Consultative Group on International Agricultural Research

CGIAR

Study Paper Number 1

Technological Innovation in Agriculture

The Political Economy of Its Rate and Bias

Alain de Janvry

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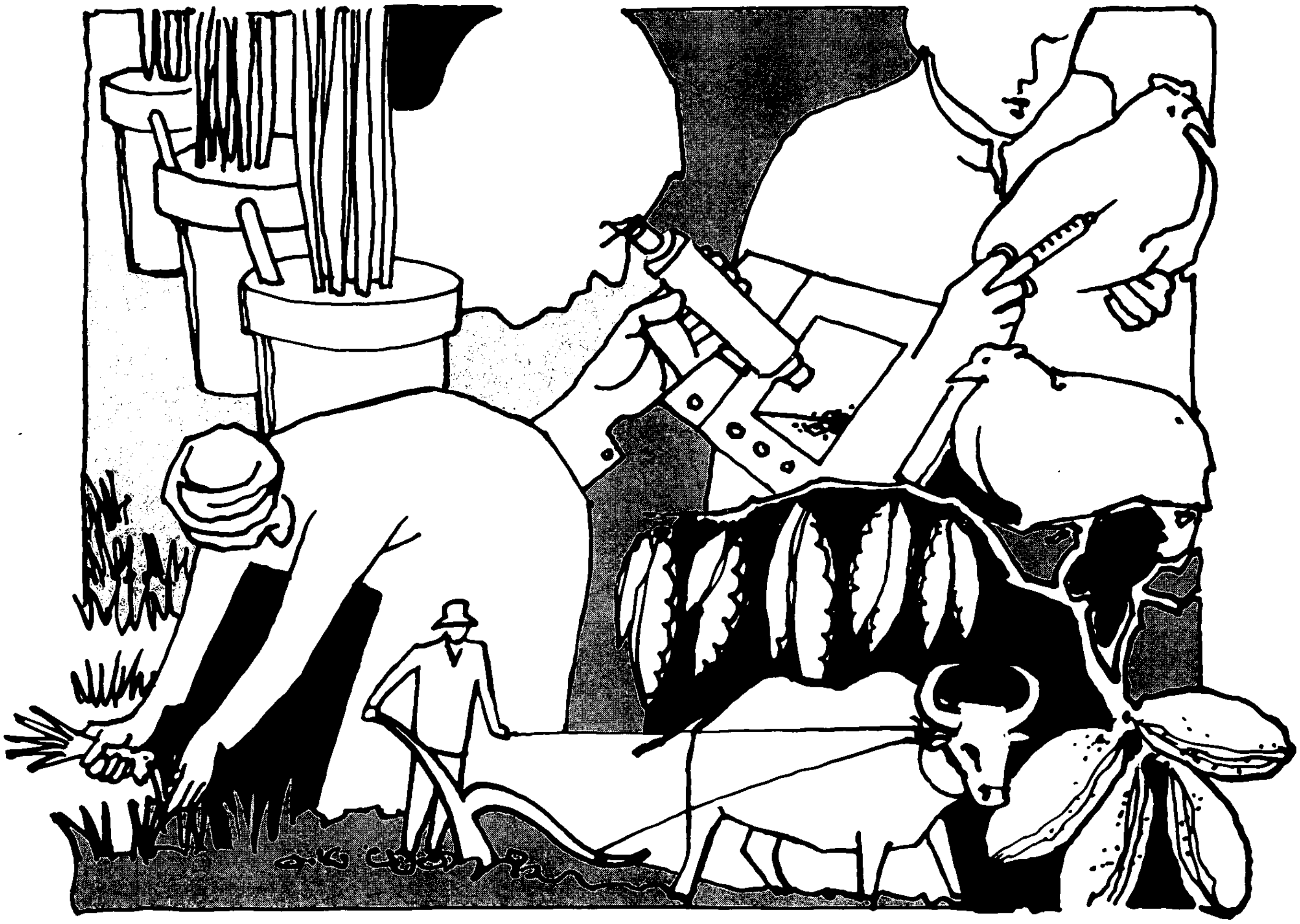

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The World Bank
Washington, D.C.

At its annual meeting in November 1983 the Consultative Group on International Agricultural Research (CGIAR) commissioned a wide-ranging impact study of the results of the activities of the international agricultural research organizations under its sponsorship. An Advisory Committee was appointed to oversee the study and to present the principal findings at the annual meeetings of the CGIAR in October 1985. The impact study director was given responsibility for preparing the main report and commissioning a series of papers on particular research issues and on the work of the centers in selected countries. This paper is one of that series.

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This paper has been prepared and published informally in order to share the information with the least possible delay.

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ABSTRACT

This paper examines the role of market and nonmarket forces in affecting the rate and bias of technical change in agriculture. It examines the process of generation of innovations and investment in agricultural research and explores, in the context of political economy, the sources of deviation from the equilibrium rate and bias of technical change.

