A View from LATHR
No. 19

INVESTMENT IN SCIENCE RESEARCH AND TRAINING:

The Case of Brazil and Implications for Other Countries

by

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The World Bank

September 1991

"A View from LATHR" is a series of occasional flyers produced by the Human Resources Division of Latin America and the Caribbean Technical Department of the World Bank for the purpose of stimulating discussion among staff on key issues facing the sector. The views expressed here are those of the authors and should not be attributed to the World Bank.

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I. THE JUSTIFICATION FOR PUBLIC INVESTMENT IN SCIENCE RESEARCH AND TRAINING IN DEVELOPING COUNTRIES

Capacity building in science is a critical input to long-term productivity growth. This is becoming increasingly important in a world in which economic success is based on the ability to incorporate new technologies into industrial processes rather than on the simple exploitation of natural resources. Investments in basic and applied scientific research and development (R&D) as well as in graduate training have had high economic returns in the developed world. Annex 1 summarizes the nature of this evidence.

A public role in support of science research and training (science being the dominant mode of knowledge generation) is needed because of the uncertain returns of basic research projects and the inability of enterprises to fully appropriate returns to that research. Intellectual property protection covers specific embodiments of knowledge rather than general scientific knowledge about nature. Yet the development of new scientific knowledge eventually results in a host of new and more efficient products, many of which are unforeseen at the time of the initial research. The discovery of the nature of DNA and the gene replication process in 1953 is a good example of basic research which is now fundamentally changing the nature of agricultural production as well as many elements of health care. Furthermore basic science research is fundamental to the training of practicing scientists, engineers, and health professionals working in applied fields. Laboratory research is fundamental to graduate training; in fact as much as 90% of graduate training in many sciences takes place in the lab. Such research helps to ensure that scientists understand the critical processes of knowledge generation and are conversant with latest developments in their areas.

The conduct of scientific research has experienced many changes in recent decades as a result of technological progress. The idea of scientists working in isolation from worldly concerns is rapidly changing as interactions between science, technology, and production become more frequent and intense. There are several ways of incorporating new scientific knowledge into industrial production. These include the pursuit of post graduate studies by engineers and scientists working in industry, ample use of university professors as consultants for industrial enterprises, cooperation between research centers and industry in undertaking applied sciences projects, and new partnerships between universities, government science and metrology laboratories and industry.

While most fundamental discoveries about the nature of the universe will continue to emanate from the industrialized countries, support of a critical mass of scientific infrastructure in the developing world is essential to enable these countries to select, incorporate and adapt technology from abroad, to improve existing technology, and, in some cases, to develop new technology meeting local as well as international needs. This requires high quality graduate training as well as laboratory research programs. However, developing countries who wish to invest in science capacity building face difficult choices because of limited funds, especially for smaller countries. The largest countries (Brazil, China, India) clearly have the economies of scale and a heterogenous industrial base to justify developing a reasonably broad based scientific establishment. The smallest countries need to carefully determine where their comparative advantage lies and to exploit niches in the science and technology system. Countries such as Israel and Singapore have been relatively successful in this effort.

A strong scientific and engineering tradition is a necessary but not sufficient condition for ensuring a country's international competitiveness. Many elements of economic policy affect the environment for technological innovation in the private sector and therefore affect the utilization of the results of science research. Furthermore, to compete in the rapidly changing world, labor forces in industrializing countries will need to have a broad base of literacy and numeracy to enable them to absorb and adapt technological change at the factory floor. For this reason support for science research and training should not be allowed to substitute for or replace investment in primary and secondary education, which are the essential building blocks for human capital.

In addition to science research and training, there is also a strong justification for a public role in areas such as industrial standards and measurement and dissemination of information on new technologies. Under-investment by industry in research in improved measurement technologies is expected because of the nonproprietary character of many of these technologies. Efficiency gains are achieved through research by a government or government-financed laboratory, as well as through programs of certification of secondary laboratories and of dissemination of information on new measurement and other technologies. Especially since the Second World War, a complex system of norms and standards has been established in industrialized countries to guide industrial production. Liability and safety legislation and the related development of specialized insurance markets have further underpinned this system. The system of standards and norms, and the metrology system that supports it contribute to the achievement of two economic objectives: (i) product uniformity and compatibility, which can lead to economies of scale and long runs throughout industry; and (ii) improvements in product quality which can lead to better performance and fewer rejects.

The World Bank is increasing its support of science and technology in developing countries. The first project in science and technology project was initiated in Brazil in 1984. Projects have been initiated or are under discussion in China, Philippines, India, Indonesia, Eastern Europe, and Mexico, and a second project has begun in Brazil. It is therefore timely to begin to take stock of experience to date as a means of providing guidance for future activities. The issues in this area are particularly intriguing since they impact down to the level of primary and secondary education, where basic science is taught, as well as out to industrial and trade policies, which must be designed to encourage technological innovation utilizing the fruits of science research and training.

This note is based on work leading to two science and technology projects in Brazil. A description of the case in Brazil is of importance because it provides a model for replication or adaptation elsewhere. The Brazil case takes a systems approach to the problem and focusses on improving the science decision-making process. The Brazil case illuminates the relationships between trade and industrial development policy, science research, and industrial innovations. Specifically this note focusses on two sets of issues--those related to strengthening public management of science research and training, and those related to encouraging private sector investment in R&D.

II. BRAZIL'S EFFORT IN SCIENCE AND TECHNOLOGY

Background

Annex 2 provides some summary tables on Brazil's comparative effort in R&D. In summary Brazil's R&D spending in relation to GNP is 0.7%. This figure is similar to that of other middle income developing countries (Taiwan and India spend about 0.9%, Mexico 0.6%, Korea 1.6%), and lower than most industrialized countries, which average two or three times as much (the United States spends 2.7%, Japan 2.9%, West Germany 2.8%). However, the productive sector accounts for only 20% of total investment in R&D, similar to that of Mexico, India and Argentina, but lower than Korea (81%), USA (52%), Japan (79%) and West Germany (61%). In absolute terms whereas the United States invests approximately US$121 billion and Japan US$46 billion per year in R&D, Brazil invests US$1.6 billion. Despite the economic crisis of the 1980s, Brazil's public effort has remained relatively stable. A large number of public institutions are engaged in graduate training and scientific research and development at the federal and state levels, including universities, research institutes, and government agencies, and a system has evolved for public financial support of these efforts.

In terms of human resources development, Brazil lags noticeably behind other industrializing countries. In 1985, total enrollment in higher education programs in science and engineering at the masters and doctoral levels was 50,000. Brazil has fewer scientists and engineers engaged in research and development in relation to population (256 per million) than Taiwan (1,426 per million), Singapore (960 per million), Korea (804 per million), and Argentina (360 per million), but somewhat more than Mexico (216 per million).

A Secretariat for Science and Technology (SCT) in the President's office has been organized to play a strong coordinating and planning role. It now includes directorates for planning, coordination, programs, and industry/science linkages. Annex 3 provides a short review of the various Government agencies supporting or undertaking research.

