficiencies are likely to rule in science and technology as well. If indeed science and technology are more developed in agriculture than in other sectors in developing countries, it is certainly the case that there is continuing concern with institutionalizing improved channels for communication of research results to farmers and other users of the information. In health as in other fields, there are continuing difficulties in the translation of scientific and technological knowledge into policies. In several recent loans, the World Bank has explicitly sought to improve the linkage between academic and governmental researchers and the industrial users of scientific and technological knowledge. It seems clear that if the Bank is to emphasize science and technology in its future programs, it will have to emphasize institution building and policy reforms to improve the efficiency, quality and relevance of the scientific and technological activities in those countries it assists. That such efforts can be effective in the proper situation is shown by the experience of the newly industrializing countries in Asia throughout the 1970s and 1980s.

Changing Intrinsic Productivity Of Science And Technology.

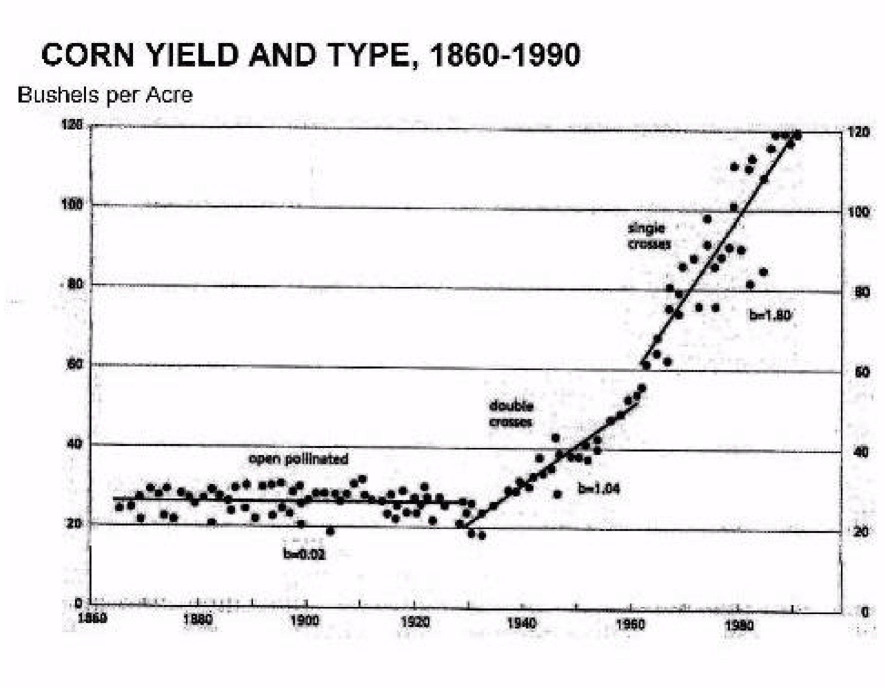
Scientific and technological power are increasing, and new techniques are added to the existing body of research technology. New instruments expand the range of phenomena that can be observed and the accuracy of observation. The body of accepted observations increases, and the body of accepted theory is continuously renewed to expand its predictive power. New materials expand the range of technological options, as new design technology empowers the engineer to explore design options and perform virtual tests on designs. Computational power expands, expanding the ability of researchers to organize and analyze data, and the power of those developing technology to model and analyze designs. Figure 2 illustrates the advances in corn yield during a 130 year period.[13] Particularly notable is an acceleration in the yield improvement in the 1930s with the introduction of hybrid corn, and a further acceleration in the 1960s with the introduction of single cross hybridization. Thus, improved techniques increased the rate of improvement in technology (embodied in seeds of improved varieties) reaching the farmer.

---

[12] See for example, Thulstrup, Erik, "Scientific Research for Development", World Bank, Washington, DC, 1994 on research efficiency; and W. Eisemon, Thomas Owen and Lauritz Holm-NielsenWeidman, "Reforming Higher Education Systems: Some Lessons To Guide Policy Implementation", World Bank, Washington, DC, 1995, John C. "Diversifying Finance of Higher Education Systems in the Third World: The Cases of Kenya and Mongolia", or West, Edwin G. , "Education with and without the State" on the efficiency of higher educational institutions.

[13] Swaminathan, M. S., "Science and Food Security", World Science Report 1998, UNESCO, Paris, 1998, pages 248-259.

Figure 2.



The rate of scientific and technological progress of course depends not only on the power of the body of techniques available to the scientific and technological community, but on the difficulty of the problems that the community faces. In physics, for example, the forefront of the field of particle physics continuously moves to new observations which require more energy, are inherently more difficult to perform, and consequently cost more. In health, the development of antibiotic technology against bacterial diseases may not have been as difficult technically as the development of vaccines for parasitic diseases or for HIV/AIDS (a retroviral disease attacking the immune system). In agriculture, concern has been expressed that there is a deceleration in research progress, as researchers encounter physical limits to yield enhancement. [14] It may well be that new approaches to yield increases will be found (such as increasing the efficiency of photosynthesis), but these may well present more severe research challenges than current plant breeding approaches.

Alfred North Whitehead wrote in 1926 that the "greatest invention of the 19th century was the invention of the method of invention."[15] Mowery and Rosenberg go on to say that "a distinctive feature of the 20th century was that the inventive process became powerfully institutionalized and far more systematic than it had been in the 19th century."[16] Especially important in developed nations were institutional development of research intensive

[14] Charles Mann, "Reseeding the Green Revolution", Science, August 22, 1997; 277: 1038-1043.

[15] In Science and the Modern World, quoted in Mowery, David C. and Nathan Rosenberg, Paths of Innovation: Technological Change in 20th Century America, Cambridge University Press, Cambridge, 1998, page 1.