It is argued that a theory of the rate and bias of technological innovation must go beyond the analysis of market forces because they explain only a fraction of changes in investment and productivity in agriculture. Such a theory must also take into account institutional forces which, on the one hand, distort and supplant market mechanisms and, on the other hand, act independently of prices on the determination of investment and productivity. In particular, the action of the state and its modes of intervention must play a central role in the analysis of investment in agricultural research.

It is further argued that the roles played by the various actors involved in agricultural research--the state and the National Research Institutes, the International Agricultural Research Centers, and the private sector--are being redefined as research moves into the "Post-Green Revolution" era. In particular, the private sector is being increasingly involved in research, and the work done at the IARCs modifies the research priorities of the NRIs. New mechanisms of identification of research priorities, of coordination of research programs, and of participation of social groups affected by research need to be devised to increase efficiency and equity in the research effort.

Empirical evidence in support of these propositions--and, for that matter, of any propositions concerning investment in research--is still fragmentary. Because of the inconsistencies in the existing data or the absence of data in certain areas (for instance, on investment on a commodity basis), the argument in this paper is mostly supported by circumstantial evidence and case studies. Attention has been mainly focussed on Latin America.

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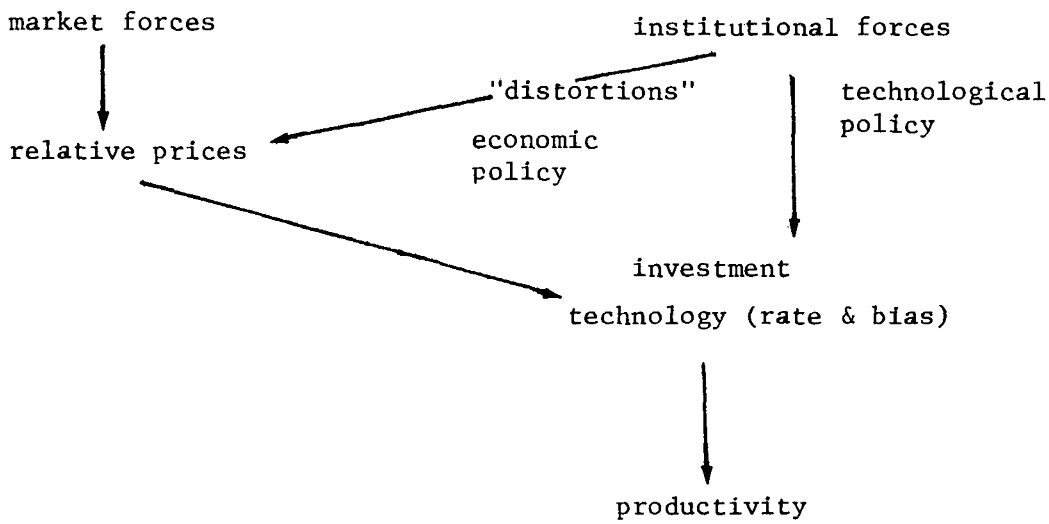
SECTION 1

SUMMARY AND INTRODUCTION: PROPOSITIONS ON INVESTMENT IN AGRICULTURAL RESEARCH

In this section, we state without elaboration the major propositions of this paper. The arguments are then developed in the body of the paper. In Section 2, we present a framework for the analysis of technological innovations which aims at taking market and nonmarket forces into consideration. In Section 3, we look at the existing data on the present level and growth trend in research expenditures. In Section 4, we review the methodology used in cost-benefit studies of agricultural research projects to examine whether they support the underinvestment thesis. In Section 5, political-economic considerations that might explain underinvestment are then examined. In Section 6, we look at the problem of variability in financial resources which is a major factor of instability of the research process. In Section 7, we examine the commodity bias in research. Section 8 presents three case studies on different modes of involvement of the state in the research process. Finally, Section 9 draws conclusions from the analysis and implications concerning the role of International Centers.

1. Market forces explain only partly long-run changes in investment and productivity in agriculture. These changes, to a large extent, are influenced by institutional forces. These forces both distort and supplant the operation of market forces in the determination of prices. In addition, institutional forces act on the determination of investment and productivity independent of the condition of relative prices.



2. In spite of a rapid increase in the level of investment in agricultural research, there is no indication that the gap between optimum and actual levels of investment has been reduced. The result is continual underinvestment in agricultural research and a suboptimum rate of technological change.

3. Because there is a high complementarity between public (especially research and infrastructure) and private investment in agriculture, public underinvestment acts as a bottleneck on productivity and output growth in agriculture. With the growing importance of agricultural research in future food supply and with the unique role of the public sector in agricultural research, this complementarity is increasingly important; and underinvestment in public agricultural research can be increasingly binding on the growth in food supply.