Public Sector Management of Science Research

In the early 1980s, the continuation of Brazil's capacity in science research was in jeopardy. Poor management of the public funds available for R&D had discouraged entrance and retention of qualified manpower in science. Graduate programs in science in most universities, which had been strongly supported in the 1970s, suffered from lack of secure funding and were losing their ability to attract and maintain faculty and students. During the last years of military rule, funding had been reduced significantly and many institutions were finding that their equipment was severely out of date.

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science equipment was under-utilized because of lack of a maintenance system, many scientific experiments were compromised because of lack of a system of provision of imported chemicals and other consumables, and research was hampered by inadequate access to timely and systematic information on Brazilian and world-wide developments. Support for science education at the primary and secondary level, as well as support for developing the capacity to analyze science issues and manage science systems, were considered essential long-term investments in the sector. Support of science education is of particular interest. This multi-faceted program supports a variety of innovations in training, curriculum, and materials for primary and secondary science education. Support for basic industrial technology was included because of Brazil's weakness in areas such as metrology and quality control, the strengthening of which will be essential if Brazil is to compete in international markets. New materials, defined as the development of materials with properties which do not appear in nature, was included because of recent major advances in knowledge in areas such as ceramics, metallics, polymers, and composites which eventually will revolutionize industrial processes and output. Brazil needs to develop its human resource capacity in this area, eventually hoping to affect areas as diverse as the automobile and petrochemical industry as well as its growing fiber optics industry. Support for environmental science has been included to complement a recently signed Environment project to be supported by the World Bank, which focuses on strengthening government environment agencies and on dealing with some specific environment problems. The environment subprogram will have the more general objective of human resource development and of establishing and supporting inter-disciplinary research teams. Annex 4 provides additional detail on some of these subprograms.

Following general instructions given by the Science and Technology Secretary, committees of scientists, engineers, and business representatives prepared draft proposals defining the objectives and the associated allocation of funds within each subprogram. These proposals were circulated throughout the concerned science, technology, and business communities, and they were revised numerous times. In addition, Bank staff members and consultants reviewed, appraised, and eventually approved the final versions of the proposals. Committee members were selected on the basis of recommendations by the various professional societies. They are scientists and engineers, most of whom are associated with universities, some of whom are involved in small technology-based firms or in R&D departments of large firms. Compared to PADCT I, the PADCT II subprogram objectives have greater emphasis on engineering research and training and on applied research. It should be noted that, by its nature, most engineering research seeks practical applications of scientific knowledge and many, if not a majority, of engineers become involved in development of new products and/or improvement of production processes. In addition, several subprogram proposals provide specifically for industry-university cooperation and the Basic Industrial Technology subprogram continues to be specifically directed at strengthening industrial infrastructure.

The overall institutional design of PADCT emphasizes giving scientists a greater role in sectoral decision making; establishing a strong and open system of peer review for award of research contracts; encouraging greater interaction between basic and applied research; and supporting multi-year integrated research and training projects.

Specifically, as noted above, under PADCT independent committees consisting mainly of practicing scientists prepare sub-sector strategies. These same committees prepare requests for proposals in broad scientific areas which are subsequently evaluated by ad-hoc committees with similar representation. Most proposals come from universities and non-profit research institutes. Some projects are executed directly by government agencies or by agencies that fall under their immediate supervision. Multi-year contracts are signed with one of four financing agencies for financial support for equipment, materials, scholarships, training, visiting professorships, hiring of researchers and support staff, seminars, meetings, information services, and monitoring and evaluation, all on the basis of open competition and reviews of research proposals. The government agency assumes responsibility for project supervision. The institutional design includes a fifteen member international advisory group composed of renowned Brazilian and foreign scientists, which conducts an extensive evaluation of the scientific merits of the program once a year. PADCT currently accounts for about 10% of the Government's effort in university based science research and training, and for 40% of funds available on a competitive basis for research proposals and which are not part of an ongoing program of institutional support.

During the period 1985-88 PADCT had a very difficult beginning, mainly because some Government agencies were opposed to the idea of devolution of decision-making. Now the agencies as well as the scientific community have become supporters. The scientific community has developed an increasing maturity in exercising its planning and peer review responsibility effectively (e.g., initially rewards were dribbled out in small packets; now committees focus on larger awards to develop national centers of excellence). The program is now beginning to have an impact through improving the human resource base for scientific research and development. A number of promising lines of research have been initiated, some of which have already resulted in industrial applications. By mid 1990 PADCT had supported over 700 research projects in over 300 institutions. Recent results of note supported directly or indirectly by PADCT include the discovery of gold in the Amazon, the development of a leishmania vaccine, improved amino acid content of bean plants and new process control and measurement devices now in commercial production.

Because of its late start and the normal delays in getting research results, little formal assessment was undertaken under PADCT I. A more comprehensive monitoring and assessment system is expected over the next few years. All subprograms will set aside funds for monitoring and evaluation. In addition the science policy subprogram will specifically include about US$1 million for overall project evaluation. The international review committee will annually review progress. The executing agencies will regularly monitor progress in research. In addition a wide variety of dissemination vehicles such as meetings, services, and newsletters, will be supported.

While PADCT is successful in terms of its goal of improving science decision-making, a number of science and technology issues remain for Brazil and have come to light in the course of the first project. The most fundamental one is that of uncertainty with regard to whether and how private sector investment in R&D will increase. If this does not increase over the middle term, then Brazil's public sector investment will have an inadequate payoff. This issue is described in further detail below.

An additional issue is related to the adequacy and appropriateness of existing programs and funding agencies. In particular CNPq has become an excessively large bureaucracy which the Government is seeking to down-size. The long-term role of PADCT in the science funding system, after Bank financing is ended, is uncertain. In principle scientists should have a variety of sources for funds to ensure that new and innovative ideas receive a hearing. However an excessive number of agencies and programs may result in a dispersion of effort.

Another question of importance is that of the respective long-term roles of the states and the federal government in supporting S&T. The potential rapid increase in state funding of S&T raises critical questions related to the role of the states in S&T and their institutional capacity for decision-making in the sector. It may be appropriate for the federal government to encourage states to reduce their unrealistically high funding objectives and to focus on primary and secondary education, with the federal government retaining its preeminent role in providing the bulk of the public funding effort in science.

Until the advent of PADCT, support for university based research was highly non-directed. At the same time the Government had created a number of highly directed research institutes in areas it considered important, such as space, aeronautics, agriculture, and the Amazon. Some of these institutes may have outlived their usefulness. The Government therefore needs to examine the balance between directed and non-directed programs. Similarly, there is a need to examine the extent to which the emphasis should be on ensuring that existing centers of excellence are of world class quality, on supporting emerging centers, on supporting regional development efforts, and on encouraging institutions to cooperate, so as to help ensure a critical mass of researchers and students and to maximize the use of expensive equipment. It may also be necessary to encourage the weaker research groups to disband.

The Government is expected to analyze the above issues in detail in a policy paper to be prepared over the next two years. This paper should help to set the goals of the system for the next decade.

Private Sector Investment in R&D

As noted above, the private (and parastatal) sector accounts for only an estimated 20% of total investment in R&D, compared to 81% in Korea and 52% in the USA. Most of this research is undertaken by large parastatals such as PETROBRAS. This low level of investment did not seem to affect Brazil's economic growth in the 1960s and 1970s mainly because growth was achieved through import substitution and importation of foreign technology. With the growing importance of technological innovation, low private sector investment in innovation threatens to become a critical barrier to future productivity gains in Brazil. Furthermore it threatens the return to investments in science research and training with their long-term aim of increasing Brazilian industry's technology capacity.