[16] Mowery and Rosenberg, op cit., pages 1 and 2.

universities, industrial research laboratories in high technology industries, and government research organizations in such fields as agriculture and medicine. One might also note the development of other institutions, such as the professional societies with their peer reviewed journals to publish research results, and the less formal networking that has taken off with the availability of computer networking in the last decades of the century. These institutions, especially in developed countries, have permitted science and technology to become large scale efforts, benefiting from economies of scale and task specialization, with strong institutional ties between researchers and the users of their results.

How Scientific And Technological Capacity Are Required By And Contribute To Development.

The portion of Gross Domestic Product devoted to R&D tends to increase across nations with increasing per capita GDP. That is, richer countries spend proportionately more on research and development. In part, the increase in R&D intensity of economies is related to the well known structural transformation by which countries move from extractive industries, to manufacturing industries, and then to service industries as development progresses. Increased R&D intensity is a result both of increased demand for R&D in the more economically advanced economies, and more capacity to provide R&D services.

The OECD has examined a tripartite model to explain differences among nations in R&D intensity.[17] The model defines three types of changes:

- **Structural**, which are greater the more a country's economy emphasizes research intensive industries (such as aircraft, office and computing equipment, drugs and medicines, and radio, TV and communications equipment) as compared with other countries;
- **Intra-industry**, which are greater the more a country's average R&D intensity within industries exceeds the average across countries; and
- Changes in **Specialization**: positive if a country is more R&D intensive than average in those industries in which its productive activities are more concentrated than average.

The three indicators are derived algebraically, so that the country's difference from the average among countries in R&D intensity may be traced with just the sum of these three components.[18]

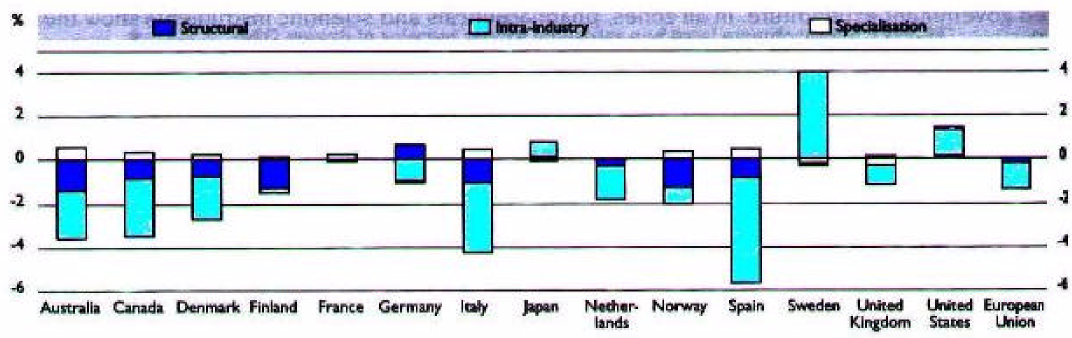
Figure 3 shows the breakdown in relative R&D intensity within the manufacturing sector in 1994 for a sample of OECD countries. The high levels of R&D intensity in Sweden and the United States are primarily accounted for by high levels of Intra-industry R&D. The

[17] Science, Technology and Industry: Scoreboard of Indicators 1997, OECD, Paris, 1997, pages 34-35.

[18] One potential difficulty with this model is that industries differ in the degree to which they create their own technologies versus importing technologies (in the form of licensing, capital equipment, or specialized services) from other industries. If there are consistent differences in the pattern of such behavior between countries, this model might be significantly affected.

lower levels of R&D in countries such as Australia, Canada, Denmark, Italy, and Spain are accounted for by both structural factors (relatively small high technology manufacturing subsectors) and by intra-industrial lower levels of R&D. Specialization effects appear in this sample to be relatively less important in determining overall manufacturing R&D intensity.

Figure 3, Breakdown of Relative R&D Intensity in Manufacturing 1994



It should be noted that such an analysis could in theory be carried farther. One could seek to see if the level of R&D intensity within an industry was due to a specialization in that industry on high or low tech activities, or to a higher or lower level of R&D intensity in the comparable products.

A complex model is suggested. First, concern is directed to the enterprise—"enterprise" here refers to those human activities that are undertaken for the direct production of goods and services, whether in the private or public sector. The defining features of enterprise include the pursuit of production objectives within specific production constraints.[19] So defined, enterprises include schools, health centers, and government ministries, as well as manufacturing and other commercial enterprises. As the production of goods and/or services is central to the enterprise, so too are the techniques used in such production (and the body of knowledge underlying such techniques and the choice of technique). Moreover, scientific and technological knowledge bears on the ways in which enterprises are organized, on the tasks set before enterprises, and on the resources with which they approach these tasks. Improved knowledge and understanding are critically important tools in improving the performance of enterprises; new knowledge and technology are needed even to maintain an enterprise in a changing world.

[19] This definition is drawn from: King, John Leslie and Kenneth L. Kraemer , "Computer and Communication Technologies: Impacts on the Organization of Enterprise and the Establishment and Maintenance of Civil Society", Appendix C in Fostering Research on the Economic and Social Impacts of Information Technology: Report of a Workshop, National Academy Press, Washington, DC 1998.

Within this model, it is considered that developing countries will show some increase in R&D intensity as existing enterprises become more R&D intensive. Note too that structural transformations that contribute to development increase productivity by:

- increasing the relative importance of enterprises that effectively utilize knowledge and technology within each sector;
- improving sectoral institutions such as markets, trade associations, and professional groups (and thus drawing on knowledge of institutions, including that gained from scholars in the social sciences);
- improving sectoral policies (and thus drawing on policy sciences).