4. Many explanations have been advanced of the tendency for underinvestment in agricultural research. They include:

   a. The existence of institutional and geographical externalities.

   b. The tendency for governments to underestimate ex ante the ex post net benefits of agricultural research.

   c. The difficulty of taxing agriculture (land tax or income tax) to finance public expenditures in research, with the result that there is insufficient public investment and that other forms of taxation--which are politically easier to enforce (low agricultural prices and indirect taxes)--create both allocative distortions and usually regressive distributive consequences.

   d. The political constituency of Schumpeterian entrepreneurs is small which reduces their capacity for collective action.

   e. The political constituency of potentially benefited consumers (lower food prices) and employers (lower nominal wages) is large, but the gains for individual consumers and employers are small which induces free riding.

   f. There is insufficient investment in human capital, especially research administrators and applied scientists.

   g. There is a lack of correspondence between technological and political horizons when the state acts in response to a crisis situation: short-run instruments--such as price interventions, trade policy, and labor policies--are then preferred over technological policies with longer maturation periods.

   h. There is a lack of coordination between technological and economic policies that undervalues the potential gains of research efforts.

   i. There is underrepresentation of specific social interests (peasants, marginal regions, etc.) at the level of the state and the public sector, with a consequent neglect of investment in many areas of high potential economic payoffs.

j. There is a general undervaluation of agricultural products in the context of cheap food policies and urban biases. Unfavorable terms of trade for agriculture discourage new investments and stifle the demand for technological innovations originating among producers.

5. Investment in agricultural research is characterized by a high level of variability even though research is a long-term enterprise not only in terms of the maturation time of specific projects but mainly in terms of institutional building and staffing. The main determinants of instability appear to be (a) the high variability in foreign aid budgets for research; (b) domestic economic instability which destabilizes public budgets; and (c) a greater degree of instability in agricultural research budgets than in public budgets due to a bias against agriculture that is exacerbated in periods of economic downswing.

6. On a commodity basis, export crops receive more research attention than food crops; and some products, such as cassava, that are important subsistence crops for peasants but are not consumed in urban areas and have no industrial use are neglected by research efforts. Moreover, crops grown by resource-poor farmers tend to be neglected because the latter are unable to voice their demand for new technology at the level of the state. Neglect in research is self-perpetuating. The time lag between initial investment and research results is longer for neglected crops than for more established crops, and the state tends to favor the latter, particularly in periods of economic crisis and tight budgets, because it yields short-term payoffs.

7. There have been important institutional changes in the allocation of research resources. Initially, National Research Institutes (NRI), under the umbrella of the state, were built around the model of technological "converters" to facilitate dissemination and local adoption of technology available internationally. But several developments, which are the products of structural changes that have taken place in third world economies, have modified the context of agricultural research. The NRIs have lost the initiative as a result, among other factors, of work conducted by the International Centers. Simultaneously, privately funded research is increasingly taking place in areas where benefits can be easily appropriated by private groups; and the principle, "who benefits pays," is applied to obviate the financial crisis of the NRIs, thus reinforcing the tendency toward underinvestment in areas where public research is required.

8. Case studies show that research strategies are successful when the state acts from above and pushes for a negotiated solution of conflicting interests in response to an agrarian crisis that affects large constituencies at the national level. In other cases, the state acts from below in response to the interests of specific groups and implements policies designed to solve particular problems obstructing the development of a productive sector. When these groups are powerful enough to activate the state from below, research efforts may lead to production increases. But the potential demand for research is not translated into actual demand when particular social classes linked to agricultural production are too weak to mobilize and coordinate government action in their favor.

SECTION 2

THEORIES OF TECHNOLOGICAL INNOVATION: MARKET VERSUS INSTITUTIONAL FORCES

2.1. Rate and Bias of Technological Change

At the level of the firm, technological change can be fully characterized by its bias and its rate (Diamond, 1965). The bias of technological change is given by the difference in the rates of change in the marginal productivities of factors due to technology. It measures which factor of production is made relatively more productive by technology and, hence, which factor is technology aiming at substituting in production. Technological change can, for example, be land-saving or laborsaving according to whether it increases most the rate of change in the productivity of land or that of labor. Land-saving technology allows the substitution of technology (capital) for land in production and, thus, increases in the level of yield. Laborsaving technology substitutes technology for labor and, thus, allows increased productivity of labor. To analyze the bias of technological change at the level of the country, the concept of bias needs to be extended to include the differential productivity-enhancing effects of technology not only among factors but also among activities, production systems, farms, and regions. In all cases, the notion of bias results in differential rates of productivity growth due to technology among factors, products, production systems, farms, and regions.

The rate of technological change is the rate in the growth of output that cannot be explained by the observed change in the levels of factor use. It is principally conditioned by two sequential processes: (1) the investment of resources in the generation of technological innovations and (2) the transfer and diffusion of innovations among users. For both bias and rate, neoclassical theory gives us the concept of an equilibrium bias and an equilibrium rate.