Brazil's deteriorated macroeconomic condition has been one of the strongest disincentives to private sector capital investment in general. Large public deficits led to high rates of inflation and high interest rates, with resulting uncertainty about the future, which strongly encouraged investors to concentrate their funds in liquid assets. An improvement in the macroeconomic situation has been therefore the most urgent short-term requirement for establishing a climate for productivity growth.

Up to March 1990 a host of barriers to competition also substantially reduced the incentive of firms to remain or become competitive in terms of product quality or process efficiency. Non-tariff import barriers operated in such a way in the 1980s that imports of virtually any industrial product with a national "similar" were, de facto, banned, even if the national similar were far higher in price and inferior in performance characteristics. Domestic competition was severely limited by regulations discouraging new entrants. In addition, fiscal and financial incentives (and broader forms of public support in the case of state-owned enterprises) supported the dominant position of a few firms and discouraged these often inefficient firms from diminishing their level of activity.

Another area of concern over the long term is that of barriers to the firm-level appropriation of knowledge. The more that knowledge is easy to "steal", the more that firms will be discouraged from investing in creating that knowledge since they will have greater difficulty in appropriating the income from it. The public subsidy of education and training, basic research, and, sometimes information provision, solves part of the problem for the firm, but a system of intellectual property rights (patents, copyright, trade secrets) is also important to encourage firms to invest in R&D. Brazil intellectual property system continues to be weaker than its counterpart in industrialized countries. In particular while its laws are relatively strong, Brazil has weak enforcement of patent and copyrights. With regard to trade secrets, the legal protection afforded to Brazilian firms for "know-how" which might not be patentable (e.g., key employees leaving the firm and using proprietary "know-how") is inadequate. Brazil will need to strengthen its intellectual property system as the general environment for innovation starts to improve and as firms move into higher technology production.

The costs of technology transfer also have an impact on the character of firm-level R&D spending, i.e., through decisions on whether to concentrate on improving existing technologies from abroad or developing wholly-Brazilian technology. The level of technology transfer is low in comparison with other countries and Brazil could benefit from greater reliance on technology transfer and adaptation to local conditions.

Informatics is of particular relevance for industrial innovation because the use of increasingly sophisticated computer hardware and software is associated closely with technological modernization, quality control, and productivity enhancement. Informatics has also been a sector which Governments up to March 1990 promoted extensively with market reservation and financial enhancements.

Not the least in importance, Brazil lacks adequate trained manpower for a modern and dynamic economy. In 1980, 73% of the Brazilian labor force had either no education or had not completed primary school, a figure which is among the highest of middle income countries. The gap between Brazil and other countries is particularly acute at the secondary level. In 1987, Brazil's total secondary enrollments represented only an estimated 37% of the secondary school-aged population, well below the average for middle-income developing countries (Brazil's heavy investment in occupational training has to some extent compensated for the weaknesses of the formal school system). Low levels of basic education and skills among workers are not compatible with the task-complexity, precision, and consistency required in modern, technology-intensive industry. It is important to ensure that support for research in no way substitutes for support for basic education. At the university level financial difficulties and the large expansion of undergraduate enrollment since the 1970s have adversely affected educational quality. In addition, as noted above, poor management of the public funds available for R&D has discouraged entry and retention of qualified manpower in science.

The Government which took power in March 1990 has set as its goal the opening of the Brazilian economy to international competition. It has ended most quantitative restrictions on imports, and is setting up a system of tariffs which, while very high at present, is to be progressively reduced. The Government also intends to privatize the major state enterprises. The Government has recently become aware of issues related to intellectual property and technology transfer and recently established a commission to examine overall issues related to strengthening its intellectual property and trade secrets legislation and enforcement as a means of encouraging industrial innovation. With regard to informatics, the Government is not expected to seek an extension of the market reserve clause of the present law beyond its statutory expiration in 1992.

In addition to changes in government policy itself, a successful transition to a more competitive industrial sector will require changes in behavioral patterns of firms, relations between management and employees, and relations between the productive sector, government, education, and the science and technology community. A report, to be completed in two years, by an independent commission, will review these types of issues. The report will be designed to complement the current changes in Government policy designed to make the economy more outward oriented and competitive in world markets.

In particular, the report will attempt to isolate the most important factors explaining quality, technological, and productivity weaknesses in Brazilian industry. Its recommendations will be directed to all relevant groups--management, labor, education, researchers, and government. It will recommend how public support for technology development can be made more responsive to the needs of the productive sectors of the economy. Some issues and possibilities include: linking the level of Government support to the level of private funding of individual R&D centers; determining the degree of public cost-sharing of technology development which has potential commercial value; and developing appropriate models for government/industry/university collaboration in establishing science parks and other mechanisms such as "incubators" to support development of new technologies. Key issues related to the role of Government in encouraging private sector financing of R&D also include: the extent to which Government should financially subsidize private sector R&D; costs and benefits of using fiscal/tax incentives, directed credit lines, or public equity participation in R&D joint ventures; and needs to restructure capital market regulations to promote more appropriate financial instruments supporting innovation.

The results of the report are expected to have a substantial impact on corporate strategic planning especially in the areas of research and development and technology adaptation, government policy in science and technology, program direction and linkages with the productive sectors in Brazilian research centers, and on the science and engineering curriculum in the education sector.

Despite the very positive changes described above, the near-term prognosis for productive sector investment in R&D in Brazil continues to be uncertain. In the near future the ongoing recession will continue to depress investment in R&D. The long-run prognosis is better. The actions in the area of trade reform taken to date, as well as those being contemplated in areas such as intellectual property and technology transfer, are expected to encourage increased utilization by the private sector of science manpower and science research results as a means of improving production processes and products and therefore to increase the likelihood that investment in science research and training will have a long-term payoff.

III. IMPLICATIONS FOR OTHER COUNTRIES AND PROGRAMS

We can expect many developing countries to request World Bank assistance for programs to strengthen science research and training. It is important to take a broad based sectoral approach to such requests. This means that, among other elements, it will be necessary to look as far afield as improving the teaching of science in primary schools, strengthening the structure of graduate education, decentralizing the decision making process in the award of science research grants, strengthening programs of norms and standards, encouraging the private sector to invest in R&D, and ensuring that trade and industrial development policies will be adequate to encourage technological innovation over the medium term. Fundamental reforms will need to be discussed in all these areas.

The Brazilian case is of importance because it sought to make many such fundamental institutional changes, especially in the science decision making process. The science education program as well as the basic industrial technology programs are of particular note because they stretch far beyond simply supporting science research. It took a long time to develop the program as well as to ensure that institutional changes were implemented.

Over time it became apparent to decision makers in Brazil that the above improvements would not be sufficient to ensure technological innovation. Macro-economic conditions need to be stable and trade and industrial policies need to encourage the private sector to utilize both specific research results and the highly trained human resources who learn within a research setting. The stage has been set in Brazil for a medium-term recovery and for the provision of the key science knowledge and manpower which will help to ensure the sustainability of such a recovery.