At a still higher level of aggregation, structural transformations increase productivity by increasing the role of knowledge intensive sectors within the economy. Again, even when science and technology can not be used to effect improvements in productivity, they may be needed to prevent a fall in productivity driven by changing tastes and resource scarcity.

In this complex model, R&D capacity is both a necessary condition for economic development (though not sufficient in isolation), and a product of that development. What should certainly be rejected is a naïve determinism, which appears to exist in some developing countries, that increasing R&D expenditures—and especially increasing R&D expenditures in manufacturing to levels found in developed countries—will in itself lead to developing countries becoming industrially competitive.

<u>The Comparative Advantage of the World Bank.</u>

The World Bank has a comparative advantage in making financial resources available to developing country governments to enable them to make appropriate investments in science and technology. Bankable **loans** might be made to develop the physical infrastructure and the institutions which train scientific and technological manpower, to conduct research and development (especially in areas such as basic research, and research relating to public goods), and to build institutions to provide services such as mensuration, standards, and intellectual property rights protection. While the Bank's **grant** making resources are limited, they have been critically important in some areas of science and technology for developing countries. The comparative advantage of the Bank as a financial institution includes, importantly, the Bank's ability to enter into dialog with borrowers and to bring the understanding of Bank staff and consultants of institutional development and development policy to bear on the plans of the borrower, and the Bank's ability to bring experience from many countries to bear on the needs of each client. While the relevant Bank staff and consulting roster is currently perilously thin, the Bank has unparalleled managerial capabilities to attract and utilize persons of the necessary expertise.

As the World Bank emphasizes its role as a "knowledge bank", it appears likely also to strengthen its comparative advantage as a "scientific and technological knowledge bank". The World Bank, of course, uses many kinds of knowledge, including institutional knowledge of best practices, legal knowledge, administrative knowledge related to the management systems of the Bank and its clients, as well as "common" knowledge from a variety of sources. In its role as a knowledge bank, it not only uses this knowledge internally to accomplish its functions, but shares it with clients and the more general development community. To these ends, the Bank is developing knowledge systems, supported by an information infrastructure, to acquire, evaluate, store, make available and disseminate knowledge.

The Bank must also effectively include scientific and technological knowledge if it is to function as a world-class knowledge bank. Given that the number of scientific and engineering articles indexed per year is approaching 200,000, simply screening the output of scientific and technological knowledge has become a major task. Identifying scientific and technological findings of critical importance to the Bank and/or to development requires not only knowledge of the literature, but effective judgment of the validity, importance and relevance of various findings. However, the knowledge bank must do more than deal with scientific and technological literature—it must link to scientific and technological networks to obtain timely access to scientific and technological knowledge, including access to tacit knowledge held by experts but not included in the literature. Thus, as the Bank develops measures to effectively include scientific and technological knowledge in its knowledge bank, it will be further developing a comparative advantage to utilize that knowledge in its development programs, and to assist developing countries in utilizing such knowledge for their own development.

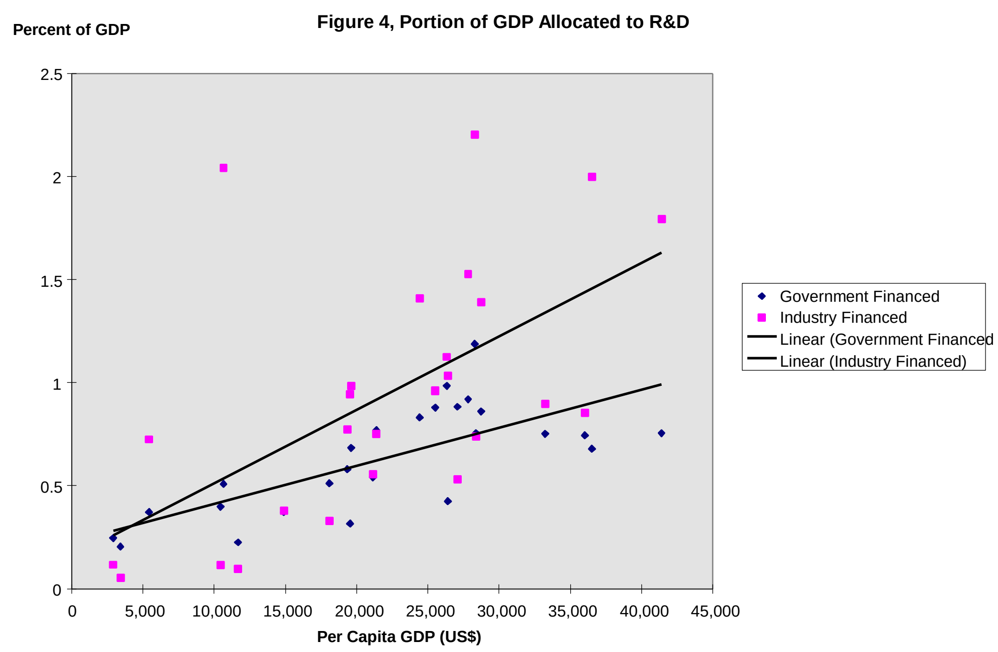
In summary, S&T investments can yield high rates of return, even in developing countries if internal and external efficiencies of S&T institutions are improved. Moreover, the intrinsic productivity of R&D is itself increasing. Economies become more research intensive with development because enterprises do, and because there are structural transformations which increase the weight of knowledge intensive enterprises and sectors in the economy. Thus the demand for assistance in S&T should grow as economies grow. The World Bank has important comparative advantages in providing S&T assistance. Thus increasing demand for high yielding investments for which the World Bank has comparative advantage should encourage increased investment.

SHOULD THE BANK STIMULATE NEW PUBLIC-PRIVATE PARTNERSHIPS IN SCIENCE AND TECHNOLOGY?