According to the theory of induced innovations, the equilibrium factor bias will be that bias which equalizes the marginal productivity ratio of factors to the factor price ratio. Marginal productivities are calculated along the meta production function which gives the set of all existing and potential technologies that can be developed with the existing state of scientific knowledge. By allowing for changes in production functions, the equilibrium bias of technological change thus increases the possibility of factor substitution in response to changes in relative factor prices relative to adjustments for a given technique. And by allowing to substitute for the factors becoming relatively scarcer, technology checks the rise in prices of these factors and gives greater stability to factor shares. Equilibrium biases can similarly be defined among products, production systems, farms, and regions.

The concept of an equilibrium rate derives from both optimum investment in research and optimum diffusion of innovations. Optimum investment in research is indicated by equalization of the internal rate of return to research to the rate of return in other government projects. Underinvestment in agricultural research would thus be indicated by an internal rate of return above that of alternative investments. Optimum diffusion corresponds to a full adoption of the innovation whenever it is profitable for entrepreneurs to do so under equilibrium (shadow) prices and full access to supportive institutions (markets, credit, information, etc.).

Economic theory thus gives us a well-defined characterization of what should be the optimum bias and rate of technological change at a particular point in time. In practice, this full potential of technology for a greater efficiency in the allocation of resources is rarely fulfilled. There exist serious distortions in the bias and rate of technological change that result from the political economy of the environment where technological change occurs. Key in the determination of these biases is the role of the state and the distribution of economic and political power in civil society.

We are principally concerned here with the generation of innovations (as opposed to diffusion) and will explore, in the context of political economy, what are the sources of deviation from the equilibrium bias and rate of technological change. Pressures on the state to satisfy clientele demands for particular types of technological change depend more than anything on the income and distribution effects which technology is expected to produce. This will be done mainly with reference to Latin America.

2.2. Neoclassical theory of Induced Innovations

In the neoclassical paradigm, explicit or implicit markets are postulated to exist with flexible prices. Given profit or net-revenue maximizing behavior, markets determine the allocation of resources and the choice of techniques. The result is that market forces lead to the full employment of all resources and to their efficient utilization. Given the stock of resources, maximum output can always be achieved by a reallocation of resources. Moreover, if there are no increasing returns to scale in the economy, the case for the competitive price system is strongest in the sense that any complaints about its operation can be reduced to complaints about the distribution of income which can then be rectified by transfers between producers and/or consumers. These propositions provide no basis for accepting the result of the market in the absence of accepted levels of income inequality as K. Arrow (1970, p. 62) has shown; but they imply that the problem of allocation of resources can be separated from the problem of the distribution of control over these resources. Since all resources have an opportunity cost determined by market forces, the allocation of own resources in production is made in terms of a user cost equal to market prices with the result that the allocation of resources (and the choice of techniques) is unaffected by resource ownership. The problems of resource allocation and resource ownership are, thus, fully separable. Stated another way, what the postulate implies is that economics (price determination on markets and the allocation and use of resources) can be separated from political economy (social classes which are, in large part, defined by unequal control over assets). This separation is particularly striking in, for instance, neoclassical models of peasant households such as those of Lau, Yotopoulos, Chou, and Leu (1981) and of Ahn, Singh, and Squire (1981). By postulating the existence of perfect labor markets for all family labor categories, perfect substitutability is implied between family and hired labor. The result is, as Lau and Jorgenson (1969) have shown, that optimal production decisions regarding the allocation of resources can be separated from consumption decisions. If we agree, by contrast, that the essential characteristic of peasants and their competitive edge against capitalist farms is their access to categories of family labor with no opportunity costs on the labor market, i.e., labor market failure, these models miss the essence of what are peasants.

The neoclassical paradigm of perfect markets and separability between problems of resource allocation and resource ownership was applied by Hayami and Ruttan to the inducement of technological innovations. The theory intends to explain the factor bias of technological change. The causal sequence begins with changes in relative factor scarcities that lead to changes in relative factor prices under the assumption that markets do work. Prices, in turn, guide technological advances toward saving on the factors that become relatively more expensive. Since agricultural research is largely a public good, it is the state that responds to market signals in allocating funds to alternative research programs. This occurs in response to producer demands for technologies that allow them to save on the factors that are becoming relatively more expensive and to increase profit levels. Changes in resource endowments thus determine through market forces the bias of technological innovations within the confines of the momentary innovation possibilities given by the state of science. In comparing the long-run history of technological change in Japanese and U. S. agriculture, for instance, Hayami and Ruttan found that, in labor-abundant but land-scarce Japan, technology has been mainly land saving, allowing to rapidly increase the productivity of land. In the United States, by contrast, where land was abundant and labor scarce, technology was mainly laborsaving and allowed rapid increases in the productivity of labor.

In judging the usefulness of the theory of induced innovations as an explanatory framework of the bias of technological change, the relevant question is: How much does the theory explain? The answers, based largely on empirical evidence from the PROTAAL studies in Latin America (Pineiro and Trigo), are that:

1. It explains more in the <u>long run</u> when relative factor scarcities have become more <u>fully reflected</u> in relative factor prices and when the allocation of public sector research budgets have started to respond to profit-maximization possibilities for producers within the potential of scientific research.