A science and technology project currently being developed in Mexico (appraisal scheduled for around November 1991) illustrates how the model developed in

Brazil can be applied elsewhere. From one point of view the Mexico project has a broader scope than that of Brazil, since the project supports a complete reorganization of Mexico's main agency supporting science research--the National Council for Science and Technology (CONACYT). CONACYT staff is being reduced by 50% while at the same time increasing funding by as much as 300%. CONACYT will achieve this increased efficiency through devolving decision making to committees of scientists, as in Brazil, as well as through devolving decision making for award of scholarships to individual institutions which will be accredited by CONACYT, and devolving administration of individual scholarships and fellowships in Mexico and overseas to private banks which would disburse funds to such students. Under the reorganization plan half the departments have been eliminated. Half of the clerical staff will shortly be dismissed, and a new cadre of 60 "analysts," many of whom will rotate in and out of universities, will provide the high quality analytical support work required to carry out the institution's mandate. In comparison, the Brazil project did not seek to down-size or restructure existing institutions, since this was not considered feasible because of political constraints. Rather, the Brazil project superimposed a new system on the existing agencies, which lost power but were still required to implement the program. Only now is the Government considering downsizing agencies such as CNPq.

The Mexico project, entitled the Program of Support for Mexican Science (PACIME) is also different, compared to Brazil, in that it will provide support to all the sciences, as well as to the social sciences. Detailed sub-sector planning has not been undertaken in advance and most of the program is non-directed. In this respect the PACIME program will act in a manner similar to the National Science Foundation in the USA, which accepts all proposals and evaluates them through peer committees, on their merits. This approach is justified in Mexico because of the expected pent-up demand by qualified researchers who have not received adequate funding in ten years. Initially a portion of the funds (probably 10%) will be reserved to "directed" programs identified as important to Mexico's development and in which Mexico has inadequate infrastructure. This amount will be reviewed annually on the basis of interim evaluations of the nature and quality of research proposals. It is expected that experience will dictate the extent to which the Mexican program becomes more directed.

Like Brazil, the Mexico project will include support for basic industrial technology (metrology) and will also seek to strengthen the Mexican patent office. However, the Mexican program does not include "support" areas such as science education, science policy, science information, and science maintenance. Most of these areas are being covered under CONACYT's regular programs. The Ministry of Education is responsible for science education and it was felt that involving another agency in the project would lead to complications.

A final difference between Mexico and Brazil is that the macro-economic situation in Mexico is very favorable. Mexico has already implemented most of the trade and industrial policies still being initiated in Brazil. In theory private sector investment in R&D should be increasing. A project supported study will monitor developments in this area to determine what additional adjustments are needed to increase investment in R&D.

In the future there are opportunities for supporting similar projects in other countries in Latin America. This might include Colombia, which has a very weak research establishment which could be strengthened as part of a higher education reform package, Argentina, once the leader in science and technology research in Latin America, and Chile, which could benefit from assistance to strengthen its own highly innovative higher education reform program. Currently a number of similar projects are being undertaken in Eastern Europe and the Far East. It would be useful to compare and contrast these programs with the Latin American experience.

REVIEW OF RESEARCH ON ECONOMIC RETURNS TO INVESTMENT IN S&T

This summary (prepared by George Psacharopoulos) reviews what is known regarding economic returns to investment in R&D.

Spillover Effects of R&D Expenditure (Externalities)

Griliches, Pakes and Hall (1985) report results by Jaffe on the spillover effects of R&D expenditure. Using technological clusters, Jaffe constructed a measure of an "R&D pool" available for spillovers, i.e., by means of borrowing or stealing. This measure of R&D pool contributed significantly in explaining several firm outcome variables. For example, firms in technological clusters with large R&D pools invested more heavily in R&D than would be predicted by their industrial classification. Firms received more patents per R&D dollar in clusters where more R&D was performed by others. And firm productivity was positively related to both the average R&D intensity of the individual firm and the change in the size of the R&D pool available to the firm.

Social and Private Returns to R&D Expenditure (Micro)

Evenson (1988, p. 510) reports social rates of return to agricultural research in different countries from ranging from 21 to 110 percent. Bernstein and Nadiri (1988) estimate private and social rates of return to R&D capital expenditure. The results are shown in Table 1. The private rate of return refers to the firm's variable cost reduction because of each firm's own R&D capital. Tassey (1986, p. 168) reports the social rates of return from R&D expenditure shown on Table 2. The social rates of return shown in Table 3 take into account the spillover effect.

Table 1: PRIVATE RATES OF RETURN TO R&D EXPENDITURE, 1981
(Percent)

	Rate of return to	
Industry	R&D capital	Physical capital
Chemical products	13.3	13.5
Non-electrical machinery	24.0	13.6
Electrical products	22.4	13.9
Transportation equipment	11.9	11.7
Scientific instruments	16.1	11.8

Source: Bernstein and Nadiri (1988), Table 4.

Table 2: SOCIAL RATES OF RETURN TO R&D EXPENDITURE, 1981
(Percent)

Source industry	Receiving industry: Chemical products	Non-electrical machinery	Electrical products	Transportation equipment	Scientific instruments	Social rate of return
Chemical products		12.6			3.2	29.1
Non-electrical machinery				21.0		45.0
Electrical products		6.2			1.6	30.2
Transportation equipment		3.5			0.9	16.3
Scientific instruments	65.7		47.1			128.9

Source: Bernstein and Nadiri (1988), Table 5.

Table 3: SOCIAL RATES OF RETURN TO R&D BY SOURCE OF FUNDING

Area/product	Source of funds: Private	Public	Rate of return (percent)
Miscellaneous industrial innovations	x		77-108
Agricultural innovations		x	10-50
Semi-conductor technology		x	98-128

Contribution to Economic Growth of R&D Expenditure (Macro)

Griliches and Mairesse (1985) examined the role of R&D expenditure at the firm level in accounting for the large differences in productivity between the United States and Japan. They concluded that the observed differences in productivity growth between the two countries cannot be accounted for by differences in either the intensity or fecundity of R&D expenditures. The main reason for the Japanese productivity advantage is that Japanese firms reduced significantly their levels of employment while US firms were increasing theirs.

Appropriability of R&D Benefits

This is the degree to which the firm itself enjoys the benefits of a new process or product innovation. The degree of appropriability differs across industries and depends on market structure, institutional setting, regulatory environment and nature of technology.

The issue is important because imperfect appropriability may lead to underinvestment in new technology. To the extent that economic growth depends on new technology, economic growth will suffer in the absence of R&D (Levin et al, 1987).

Appropriability can be measured in a variety of ways, e.g., what the firms themselves think of the degree to which they can monopolize the benefits of their own innovation (Cockburn and Griliches, 1987). Or the number of patents can be used as a proxy for R&D activity when the latter is not readily available. Griliches, Pakes and Hall (1986) report that in the United States an unexpected increase in one patent by a firm is associated with an increase in the firm's market value of $810,000, while an unexpected increase of $100 of R&D expenditures is associated with a nearly $2,000 increase in the value of the firm.

Cockburn and Griliches (1987) found that in the United States a two standard deviation increase in the index of patent-effectiveness would raise the value of the patent held by the average firm from $400,000 to $1 million.