> *What can the Government do now and in the future to aid research activities by public and private organizations? The proper roles of public and of private research, and their interrelation, should be carefully considered.*
>
> Franklin D. Roosevelt[20]

[20] letter to Dr. Vannevar Bush, November 17, 1944. Edwin G. , "Education with and without the State"

Figure 4, based on data from a sample of OECD countries,[21] shows that the trend to increase R&D spending with per capita GDP occurs in both government and industrial financing of R&D, but that industrial spending on R&D grows faster than does government spending. There is considerable variance around the trend line, supporting our understanding that R&D intensity is not simply determined by level of economic development; it is indeed the result of a variety of structural and policy determinants. Still, the data support a model in which economic growth is accompanied by structural transformations which involve especially the strengthening of R&D capacity in the private sector.



Privatization of quasi-governmental enterprises has been a strong policy objective in many developing counties. Obviously, R&D conducted within such enterprises changes from "public" to "private" when the enterprise is privatized. This change in not merely an accounting change, as in many countries strong R&D programs in public enterprises have been downsized as a result of privatization.

Thus in development, countries must continue to strengthen government and academic scientific and technological institutions, but must strengthen such institutions in the private sector even more rapidly. As the balance of S&T capacity shifts between public and private sectors, and as the demand for S&T services grows, they face the need to radically restructure the scientific and technological linkages among government, academia, and industry.

[21] OECD in Figures: Statistics on the Member Countries, 1998 Edition, OECD, Paris, 1998.

In many developed countries there is considerable dissatisfaction with the linkages between government laboratories and both industry and universities. Similarly, there is concern about the links from university S&T to the private sector and to government. Considerable effort is now devoted to inventing new and better institutional forms for such linkages.[22] Thus developing countries seeking models for new linkages among universities, government and industry often find few appealing models in the North.

Bank S&T strategy should be generally responsive to institutional concerns: thus, the approach to strengthening science and technology capacity in a governmental organization should be tailored to the bureaucratic and hierarchical structures and processes of such an institution, while the approach to strengthening science and technology in the private sector should take advantage of not only the internal organization and processes of the enterprises but also of other private sector institutions such as markets and associations. As suggested above, however, institutional innovations linking the two may be important. It may make sense for government in some cases to provide extension services to private industry rather than develop a market for consulting services, or for a government agency to fill its own technological needs by purchasing services competitively from private firms.

The institutional complexity of the "broadly defined"[23] technological system should be recognized. Thus, the technological system involving small and medium manufacturing enterprises includes:

- intra-firm technology systems;
- technology transferred through markets for inputs such as labor, financing, equipment, and intermediate goods;
- technology transactions through output markets, such as technological links between large manufacturing firms and their parts suppliers;
- technological transactions with government and academic organizations providing technological services (patents, standards, mensuration and quality control, research and development, technical training, consulting services, etc.); and
- technology relationships among firms through trade associations, clustering of related or mutually interdependent firms.

The institutional complexity of the "narrowly defined" scientific and technological system should also be understood. The technology system of research and development includes:

- the systems internal to the R&D laboratory;
- technology service institutions such as those repairing scientific instrumentation,

[22] Cf. The Home page for a series of conferences titled: "A Triple Helix of University- Industry-Government Relations," http://www.chem.uva.nl/sts/loet/th2/index.htm

[23] see attachment 1 for the differentiation between broadly and narrowly defined S&T.

- institutions financing research and development (and, internationally, extending into a complex institutional network influencing the allocation of R&D financing);
- institutions providing human resources for R&D, those involved in the design and construction of R&D facilities, etc.

The balance between private and public sector science and technology approaches should be based on local circumstances. Low income countries finance most science and technology from public sources, and conduct research and development largely in academic and public institutions; Bank programs should correspondingly respond to the demand for public sector support in science and technology. On the other hand, middle income countries increasingly finance and conduct research and development in the private sector, and the Bank science and technology portfolio should reflect this shift in demand. However, in all circumstances there is a need to deal with institutional issues with understanding and sensitivity, and often to find new approaches to building public-private (and academic) partnerships.

SHOULD THE WORLD BANK MODIFY THE WAY IT SUPPORTS SCIENCE AND TECHNOLOGY IN COUNTRIES WITH SMALL ECONOMIES?

The portfolio of scientific and technological activities in the World Bank portfolio will depend on the circumstances in the country, and on the country development strategy that the Bank puts into effect to aid development in that country. Thus, country programs will be individually tailored. Science and technology strategy should be linked to level of development: While there are likely to be leading investments in scientific and technological capacity, the Bank's science and technology portfolio should be strongly influenced by the existing demand for scientific and technological knowledge.

Science and technology strategy will therefore be significantly affected by the size of the country and its economy.[24] Small countries, especially when poor, will face difficulties in institutionalizing a wide range of scientific and technological services, and will consequently have to choose which to support and which to seek abroad. (Large countries, on the other hand, will face the potential of internal geographical variance in the availability of scientific and technological services, and in consequence will confront equity issues unknown to smaller countries.)

Review of the World Bank loan portfolio[25] shows a strong emphasis on lending to large countries (China, Mexico, Brazil, Russia, Indonesia, Philippines) or to technologically and industrially more advanced countries (Korea, Malaysia, Thailand). Thus of 46 projects

[24] A useful discussion of the different requirements of large versus small countries is found in Mayorga, Roman, "Cerando la Brecha: Bases para una Estrategia de Ciencia y Technologia del BID", Interamerican Development Bank, Washington, DC, 1997.