2. It explains more technological change in the <u>aggregate</u> for the whole agricultural sector than for specific <u>crops, farms</u>, and regions.

3. It explains more the <u>adoption</u> than the generation of innovations and <u>private</u> sector research than public since both of those are <u>more directly</u> guided by price signals and profitability considerations than public sector research.

4. It works better for advanced capitalist democracies where markets are more developed and the state relatively less interventionist than in most third world countries in which markets notably fail; where the state is generally actively involved in economic affairs; and where the distribution of wealth and political power (and, hence, influence on the state) is highly unequal and more so than it ever was in the modern history of advanced economies.

The theory thus does not adequately explain generation of technology in a context where markets tend to fail, where the state is highly interventionist, and where the short run matters to human survival. It thus fails to deal with the main components of the "agrarian question" in the third world--inadequate access to food for many, poor performance of agriculture in assisting economic development, and extensive rural poverty. This, of course, does not mean that prices do not matter: they do, particularly in determining whether the generation of technology will be profitable for the private sector and adoption profitable for particular groups of producers. But market prices do not necessarily reflect shadow values, net prices are generally not the same across social groups, and the state does not necessarily respond to relative prices in allocating resources to agricultural research.

"Getting the prices right" is, thus, necessary but not sufficient for an optimum rate and bias of technological change. While prices are important in creating production incentives, nonprice policy efforts to raise yield through public investments in technology and infrastructure are essential. The reason why prices are systemically found to be a weak determinant of long-run aggregate supply in agriculture is precisely due to the failure of public investment in agriculture in a situation where there exists a high degree of complementarity between public and private investment.[1] Public underinvestment, in addition, increases the variability of agricultural output and leads to substitution of private for public inputs which favors the wealthier farmers who can afford it and tends to bias technological change toward labor-saving mechanical innovations.

2.3. A Structuralist Theory of Induced Innovations

A non-neoclassical theory of induced innovations is based on two premises. One is that institutional forces have an important complementary role to play to that of market forces. This is clearly all the more important when markets openly fail either because they do not exist or because of state interventions, externalities and public goods, excess supply at prevailing prices with downward inflexibility (e.g., surplus labor), or the existence of market power through different institutional mechanisms (restricted competition, bribery, etc.). Institutional forces can thus act in the determination of relative prices (resulting in "price distortions" relative to their determination by unchecked market forces), of technological innovations, and of institutional change itself. In Figure 2.1, these are identified as the structuralist loops by contrast to the neoclassical loop where market forces determine relative prices and technological innovations.