Public Versus Private Financing of R&D

Expenditure on R&D has a lagged and uncertain payoff. Because the outcome of any research project is uncertain, it is in society's interest to hold a portfolio of active research projects, i.e., parallelism need not imply waste (Dasgupta and Maskin (1986), unless of course there are increasing returns to scale. The degree of parallelism can be influenced by direct government participation (e.g., by public funding of research), or by setting the reward system (e.g., the length of patents).

According to the sociology of science, scientific discoveries are often made independently by many researchers. This is called "multiples." For example, if the transistor exists, several firms will come up with some version of a personal computer.

In a theoretical analysis, Dasgupta and Maskin (1986) claim that the market induces the development of too many inventions, too large a spread in the distribution of the quality of these inventions and an excessive occurrence of multiples. So, market research portfolios might be inefficient. The reason is that only the best solution among the different discoveries produces a social surplus--the rest being waste. But then multiples are rarely identical, c.f. the case of the PC. So there is some value to the existence of multiples.

The degree of appropriability can influence both the causes and results of R&D expenditure. R&D expenditure by one firm reduces its own production cost, and via the spillovers, it can reduce the production cost of other firms. Thus, each firm engaging in

R&D is both a source and recipient of spillovers, although the degree of spillover effects may differ among different industries.

Bernstein and Nadiri (1988) report results on the effect of R&D spillover on cost reduction of the following order of magnitude: A one percent increase in spillover causes average cost to decline by 0.2 percent. They further studied the spillover effect of five high-tech industries on reducing each other's variable cost. The effect of spillover is measured by means of a variable cost production function where the firm's own R&D capital, and that of other firms in the industry, enter the function as explanatory variables. The results are shown in Table 4.

Table 4: SPILLOVER EFFECTS ON COST REDUCTION, 1981

Receiving industry	Source industry	Variable cost reduction (percent)
Chemical products	Scientific instruments	8.9
Non-electrical machinery	Transport equipment	5.8
Electrical products	Scientific instruments	11.9
Transport equipment	Non-electrical machinery	9.2
Scientific instruments	Transportation equipment	7.8

Source: Bernstein and Nadiri (1988), Table 3.
Note: Numbers refer to the percent decrease in variable cost followed by a 1 percent increase in spillover.

Programs on Standards

Standards and measurement is a kind of "infratechnology" that is likely to be socially underfunded if completely in private hands (Tassey 1986). Such underinvestment could be manifested by reduced funding or the diversion of R&D from basic or long term research towards applied or short-term development projects. Namely, the result could be insufficient level of R&D funded by the private sector, or a shift in the composition of R&D from a long-to-short-term mix of projects.

Tassey defines underinvestment in technological change as an insufficient volume of investment relative to the volume deemed necessary to achieve some economic goal. Although a precise measure of underinvestment requires an estimate of the optimal investment level, there exist indirect indicators such as the loss of world market share, and low or negative productivity growth (p. 163).

Underinvestment in measurement and test methods can occur for a number reasons, especially because such research is very taxing, e.g., (Tassey, 1986, p. 166).

- complex, expensive, time consuming;
- requires different skills than those available in private firms concerned in line production or applied research;
- difficult to make proprietary, i.e., difficult to capture an adequate return on the investment without preventing uncompensated diffusion;
- capital-intensive so that the level and frequency of use of the research results by any one firm is insufficient to justify the large investment (e.g., when there exist economies of scale).

Evenson (1988, p. 515) reports the results of a study on the effect of R&D in agricultural implements in Brazil. This industry was dominated by multinational firms. Small firms undertook informal R&D and by the 1970s they could produce and develop new designs, and produce for less than large multinational firms. By 1980 the multinational firms had lost nearly all of the implements market to aggressive Brazilian firms, except for the most complex machines like tractors and combines. According to Evenson, inventive effort led to design changes and increased the competitiveness of smaller firms.

References

Bernstein, J.I., and M.I. Nadiri, "Interindustry R&D Spillovers, Rates of Return and Production in High-tech Industries," NBER Working Paper No. 2554, 1988.

Cockburn, I. and Z. Griliches, "Industry Effects and Appropriability Measures in the Stock Market's Valuation of R&D and Patents,", Harvard Institute of Economic Research, Discussion Paper No. 1360, 1987.

Dasgupta, P. and E. Maskin, "The Simple Economics of Research Portfolios," University of Cambridge, Economic Theory Discussion Paper No. 105, 1986.

Evenson, R., "Technology, Productivity Growth and Economic Development," in G. Ranis and T.P. Schultz, The State of Development Economics, Blackwell, 1988, pp. 486-524.

Freeman, C., "Technical Change and Long-term Economic Growth," Paper presented at the World Bank Seminar on Technology and Long-term Economic Growth Prospects, Washington, DC, 16-17 November, 1988.

Griliches, Z. and J. Mairesse, "R&D and Productivity Growth: Comparing Japanese and U.S. Manufacturing Firms," NBER Working Paper Series, No. 1778, 1985.

Griliches, Z., A. Pakes, and B.H. Hall, "The Value of Patents as Indicators of Inventive Activity," NBER Working No. 2083.

Levin, R.C., A.K. Klevorick, R.R. Nelson, and S.G. Winter, "Appropriating the Returns from Industrial Research and Development," Brookings Papers on Economic Activity, 1987: 783- 831.

Mansfield, E., "Protection of Intellectual Property Rights in Developing Countries," mimeo, 1988.

SRI International/Science and Technology Program. New Directions for U.S.-Latin American Cooperation in Science and Technology, Technical Note STPP-TN-3164-4, 1988.

Tassey, G., "The Role of the National Bureau of Standards in Supporting Industrial Innovation,", IEEE Transactions on Engineering Management, Vol 33, No. 3, 1986: 162-171.

UNESCO, Statistical Yearbook 1988.

STATISTICAL REVIEW OF BRAZIL'S EFFORT IN S&T/1

Table 1: R&D EXPENDITURES IN SELECTED COUNTRIES
(As % of GNP)

Country	1970	1975	1978	1980	1982	1985
Brazil	0.24	0.70/a	0.60	0.55	0.70	0.60/a
South Korea	0.39	0.42	0.63	0.58	0.90	1.59
Taiwan	----	----	0.66	0.72	0.91	1.06
Japan	2.22	2.40	2.36	2.63	3.01	3.49
West Germany	2.10	2.20	----	2.40	----	2.70
United States	2.82	2.45	2.36	2.57	2.83	3.06
Mexico	0.20	----	----	----	0.50	0.60/b

Sources: Dahlman (1988); Frischtak (1988)
Note: ---- = data not available.
/a Figures refer to R&D as % of GDP.
/b Figure refers to 1984.