[25] Crawford, Michael F., "Review of World Bank Lending for Science and Technology," TechNet Working Paper, November 11, 1998.

identified, 36 were in these nine countries. Mauritius had four, and Ghana, Kenya and Tunisia two each; there were no other countries with S&T projects. While the Bank has funded the Special Program for African Agricultural Research, it has not funded regional S&T projects in areas such as the Caribbean or Central America where small nations have sought to collaboratively develop regional S&T capacities. The Bank might seek to support S&T in new S&T areas in small countries, and it might seek new modalities for support of appropriate regional S&T programs serving such countries.

SHOULD THE WORLD BANK INCREASE EMPHASIS ON GLOBAL S&T APPROACHES TO SOLVING GLOBAL PROBLEMS?

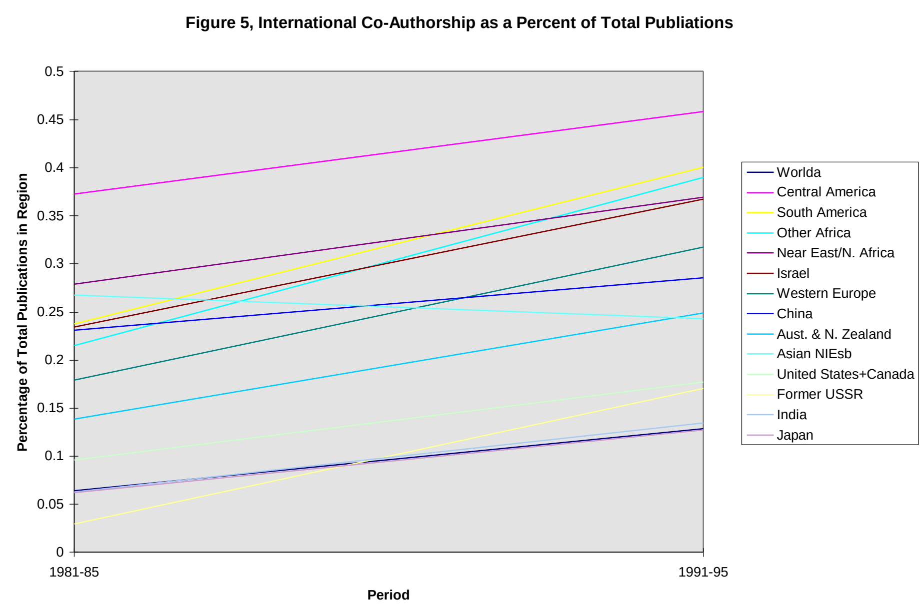
> *The most crucial social challenges requiring scientific input today, from the loss of global biodiversity to newly emergent disease, are global ones. But global solutions will not emerge as accidental spin-offs from research focused exclusively on lucrative or prestigious areas of science. Nor is it sufficient to suggest that 'user-led' science will guide science policy for the public good if that term means nothing more than 'consumer-led' science for those with buying power.*
>
> Federico Mayor[26]

There are international dimensions to Bank science and technology strategy: while Bank lending is country specific, science and technology are international in important respects. “The most crucial social challenges requiring scientific input today, from the loss of global biodiversity to newly emergent disease, are global ones.”[27] Figure 5 shows that scientific and technological publications are more frequently co-authored in all parts of the world, suggesting that (perhaps due to improving communications) science and technology are becoming more international with time. Importantly, Bank strategy must contemplate the need for North-South scientific and technological cooperation. It should also consider other modes of cooperation, such as among archipelago nations, nations sharing major riverine systems, or regions confronted with a major tropical disease or crop pest.

[26] Mayor, Federico, “In Search Of A New Global 'Contract' For Science”, Nature. http://helix.nature.com/wcs/c01.html

[27] idem.

Figure 5



The World Bank supports the international agricultural research centers and for the Consultative Group on International Agricultural Research (CGIAR), and its supports and participates in the management of the Tropical Disease Research program. These efforts combine relatively local concerns (*i.e.*, building capacity to carry out world class work in developing countries themselves), and recognition of the international character of science and technology by the institutionalization of networks.

Such networks are neither new nor unique to the Bank's portfolio. The Canadian IDRC and French ORSTOM both work with excellent research centers in developing countries, and both explicitly emphasize networking (notably through the IDRC-PAN program and the ORSTOM-RIO network). International networks are perhaps most developed in the European Community, including the European Association of Contract Research Organizations (EACRO) and the Federation of European Industrial Cooperative Research Organizations FEICRO. Those including developing countries are exemplified by the MIRCEN networks, which include 31 microbiological research centers, the World Association of Industrial and Technological Research Organizations (WAITRO) with 121 members, and the International Association of Science Parks (IASP), with member organizations in 42 countries.

The World Bank supports science and technology through its lending and its grants programs. Project lending, leveraged by matching funds from governments, far exceeds grant funding (from Bank income on loans). Project lending responds to the scientific and technological priorities specified by the borrowing countries. The issues are whether this balance between such loan and grant programs in science and technology is appropriate, and whether the Bank should seek to institutionalize new mechanisms to increase the global coordination of research. For example, partnerships could be developed with other donors to fund added global or regional research programs, new loan modalities could be sought to encourage international S&T cooperation, or linkages among researchers could be could be institutionalized crossing project boundaries.

SHOULD THE WORLD BANK DEVELOP A "CENTERS OF EXCELLENCE" PROGRAM?

> *As we prepare to enter the twenty-first century, our world faces two important challenges to both its political stability and its potential for sustainable growth. The first is the growing gap between the science-rich countries of the North and the science-poor countries of the South in the production and use of scientific and technological knowledge. The second is the increasing complexity of the problems whose solution, drawing on such knowledge, is needed to achieve equitable, environmentally sustainable, development.*
>
> Mohamed Hassan[28]

A network of Millennium Institutes in the Southern Cone of Latin America[29] has been proposed in which the World Bank would provide assistance to a number of developing countries to enable them to establish "centers of excellence." These centers would conduct research and graduate training in research with both a critical mass of excellent scientists and adequate financial resources. They would also be networked across national boundaries. The first such loan,[30] made in Chile, has drawn specific comment.[31] Other projects are under discussion outside of the Southern Cone.