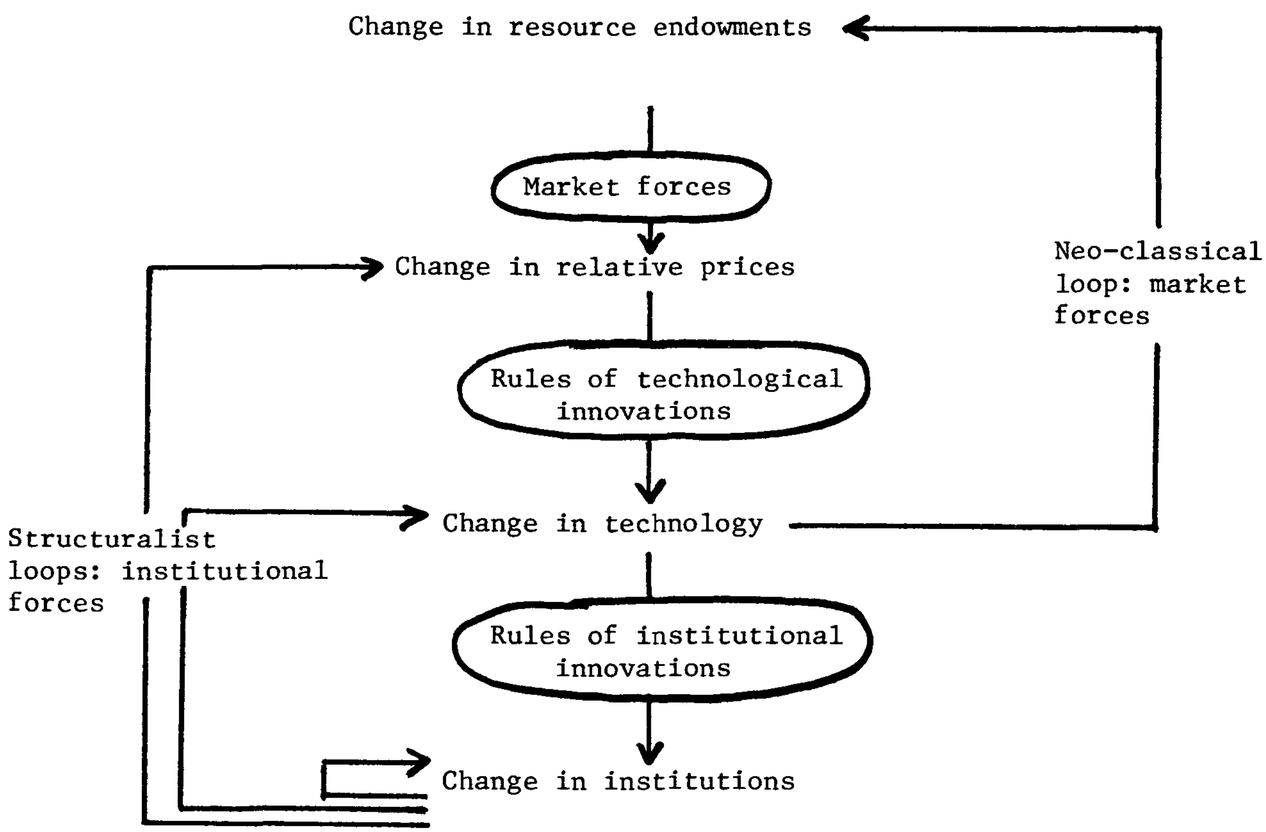


Figure 2.1 - Market and Institutional Forces in the Inducement of Innovations

The second premise of a structuralist theory of induced innovations is a different rule of survival for technological and institutional innovations. In the neoclassical paradigm, technologies and institutions survive only if they are allocatively efficient in a given economic environment and they change when they fail to satisfy the criterion of allocative efficiency and are replaced by new ones with a superior allocative efficiency. Neoclassical economists have thus explained the permanence of institutions such as traditional agriculture (Schultz) and sharecropping (Cheung) on the basis of their allocative efficiency in a given context. They have also explained public sector induced technological innovations in terms of the generation of that technological alternative within the confines of momentary scientific capabilities which optimizes resource allocation (Ahmad).

A structuralist approach to technological and institutional change introduces another rule of survival for innovations. It rejects allocative efficiency as a meaningful criterion of selection because markets are seen to fail in many different ways. The result is that there exists no global allocative efficiency and that what matters for the survival of innovations is "class efficiency" rather than allocative efficiency, namely, the effectiveness of technologies and institutions in allowing surplus appropriation by a specific social group. Particular technologies and institutions may thus be class efficient in allowing surplus appropriation by a specific social group (landlords or large farmers, for instance) while eventually creating a great deal of global allocative inefficiencies and a net social loss. This is how, for instance, Badhuri (1983) has explained technological stagnation in a context where interlocked land and credit markets allow landlords to extract surplus through perpetuation of debt peonage and usurious credit terms.

A structuralist theory of induced innovations thus locates the determinants of technological innovations in both changes in relative prices and in direct institutional forces where prices themselves are influenced by institutional forces that distort them away from the efficiency prices that could presumably have resulted from the free play of market forces. As a starting point, it is useful to catalogue the sources of distortions that a structuralist approach reveals relative to the neoclassical paradigm for the determination of the rate and bias of technological change.

We reemploy for this purpose a framework developed some years back to characterize the supply and demand of technological innovations (de Janvry, 1977). We use this framework to locate the various sources of distortions; that is, the social and political elements from which departure from equilibrium rate and bias originate (see Figure 2.2).

Four major sources of distortions can be distinguished: (1) the role of the socioeconomic structure which influences the formation of expected and actual payoffs; (2) the unequal distribution of information about technology which affects the latent (potential) demand for innovation; (3) the political structure and the patterns of state behavior which affect the way in which latent demand is transformed into actual demand; (4) the degree of "articulation" between institutions that are demanders and suppliers of technology.