Table 2: EXPENDITURE FOR SCIENCE AND TECHNOLOGY IN BRAZIL, 1981-88
(US$ Million of 1987)

	1981	1982	1983	1984	1985	1986	1987	1988
Federal Government:								
(A) Initial Allocation	558	793	812	509	686	1,005	432	396
(B) Actual Expenditure (i)	984	1,200	963	962	1,280	1,455	1,485	1,383
(C) Variance (B-A/A*100)	76	51	18	88	86	44	243	248
State Governments:								
(D) Initial Allocation (ii)	266	295	261	194	199	398	152	71
(E) Actual Expenditure (iii)	435	421	301	337	343	437	274	219
(F) Variance (E-D/D*100)	63	42	15	73	71	9	79	206
Government Expenditure in S&T:								
(G) (B)+(E)	1,419	1,622	1,265	1,300	1,628	1,892	1,759	1,602
Expenditure by the Productive and Financial Sectors:								
(H) = 0,25 * (G) (iv)	354	405	316	233	405	473	439	400
National Expenditure in S&T:								
(I) = (G)+(H)	1,773	2,027	1,581	1,533	2,033	2,365	2,198	2,002
GDP:								
(J) (v)	258,575 (1981)	261,453 (1982)	254,065 (1983)	268,492 (1984)	290,997 (1985)	314,442 (1986)	323,572 (1987)	322,602 (1988)
National Expenditure in S&T/GDP:								
(L) = (I)/(J) %	0.67	0.78	0.62	0.58	0.70	0.75	0.68	0.62

Source: Primo Braga, C. and Shepherd, G., 1989.

Note: (a) exchange rate US$1,00 = Cz$39,523, which was the average sale price of the dollar in 1987, according to the Central Bank of Brazil. (b) In calculating (H), it is assumed that the productive sector share represents 25% of the government expenditure in S&T.

/1 Prepared by Alcyone Saliba

Table 3: RESOURCES ALLOCATED FOR S&T AT THE STATE LEVEL
(Percentage Allocated by the New State Constitutions)

State	Amount
Maranhao, Mato Grosso do Sul and Sergipe	0.5% of general tax revenues
Tocantins	0.5% of total state budget
Acre and Pernambuco	1.0% of total state budget
Para and Sao Paulo	1.0% of general tax revenues
Bahia and Rio Grande do Sul	1.5% of general tax revenues
Rondonia, Alagoas and Paraiba	2.0% of total state budget
Santa Catarina	2.0% of general operating
Ceara, Parana and Rio de Janeiro	2.0% of general tax revenues
Espirito Santo	2.5% of total state budget
Minas Gerais	3.0% of total state budget
Amazonas and Goias	3.0% of general tax revenues

Source: Forum Nacional de Secretarios Estaduais de Ciencia e Tecnologia and Secretaria Especial de Ciencia e Tecnologia, 1989.

Table 4: R&D EXPENDITURE IN BRAZIL BY RECIPIENT SECTOR
(In Percent)

Year	Government	Higher education	Industry	Total
1977	11	31	58	100
1979	32	16	52	100
1981	32	16	52	100
1982	53	17	30	100

Source: Figures for 1977 are estimations based on UNESCO Statistical Yearbook 1988. Figures for 1979 are from The World Bank, Brazil: Issues in Science and Technology Development, Report N.4819 (a)-BR, mimeo, January 1984. Figures for 1981 are from The World Bank, Brazil: Project for Science and Technology, Staff Appraisal Report No. 5153-BR, mimeo, January 1985. Figures for 1982 are from UNESCO Statistical Yearbook 1988.

Table 5: SELECTED S&T INDICATORS IN BRAZIL, 1973-86

Year awarded	Higher education institutions	Number of individuals			Number of programs	
		Researchers	Graduate students	Graduate fellowships	Graduate programs	Graduate degree programs
1973	780					
1974	848	7,725	14,914			2,130
1975	877	8,232	22,245	3,789	681	2,309
1976	885		26,255	5,801		2,387
1977	863	17,187	31,532	7,717		3,223
1978	861	24,015	33,631	8,621		4,261
1979	862		36,608	9,689	974	5,057
1980	872		38,609	13,685	982	4,634
1981	867	12,058	40,184	13,688	1,021	4,863
1982		32,508	42,838			4,520
1983			45,421			5,696
1984			47,759			6,025
1985			50,054	9,140		6,349
1986				10,044		

Source: SRI International, New Directions for U.S.-Latin America Cooperation in Science and Technology, Technical Note STPP-TN3164-4, 1988. The World Bank, Brazil: Science and Technology Sector Memorandum, mimeo, June 1988. CNPq, PADCT Documento Basico, 1984.

Table 6: PATENT APPLICATIONS AND PATENTS GRANTED IN BRAZIL, 1973-87

Year	Patent grants	Patent applications
1973	264	10,288
1974	1,154	10,936
1975	985	11,365
1976	3,200	11,444
1977	2,420	11,342
1978	2,469	11,678
1979	2,517	11,496
1980	8,204	11,312
1981	11,538	11,351
1982	11,561	10,453
1983	7,338	11,144
1984	5,749	10,864
1985	4,926	10,426
1986	3,804	10,371
1987	3,130	14,157

Source: CNPq, 1989.

References

CAPES, Brazil, "Plano de Metas para Formação de Recursos Humanos e Desenvolvimento Cientifico e Tecnologico 1987-89", preliminary version, 1987.

CNPq, "Ciencia e Tecnologia, Recursos do Tesouro da União: Dotaçao Inicial, Dotação Final, e Despesa Realizada 1980-89," May 1989.

———— (1984?), PADCT Documento Básico, mimeo.

Ferreira, J.P., "Diretrizes de Política Científica e Tecnológica." Paper presented at the Forum Nacional Idéias para a Modernização do Brasil, November 23-25, 1988, (city), Brazil, p.14.

Frischtak, C.R., "The Protection of Intellectual Property Rights and Industrial Technology Development in Brazil," The World Bank Industry and Energy Department, Industry Series Paper No. 13, September 1989.

Holanda, N. and Z.S. Reis, Financiamento ao Desenvolvimento Científico e Tecnológico. Paper presented at the Forum Nacional Idéias para a Modernização do Brasil, November 23-25, 1988, Brazil.

Kim, H.K., "Brazil Science and Technology Science Memorandum," The World Bank, June 20, 1983.

SRI International/Science and Technology Program. "New Directions for U.S.-Latin American Cooperation in Science and Technology," Technical Note STPP-TN-3164-4, 1988.

UNESCO, Statistical Yearbook 1988.

The World Bank, "Brazil: Project for Science and Technology," Staff Appraisal Report No. 5153-BR, mimeo, 1985.

————, "Brazil: Issues in Science and Technology Development." Report No. 4819(a)-BR, mimeo, 1984.

————, "Brazil: Science and Technology Sector Memorandum, mimeo, June 20, 1983." (Original source: CNPq, Dados Básicos de Ciência e Technologia; E.I. Paulinyi, Revista Brasileira de Tecnologia, 1982, 13:4, p. 51.)

BRAZIL'S SCIENCE FUNDING AGENCIES

The most important Government agency financing and undertaking science research is the Council for Scientific and Technological Development (CNPq). The CNPq provides funds for researchers in the form of salary increments and also provides support in the form of research grants, usually to individual researchers and for relatively small amounts. Along with its grant program, CNPq administers eleven separate research institutes and a large scholarship program (at present, there are 30,000 scholarships inside Brazil and 3,500 overseas). CNPq employs 1,000 employees, and has a modest science planning and analytical capacity. Each year, 40,000-50,000 applications for grants come in to CNPq's offices (including travel grants), along with 100,000 applications for scholarships. CNPq provides for a third of the applicants in each category. The total budget in 1989 was US$291 million most of which went to top off researchers' salaries. An estimated US$50 million went for research grants. CNPq uses a peer review system to evaluate research grant requests, which are generally unsolicited, and approves such grants about four times a year.