Many of the Bank supported networks described in the previous section of this paper involve centers of excellence. A number of developing countries have independent

---

[28] Hassan, Mohamed, "North-South Disparities In The Production And Use Of Knowledge", Nature. http://helix.nature.com/wcs/c00.html

[29] "Realizing the Globalization of Science: Report of the International Advisory Group on Science and Technology", Santiago, Chile, unpublished, 1998.

[30] "Project Appraisal Document on a Proposed Learning and Innovation Loan (LIL) in the Amount of US$5 Million to the Republic of Chile for a Millennium Science Initiative Project," World Bank, April 1, 1999.

[31] Sir Ian Lloyd, "Science in Chile, the World Bank and the IMF," March 11, 1999, and Cabello, Felipe, "Don't count on World Bank Initiatives", February 18, 1999, in World Conference on Science: Comments from Readers, Nature, http://helix.nature.com/wcs/e01.html.

experience with development of centers of excellence which might be considered exemplary for the Millennium Institutes program, such as Sri Lanka's Institute of Fundamental Studies, or the Weizmann Institute of Science in Israel. There are national and state networks of "centers of excellence", such as the systems of SEP-CONACYT research centers in Mexico, the genome sequencing centers linked in Sao Paulo's ONSA program, The Korean Basic Science and Engineering Research Centers Program, and the university-industry cooperative science and technology centers funded by the U.S. National Science Foundation.

It is beyond the scope of this paper to examine the literature relevant to centers of excellence or related networks, and, indeed, a meta-analysis of evaluations of such programs might be a worthwhile effort for the World Bank. It is clear that such institutions are sufficiently common that they must be functional in many settings. It might be noted, however, that there are cautionary notes. For example, the Howard Hughes Medical Research Institute (which appears to have successfully translated its "virtual research institute" concept from developed countries first to the former Communist countries in Europe and then to Latin America), has moved to developing countries with considerable caution. The U.S. National Institutes of Health eventually terminated support for its International Centers for Medical Research and Training, as did the U.S. government for the National Academy of Sciences' program which networked developing excellent country laboratories in six research areas.

Certainly, perpetuation of centers of scientific excellence has been impossible in some countries faced by economic or political crises or war. The difficulties faced by the CGIAR network and others in maintaining a stable budget suggest that there is a fine line between assuring financial sustainability for valuable international networks, and developing "sunset provisions" which allow for orderly termination of support for networks which have outlived their utility. Similarly, there are difficult conflicts inevitably to be found between providing sufficient administrative freedom that such institutes can eliminate bureaucratic constraints to their scientific and technological productivity, and establishing sufficient interdependence with local institutions that they feel a sense of ownership and responsibility for sustaining the centers. Staffing and managing a highly productive center of excellence are not easy, especially in the context of a developing country, in which a range of problems from customs duties to electrical power outages can be found. Moreover, there must be the capacity to renew leadership and staffing if and when a center falls into temporary difficulties.

A fundamental issue involves the best way to allocate S&T financing in developing countries. With very limited resources, there is often a decision to be made as to whether to provide small amounts of funds to many researchers, or larger amounts to a few judged outstanding. The best policy probably depends on circumstances: there is much to be said for the Soros program which made very small grants to scientists from the former Soviet union in the early 1990s, grants which satisfied a crucial need for bridge and transition funding. On the other hand, there is a strong position that starving the best scientists for resources may gravely limit national research productivity.

Thus, while networking centers of excellence is a useful strategy for the Bank to continue to develop, it should do so carefully and draw deeply from knowledge developed in comparable situations by other institutions.

WHAT SHOULD BE THE ROLE OF THE WORLD BANK VIS A VIS OTHER INTERNATIONAL ORGANIZATIONS IN THE FIELD OF SCIENCE AND TECHNOLOGY?

> *In the twilight of the 20th century, a look at the past 100 years reveals a rich history of unprecedented scientific discovery and technological advancement. From antibiotics to electricity to semiconductors and electronic mail, science and engineering have served as fundamental agents for improving the quality of life in our society. As we move forward into the next century, focused attention must be paid to the importance of the science and engineering enterprise.*
>
> Bruce Alberts, Wm. A. Wulf, and Kenneth I. Shine[32]

The Bank has a special role in the development community in convening coalitions of partners for scientific and technological purposes. It has already done so in many cases, such as the Consultative Group on International Agricultural Research, *info*Dev (which promotes the application of information and communications technology for development), the Tropical Disease Research Program, and the Special Program for African Agricultural Research. Coalition formation seems especially important in scientific and technological arenas. There is need to bridge gaps between the professional scientific and technological communities, governments, the private sector and civil society. There is also a need to expand North-South scientific and technological coalitions, and to help these coalitions change as strengthening developing country science and technology capacity may eventually lessen the inequality of the partners.