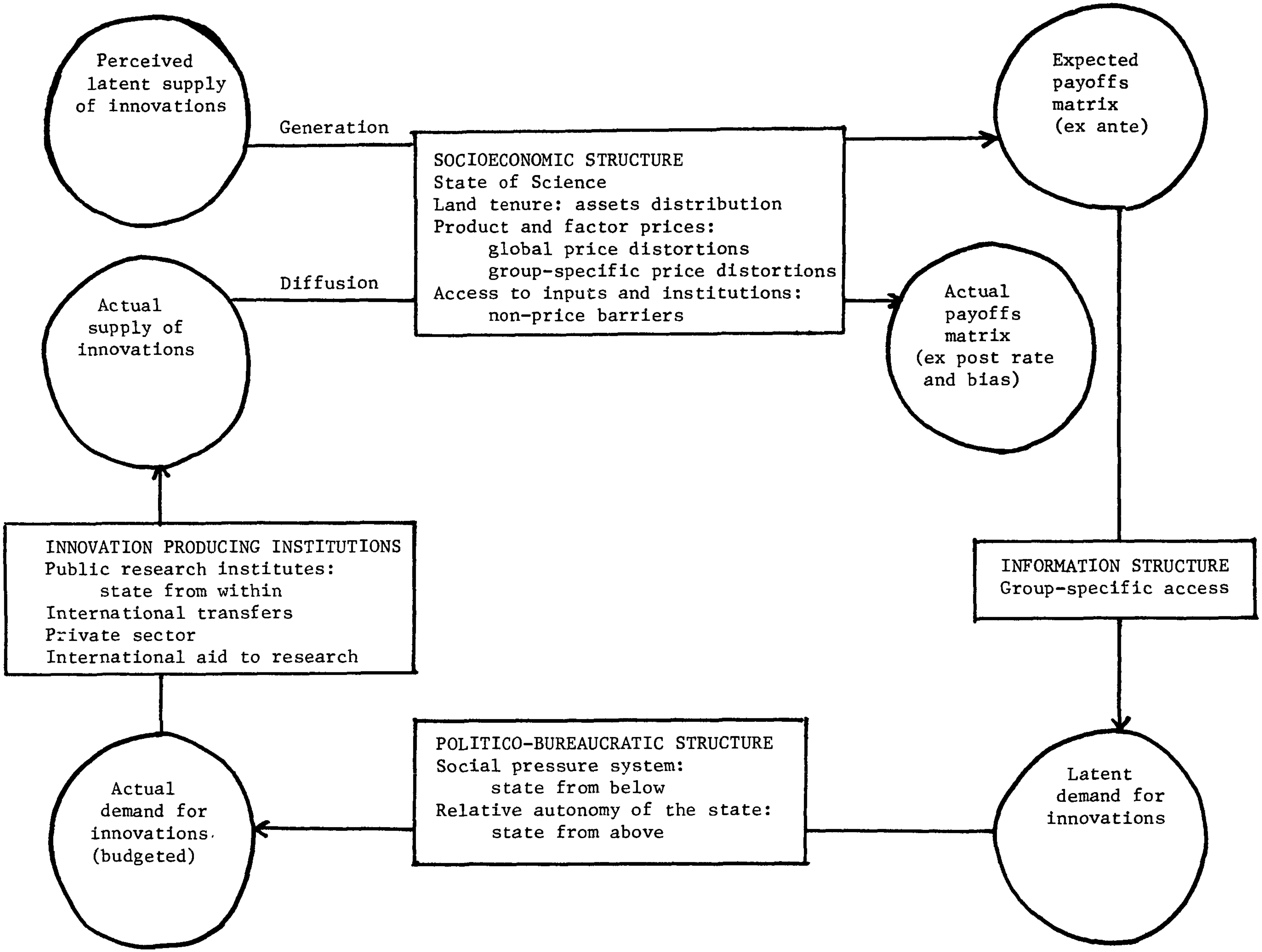


Figure 2.2 - Supply and Demand for Technological Innovations

A. Socioeconomic Structure

The first source of distortion is the characteristics of the socioeconomic structure which influence the formation of expected and actual payoffs. They include:

a. Market failures that lead to product and factor price distortions such as surplus labor (unemployment) which implies that wages are not determined by supply and demand on labor markets.

b. Government interventions in the price mechanism such as price fixing, subsidies, and overvaluation of the exchange rate.

c. Macroeconomic and monetary policies that affect real prices such as Dutch disease and inflationary spirals.

d. Social groups' specific product and factor price distortions. Different social groups face different prices for the same product or the same factor. This is due to their differential access to markets and to complex patterns of interlocking in product and factor markets. It is also due to differential access to institutional rents (subsidized public credit, subsidized water rights, etc.) which are distributed by nonmarket mechanisms. These unequal prices are, in part, determined by unequal asset distribution (dualism) and by unequal mobilization of political power.

e. Nonprice barriers. Different social groups face different barriers in either their direct use of technology or in deriving benefits from technological change. These barriers include access to inputs, access to markets, availability of nontraded factors, skill differentials, etc.

f. Land tenure patterns affect the payoffs from technology through economies of scale (indivisibilities in tubewell irrigation and machinery), the extensiveness of homogenous cropping patterns, etc.

B. Information Structure

A second source of distortions is in the formation of a latent (potential) demand for innovations. This originates in the fact that information about the potential payoffs from technology is imperfect. The state, in particular, may have a misconceived perception of the potential gains from technological change. This will be all the more the case if there is little communication (articulation) between those who budget research, those who generate new technologies, those who are the potential users of new technologies, and those who will ultimately benefit from technological change. Information about the potential benefits from technological innovations is also highly unequally distributed among potential beneficiaries (or losers) with, typically, peasants, landless workers, and consumers being the least-informed groups.