The Agency for Financing Studies and Projects (FINEP) is a public corporation which acts both as a conventional research foundation and as a development bank lending funds for technological innovation in Brazilian industry. FINEP was set up in 1967 to develop Brazil's engineering industry. FINEP has 700 staff, more than 100 with doctoral or masters degrees, and in 1988 supported 1,840 projects split almost equally between scientific research and technological development (projects range from university research on AIDS to an industrial company's first attempt to develop the first fully Brazilian automobile). FINEP also functions as the Executive Secretariat for the National Scientific and Technological Development Fund (FNDCT), a major government source of grant funding for infrastructure, new buildings and new equipment in the science and technology sector. In 1989 about US$60 million was expended under FNDCT. Traditionally FINEP makes awards under FNDCT on the basis of evaluation by its own staff, as well as some ad-hoc reviewers from the science community. In addition for many years, FINEP, a Rio based institution, has been providing large scale institutional support to an engineering center at the Federal University of Rio de Janeiro as well as support for science research at the Catholic University of Rio. Almost 90% of FINEP awards are for continuation of ongoing research programs.

The Agency for Training of High Level Personnel (CAPES) of the Ministry of Education and Culture (MEC) is the coordinating agency for graduate education in Brazil. CAPES's principal instruments of support have been grants and fellowships for study in Brazil and abroad for individuals preparing for careers in university teaching and research (in 1989, CAPES supported 14,000 students at Brazilian universities and to 2,000 students in North America and Europe). CAPES certifies and rates all graduate programs in terms of overall quality and provides support to 700 graduate courses (two-thirds of all the courses in the country). It also runs a program to help build up institutions so that they can offer new courses. In 1989 CAPES' total budget was equivalent to US$200 million.

The Institute of Metrology (INMETRO) is Brazil's national bureau of standards and measurement. It includes a national standards laboratory, with world class equipment (located near Rio de Janeiro) and provides support for secondary measurement laboratories throughout the country as well as for state and local efforts in legal metrology. INMETRO is currently subordinated to the Ministry of Justice but efforts are underway to incorporate it into SECT. INMETRO has a reasonably strong corps of technicians but has been beset for some time by lack of high level scientific research capacity. The National Institute of Intellectual Property (INPI), Brazil's patent office, is also currently located in the Ministry of Justice.

Recently state efforts in S&T have increased significantly. The Foundation for Promotion of Science in Sao Paulo (FAPESP) is the oldest and strongest of these institutions. In 1990 FAPESP will receive by law 1% of state income each year to spend on scientific research. In 1989, this agency provided approximately US$20 million in research funding (0.5% of state income). FAPESP has a very small permanent staff, utilizes active scientists at all levels of decision making, and is a highly efficient and effective institution, albeit relatively small. Within the last few years, numerous states, including Rio Grande do Sul, Rio de Janeiro, and Minas Gerais, have set up similar funding agencies, most of which are in the process of getting organized. In the near future these states may be funding as much as US$250 million per year in R&D and a mechanism will need to be set up for coordinating these various efforts.

A variety of other federal institutions also undertake basic and applied research. The most important of these is the Brazilian Agricultural Research Corporation (EMBRAPA), which in 1988 expended more than US$200 million for applied agricultural research. The World Bank has been supporting EMBRAPA's research effort through a series of loans, the last one being a US$47.0 million loan presented to the Board in late 1989 mainly to strengthen agricultural research in the Amazon and Northeast. Other key agencies include the National Council for Nuclear energy (CNEN), the Institute of Space Research (INPE), and the Oswaldo Cruz Foundation doing health research (FIOCRUZ). In addition the military undertakes a variety of research programs.

The main implementing agencies for science research are the graduate programs of federal and state universities. In particular the State Universities of Sao Paulo and of Campinas (in Sao Paulo) do research of world class quality. Other strong research universities include the federal universities of Rio de Janeiro, Santa Catarina, Minas Gerais, Rio Grande do Sul, Pernambuco, and Bahia. Except for the Catholic University of Rio and one or two other confessional universities, private universities do not engage in science research. In addition a number of public institutes do specialized research in areas such as health, space technology, and agriculture. A few large parastatals, especially Petrobras, have strong research groups.

SAMPLE SUB-PROGRAM SUMMARIES: BIOTECHNOLOGY, GEOSCIENCES, ENVIRONMENTAL SCIENCE, SCIENCE EDUCATION

Each of the sub-programs in PADCT is based on a document prepared by a technical committee which provides a detailed analysis of the situation in the area as well as a six year plan of action. Below are summaries of four of these programs, which are selected here to give the reader a feeling for their variety as well as complexity.

Biotechnology

Biotechnology, the manipulation of cell systems for specific and pre-defined goals, is progressing rapidly worldwide. The impetus for this growth was the discovery of the nature of DNA, the fundamental building block of life, in the late 1950s. Recent products of economic importance generated by biotechnological means include vaccines, diagnostic kits, and plants resistant to pathogens and herbicides. In the future the use of biotechnology is expected to multiply as techniques become more widespread and more knowledge becomes available. Brazil's extraordinarily diverse biomass constitutes an important resource for entering this field. Brazilian scientists may be able to identify new uses for this biomass. Furthermore, many applications in biotechnology, such as crop improvement, must be developed locally. Since the discipline is still in its infancy, Brazil has the opportunity to make a rapid entry requiring relatively little catching-up, provided it has an adequate number of well trained people and R&D centers.

With this in mind, a central objective of PADCT I was human resource formation and stimulation of research in the specific areas of health, agriculture, animal husbandry, and energy. To date the sub-program has supported 125 projects. Some projects of particular interest are: the development of a virus-resistant potato strain; a leishmania vaccine is now available through the joint efforts of the Federal University of Minas Gerais and Biobras; the first steps have been taken to produce insulin by genetic engineering after having first established the technique of extracting insulin from animals and humanizing this protein for human consumption through enzymatic cleavage; and work is underway on the preservation of animal germ plasmas to improve livestock through embryo transfer techniques is underway.

The general objectives under PADCT II are to continue to strengthen Brazil's human resource capacity for basic and applied research in biotechnology, which will eventually result in the establishment of biotechnology industries. The specific objectives are outlined below.

(a) Strengthen biotechnology in human health:

(i) Support research leading to production of immunobiological materials;

(ii) Develop methods for diagnosis or treatment of illnesses, using monoclonal antibodies, molecular probes, and recombinant or synthetic proteins.

(b) Strengthen biotechnology in agriculture:

(i) Obtain genetically improved plants;

(ii) Obtain secondary metabolites of commercial interest through cell cultures and vegetative growth;

(iii) Genetic improvement of micro-organisms for purposes of control, diagnosis, or improved absorption of nutrients.

(c) Biotechnology in animal husbandry:

(i) Develop diagnostic methods and immunological and molecular techniques;

(ii) Produce vaccines using biotechnology;

(iii) Improve reproduction using biotechnology.