Within the donor community, the United Nations family of agencies, including the World Health Organization (WHO), the U.N. Industrial Development Organization (UNIDO), the Food and Agriculture Organization (FAO), the United Nations Environmental

---

[32] "Preparing For The 21st Century: Statement from the Presidents of the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine", January 29, 1997 http://www4.nas.edu/pd/21st.nsf/852562de00796ff4852562cb0073ff22/f2209251e416e4b08525642d007918d7?OpenDocument

Program (UNEP) and the U.N. Educational, Scientific and Cultural Organization (UNESCO) have focused on scientific and technological issues and services, while the international financial organizations have, of course, been a primary source of financial services for developing countries. It seems clear that coalitions with U.N. S&T agencies are appropriate to Bank projects which emphasize science and technology. Other international financial institutions, such as the Inter American Development Bank have major S&T programs in their regions, and should be partners with the World Bank. Similarly, in many cases bilateral donors have emphasized science and technology in their programs, especially in such agencies as the Canadian International Development Research Center (IDRC) and the Swedish International Development Agency (SIDA); again, coalitions involving the Bank and such agencies appear natural in some contexts. The Bank might also benefit from drawing upon the international scientific and technological expertise of some foundations, such as the Howard Hughes Medical Research Institute, the Wellcome Trust, the Polar Foundation or the Tata Foundations.[33]

HOW SHOULD THE WORLD BANK STRATEGY VARY FROM SECTOR TO SECTOR?

> *Science is intimately integrated with the whole social structure and cultural tradition. They mutually support one other—only in certain types of society can science flourish, and conversely without a continuous and healthy development and application of science such a society cannot function properly.*
>
> Talcott Parsons[34]

Defined broadly, science and technology must play a role in every sector. However, there are major differences in the development of science and technology in different sectors. Thus Ruttan, Bell and Clark note:

> "If the global research system for agriculture now faces the challenge of maturity, and the system for health confronts those of adolescence, then the global environmental research system still requires pre-natal care.[35]

[33] cf. Daly, John A., "The World Bank and Foundations in Science and Technology for Development: A Background Paper for a Panel Discussion", 1997. http://www.worldbank.org/html/fpd/technet/wb-found.htm

[34] The Columbia Dictionary of Quotations.

[35] Ruttan, Vernon W., David E. Bell and William C. Clark," in Climate Change and Food Security: Agriculture, Health and Environmental Research", Global Environmental Change: Human and Policy Dimensions, Volume 4, Number 1, March 1994, pages 63-77.

Moreover, the World Bank has historically utilized science and technology differently in different sectors. Such differences arise from a variety of causes, including:

- internal scientific and technological differences, fundamental in the nature of the applications of science and technology in different sectors;
- external social differences, arising from the different institutions which characterize different sectors, and
- differences which have developed in the approaches to the sectors in the development assistance community and the Bank itself due to the differences in the historical paths taken by assistance theory in these sectors.

Attachment 2 illustrates the differences and similarities in the role of science and technology in different sectors.

Two sectors—agriculture and health—can be used to illustrate the critical importance of scientific and technological advances. In agriculture, in order to sustainably increase food production to meet the foreseeable demands in the next century, it will be necessary both to improve understanding of complex underlying scientific issues, and to develop and disseminate radically improved technology. In the case of health, there remain major needs of scientific understanding and technology development in areas such as AIDS and tropical disease control, while many developing countries will have to adopt and adapt, on a very large scale, technologies to meet the emerging health needs of their more affluent and aging populations. Cross-cutting technologies such as biotechnology, information and communications technology, and materials technology may help in both sectors. The technologies to be developed in the two sectors are in many ways fundamentally different each from the other, the institutions for technology creation and dissemination are fundamentally different in each from the other, and the policies that will work in one may not work in the other. Thus, in agriculture and in health there is a need for technological programs which meet sectoral needs, work through sectoral institutions and are managed by experienced officers from the sectors.

One of the critical differences among sectors is the degree to which they include direct R&D activities to produce scientific and technological knowledge internally, versus acquiring scientific and technological knowledge from other sectors. Only recently have data become available in some countries to allow analysts to account for both types of technological intensity, and reinterpret technological intensity.[36] Reinterpretation has presented high technology industries as even more technology intensive, but could result in revision of the ordering of other industries by technology intensity.

Science and technology strategy should be fundamental to all sectoral strategies: given that the specific scientific and technological challenges differ from sector to sector, that science and technology institutions and policies are often sector specific, and that science and technology efforts have to be integrated with financial, institution building and other sectoral efforts, sectoral science and technology programs are central.

[36] "Technology and Industrial Performance: Technology Diffusion, Productivity, Employment and Skills, International Competitiveness", OECD, Paris, 1996.

It should be noted that it is increasingly common in developing countries to find a "science and technology sector" which supports basic or fundamental research, and which provides science and technology services to several sectors. Consequently, the Bank should also include cross-cutting science and technology programs in its portfolio: developing countries spend as much as twenty percent of their R&D budget on basic research, while OECD countries spend from ten to sixteen percent of R&D budgets on basic research.[37] The infrastructure for basic research is a significant capital investment in developing countries, meriting Bank financing for well designed projects. Moreover, in biotechnology, information and communications technology, and other fields, individual researchers and laboratories may work simultaneously on agricultural, health, and industrial research; in these fields the traditional sector specific nature of science and technology is breaking down. Similarly, systems such as intellectual property rights and mensuration and standards (which were once seen as largely serving industry) increasingly provide services to primary and tertiary sectors of economies. Thus, there is increasing utility in providing support to such infrastructure outside of the framework of the industrial sector.

HOW SHOULD THE WORLD BANK CHANGE ITS ORGANIZATION TO BETTER DEAL WITH THE CHALLENGES OF SCIENCE AND TECHNOLOGY?

> *One of my goals during the past three years as President of the World Bank Group has been to highlight the vital importance of information and knowledge as tools of sustainable development, and to enable us both to share our own knowledge more widely and to learn more effectively from others.*
>
> James Wolfensohn[38]

<u>The Potential Role For Central S&T Support In The World Bank</u>:

It has been argued the World Bank has and should continue to institutionalize scientific and technological capacity in the offices and staff that deal with sectoral issues. The Bank is developing horizontal knowledge communities and systems across the hierarchical structure of the Bank which link sectoral experts. Scientific and technological issues are critically important in many, if not all, of these horizontal knowledge systems. In addition,

---

[37] Salomon, Jean-Jacques, "National Science Policy in a Changing World", in Asher, Irvin, Alex Keynan and Meir Zadok (eds.), <u>Strategies for the National Support of Basic Research: an International Comparison</u>, The Israel Academy of Sciences and Humanities, Jerusalem, 1995, page 34.