(d) Industrial biotechnology:

(i) Improve processes;

(ii) Develop biotechnology products.

Geosciences and Mineral Technology

The rationale for including this area in PADCT I was Brazil's richness in mineral resources, coupled with a level of exploitation of these resources far below what was potentially possible. Lack of adequate human resources was identified as a significant bottleneck for the development of this field. The geosciences and mineral technology institutions in the country were assessed as widely variable, both in terms of standards and productivity, and there was little interaction between more theoretical and more practical work. In this field interfaces are important because the economic return from investment in R&D depends to a large extent on an efficient flow of information from science into both exploration and exploitation of resources. There are extensive deficiencies in basic geosciences knowledge about Brazil. In addition, a series of issues associated with mining effects on environmental degradation need to be considered.

Under PADCT I, the infrastructure of laboratories operating in geosciences and mineral technology was improved, new research activities were initiated, and the training of graduate students was increased. New laboratories in part supported by this subprogram have enabled Brazilian earth scientists to produce high quality data. New types of mineral deposits were discovered as with the gold deposits of the Amazon region (a single, new, gold deposit recently discovered in the Amazon will more than pay for the proposed total cost of PADCT II). Some specific achievements include the installation of a modern mass spectrometry laboratory aimed principally at geochronological studies, publication of research on the Parana basin, and research on modelling of processes aimed at better use of coals. Earlier editais were found to be excessively detailed and awards were too small; the last edital attempts to overcome this problem through proposing larger awards for major centers.

PADCT II objectives and strategy are as follows:

(a) Support basic research in geosciences. Strengthen infrastructures of laboratories, including laboratories in geochronology, stable isotopes, analytical laboratories, geophysics, petroleum/mineralogy analysis, remote sensing, experimental geology, and seismology.

(b) Support applied mineral research. Strengthen laboratories in universities and publicly financed research institutes in the areas of applied geophysics, analytic prospecting, mining, rock mechanics, and mineral treatment.

(c) Develop extractive processes. Establish or strengthen laboratories in universities and in publicly financed research institutes in hydro and electro metallurgy, pirometallurgy and extractive processes.

(d) Support research on physical environment use and occupation. Support laboratories in geotechnics, environmental geology, hydro-geology, mineralogy and environmental, and mineral pollution.

(e) Establish a system to evaluate and monitor the subprogram activities.

Environment

The Brazilian Government's recently increased commitment to protecting its environment requires strengthening its institutional and analytic capacity so as to ensure that policies are undertaken with a firm scientific basis. In particular, Brazil needs to train multidisciplinary scientists who can together tackle the complexity of the country's vast environmental diversity. More knowledge is especially needed about the Amazon ecosystem.

This subprogram will promote an intersectoral approach to environmental research through the creation of multidisciplinary teams, the integration of training and research, and the study of technologies to maintain and improve the quality of the environment. Special efforts would be made to train economists and other social scientists in environmental issues. Particular attention will be placed on coordinating with other PADCT subprograms to devise ways of integrating diverse scientific disciplines, and of organizing research tasks for addressing environmental issues around multidisciplinary teams, especially in the areas of geosciences and mineral technology and biotechnology. An outline of detailed objectives and strategy follows.

(a) Support graduate training programs that emphasize interdisciplinary research and holistic approaches to environmental issues:

(i) Finance installation, improvement, and/or upgrading of facilities and equipment used by 5 graduate programs;

(ii) Grant scholarships and fellowships for attendance of degree-as well as and non-degree graduate programs in the country and overseas;

(iii) Promote exchange programs of national and international researchers.

(b) Support interdisciplinary research projects, organized intra- or inter-institutionally, that approach environmental dynamics from an open system perspective:

(i) Support, on a multi-year basis, existing, well established research groups;

(ii) Encourage the emergence of new research groups.

(c) Support research and development of methods, processes, techniques, and products for diagnosis, prognosis, and prevention of environmental problems, as well as the restoration of environmental quality.

(d) Monitor and evaluate subprogram activities:

(i) Promote the organization of scientific events where subprogram participants can share research outcomes;

(ii) Conduct studies to understand the impact of the subprogram activities on the nation's environment management;

(iii) Organize procedures to monitor and evaluate the contracted projects.

Science Education

The improvement of science education in primary and secondary school is essential for increased utilization of science and technology in the Brazilian economy, not only because it helps to identify and encourage talented students to become working scientists, but also because a basic knowledge of science is becoming increasingly important for manpower working in agriculture, industry, and commerce. While few facts are available, it is generally acknowledged that science education at the primary and secondary level, except in a few private schools, is inadequate by any standard. This is undoubtedly part of larger problems with public education in Brazil, which suffers from high rates of drop-out and repetition, a continuing drop in the prestige of the teaching profession, and continuing middle class flight from public to private schools, especially in secondary education. Science education may be particularly weak because of lack of funds for equipment, the generally low level of teacher training, and, until recently, lack of interest by scientists in pedagogical problems.

In response to these difficult and complex problems, the science education subprogram under PADCT I set out to encourage practicing scientists to join with educators in trying to improve science education. As a result, during project implementation this sub-program supported a wide variety of experiments and programs in in-service teacher training, curriculum and materials development, as well as masters and doctoral level programs. The sub-program also successfully linked educators and scientists in the beginnings of a constituency concerned with the problems of science education in Brazil. Given the recent start of the program and the limited number of persons involved, as yet the sub-program has not had a significant impact on science education as a whole.

In view of this situation, under PADCT II the sub-program will focus on establishing networks of university, local and administrative groups committed to innovation in science education and on expanding successful pilot programs through seeking co-financing with state and local governments and industry. To correct observed problems under PADCT I, the sub-program will concentrate resources on fewer programs and will support advanced degrees in the areas of science and mathematics, curriculum development, as well as in tests and measurement. Proposals will be prepared for Brazil's participation in international assessments of science and mathematics. The specific objectives are outlined below.

(a) Support research and studies in science education (10 consolidated groups and 20 emerging groups);

(b) Support innovative programs for training primary and secondary school science teachers in areas such as curriculum, methodology, exchange programs and sandwich type courses (100 training programs, 15 specialization courses, and 7 masters or doctorates);

(c) Strengthen in-service training, with an emphasis on continuous up-grading and on participation of local and state authorities (10 in-service training programs and three distance teaching programs);

(d) Strengthen five interdisciplinary centers;

(e) Support production and dissemination of educational materials (a variety of groups producing materials, as well as five books, five bulletins and experimental mass media programs);

(f) Disseminate science knowledge and awareness to the larger community (science centers, science fairs, meetings, and periodicals);

(g) High level human resource development (overseas and Brazilian masters and doctorates);

(h) Programs on local and international evaluation, competitors, and awards.

Views from LATHR

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No. 18 "*Wage Trends in Latin America*" by Alejandra Cox Edwards, September 1991

No. 19 "*Investment in Science Research and Training: The Case of Brazil and Implications for Other Countries*" by Laurence Wolff, with contributions from George Psacharopoulos, Aron Kuppermann, Charles Blitzer, Geoffrey Shepherd, Carlos Primo Braga and Alcyone Saliba, September 1991