[38] In the Speakers Corner on the occasion of the opening of the Development Forum, http://www.worldbank.org/devforum/speaker-wolf.html

the Bank has developed a thematic group on information and communications technology, recognizing the fact that this revolutionary technology is affecting many, if not all, sectors.

It is also suggested that the Bank complement these existing structures, creating a Science and Technology Unit. Such a unit might be built around TechNet, which has been defined as for the Agency. Its key function would be to support the Bank's portfolio of (cross-cutting) science and technology projects.[39] Specific functions might include:

- promotion of networking and cooperation on multisectoral S&T issues;
- provision of highly specialized resources to deal with cross-cutting S&T issues such as intellectual property rights, standards, and the ethical conduct of research;
- provision of Bank-wide support for critical technologies (e.g. biotechnology, materials technology);
- provision of S&T expertise to sector staff wanting complementary S&T expertise, e.g. education [e.g. cognitive science or educational technology], or financial services [e.g. venture capital for high tech enterprises];
- provision of experts in the economics and management of research.
- assisting sector staff in developing sectoral S&T units where needed (perhaps in manufacturing, environment);
- helping sector staff examine or reexamine S&T strategy within the Bank's sector programs;
- supporting Bank S&T projects in non sector specific areas such basic research infrastructure and development of national IPR and standards and mensuration institutions.

TechNet

At the request of the World Bank, the U.S. National Research Council held a conference in 1995.[40] The meeting documented the developmental potential of advanced areas in science and technology, and lead to the creation of TechNet to encourage understanding of, and promote the use of science, technology and information in development. TechNet, was originally created under the Vice Presidency for Finance & Private Sector Development (FPD), was housed in the Energy, Mining and Telecommunications (EMT) Department in 1998, and then transferred to the Economic Development Institute in 1999.

TechNet has been designated the Science and Technology Thematic Group for the Bank. It has developed some knowledge management facilities, and has begun to build a

[39] Several documents have described this portfolio, including Crawford, Michael, "Review of World Bank Lending for Science and Technology: 1992-98", TechNet Working Paper, November 11, 1998. Muskin, Joshua, "World Bank Lending for Science and Technology, Human Resources Department, 1992. Weiss, Charles Jr., "Science and Technology at the World Bank", presentation to the Annual Meeting of the American Association for the Advancement of Science, 1984.

[40] Marshaling Technology for Development: Proceedings of a Symposium, National Academy Press, 1995.

community of people interested in the applications of S&T to development within and outside the Bank. Especially important in this respect have been 17 Think Tanks, or computer conferences.[41] These have each involved hundreds of people in discussions of key issues such as Decentralization of Industrial Promotion, Identifying Critical Technologies for Developing Countries, and International Research Networking. Some, such as Building a Learning Society in El Salvador, have directly supported Bank programs. There has been an active series of TechNet seminars given at the Bank, and publications on matters of science and technology policy. TechNet sponsored the Science and Technology for Development symposium at Global Knowledge 97, which was attended by several hundred people.[42]

TechNet, however, is encountering difficulty in acquiring adequate financial and staff resources, due largely to the fact than none of the operational divisions of the Bank perceives it to be their direct responsibility to promote science and technology. It is suggested that either TechNet be abolished, or it should be given higher priority and adequate resources assured.

<u>Ethical Conduct of Research</u>:

The conduct of research involves risk. Some risks raise ethical concerns, especially in terms of the treatment of human subjects of research, the safety of researchers and their neighbors, and the humane treatment of animals. Prudent management of a public research funding program should involve measures to assure that unnecessary risks are avoided, and risks undertaken are consonant with the potential benefits from the research. The World Science Conference promulgated the following recommendation in its Framework for Action:

> Governments should encourage the setting up of adequate mechanisms to address ethical issues concerning the use of scientific knowledge and its applications, and such mechanisms should be established where they do not yet exist. Non-governmental organizations and scientific institutions should promote the establishment of ethics committees in their field of competence.[43]

The World Bank should, correspondingly, include as a standard practice the discussion of routinized processes to deal with research risks in the projects it funds. These processes need not be extensive nor burdensome, but they should be effective, and applied uniformly where appropriate. In general, the responsibility to manage risks should lie with the researchers themselves and their institutions. The role of intermediate governmental organizations should be to assure that:

- protocols for managing risks are included in proposals where appropriate,

[41] http://www.vita.org/technet/

[42] http://www.worldbank.org/html/fpd/technet/gk97.htm

[43] "Science Agenda - Framework for Action," World Conference on Science, Budapest, July 2, 1999. http://helix.nature.com/wcs/02-1h.html

- the protocols are reviewed by appropriate peer and ethical review committees,
- proposals involving risks in excess of those justified by the potential value of the research results are not funded,
- periodic progress reports submitted by the investigators report any changes in protocols or any incidents that occur,
- such reports are reviewed and acted upon promptly, and that
- the intermediary agency records demonstrate that research risks are prudently managed.

The World Bank's role should be to assure that such responsibilities are formalized in operational manuals for those projects to which they pertain. In a large program, such as that represented by the total portfolio of science and technology activities funded by the World Bank, some unfortunate incidents will almost certainly occur. A clearly defined and functioning risk management system is the best protection for Bank and intermediary agency staff and programs when those incidents do occur.

Attachment 3 provides a brief discussion of issues and standards to assure the ethical conduct of research.