C. Political Structure

A third source of distortion is at the level of the politico-bureaucratic structure. According to neoclassical ideals, the state should react to market signals by transforming the latent demand for innovations into an actual (budgeted) demand for innovations. In practice, however, the state is a highly complex institution that is motivated by a whole spectrum of forces that only indirectly reflect market forces and many times not at all. We can, in particular, distinguish two contrasting patterns of state behavior.

a. The State Acting From Above

The state is an institution which benefits from a certain degree of autonomy relative to civil society. This autonomy is clearly constrained by both economic and political forces. Economically, the state needs to generate its resources from within civil society and, hence, is committed to reproducing the surplus generation capacity of civil society, part of which it can appropriate via taxes and loans. The state is largely excluded from direct surplus generation and, hence, dependent on surplus being generated in civil society. The result, in terms of state behavior, is that it is committed to surplus generation in civil society and, consequently, will be drawn into making policies that promote capital accumulation and surplus growth. Politically, the state needs to legitimize itself which implies maintaining a clientele in civil society, making the necessary concessions to organized groups, and opening channels of communication with them but at the same time actively controlling and possibly suppressing the emergence of antagonistic pressure groups.

This relative autonomy of the state can fundamentally be used for two contrasted projects. One is to act as an "ideal collective capitalist" in insuring both the conditions for capital accumulation in civil society and the reproduction of the existing social order. This reformist project is typical of the Keynesian state, for example, which uses fiscal and monetary policies to counter cyclical downturns in capital accumulation. It is also typical of a state which promotes particular technological advances in agriculture to overcome inflationary pressures, deficits in the balance of payments, or insecurity in food supplies. The type of state intervention and the choice of instruments will depend upon whether the state acts in anticipation of economic crises in what can be called a "planning mode" of action or if it acts in reaction to an ongoing crisis in what can be labeled a "crisis mode." The two modes of response are significantly different, for instance, in terms of using agricultural technological innovations as an element of crisis response. Since technological innovations require a fairly long-run maturation period, technology can hardly be used as a policy instrument if the state basically acts in a crisis-response mode. In this case, other more immediate policy instruments will be chosen such as price controls or trade policies.

The second project is for the state to use its relative autonomy to promote structural change on behalf of dominated classes in what has been called "revolutions from above" (Trimberger). Typical of these state projects is the role of the military and bureaucrats in promoting modernization in certain phases of the history of Japan, Turkey, Egypt, Peru, and Mexico. In this case, the political elites are the agents of change, and the result can be drastic structural changes in civil society. This is typical of intermediate regimes in periods of transition between economic systems where the old dominant classes are in economic or political disarray, and the state can emerge as a powerful force in structuring the emerging social order.

Thus "acting from above," the state can dramatically alter the transformation of a latent demand for technological innovations into an actual demand. Key here are (1) whether the state acts with reformist or structural change objectives, (2) whether it acts in a planning mode or a crisis response mode, and (3) how restrictive are the economic and legitimacy limits on state initiatives.

When the state acts with reformist or structural change objectives and when the economic and political limitations on state initiative do not restrict these objectives, the latent demand for generation of agricultural technology is likely to be translated into actual demand and generous budget allocations to agricultural research. By contrast to this planning mode, in crisis periods the state will face a "hard" budget constraint and its capacity to invest in the future will be reduced. Therefore, latent demand is less likely to be translated into actual demand. In terms of evaluation of public projects, a planning mode corresponds to a low value of the discount rate, and a crisis mode corresponds to a high value of the discount rate used to compute the present value of benefits from agricultural research.

b. The State Activated From Below

While the state can act with a certain degree of autonomy relative to civil society, it is also appropriated by interest groups which use it as both an object and an instrument of competition--an object in that organized groups compete to control the policymaking capacity of the state and an instrument in that differential appropriation of the benefits of policy (under the form of institutional rents) is an important element of the outcome of competition. The key issue here is that the state allocates resources and rents by nonmarket mechanisms and in response to the social pressure system, the electoral and bureaucratic reward systems, and the mechanisms of budget appropriations. Since, here, markets do not work, inequality in the distribution of assets and uneven distribution of economic and political power are keys in explaining state behavior. The course of agricultural technology can thus be powerfully influenced by organized lobbies, both on the side of producers and of consumers and employers. The key in understanding how state activation from below affects the rate and bias of technological change are (1) the degree of organization and the relative strength of different social groups; (2) the extent of cohesiveness or balkanization of the state itself, the latter allowing greater possibilities for particular interest groups to capture the state from below; and (3) the degree of relative autonomy of the state (and, hence, the stringency of economic and legitimacy constraints on the state) which makes it more or less immune to interest group demands.

D. Institutions Producing Innovations

Finally, a fourth source of distortion in the determination of the rate and bias of technological change is the way the innovation-producing institutions transform the actual demand for innovations into an actual supply. The main issue here is that of the degree of "articulation" between demand and supply (Pineiro and Trigo) in the choice of research priorities within research institutions.[2] While the total level of research activity in these institutions is largely determined by budget appropriations (actual demand), they generally enjoy a considerable degree of autonomy in deciding the budget use among research alternatives. Research institutions, like other agencies of the state, are also internally divided along lines which do not necessarily correspond to divisions in civil society, resulting in a third pattern of state behavior (beyond the state acting from above and the state activated from below) which can be called the state activated "from within." The response of research scientists and administrators represents a critical link in the inducement mechanism. Within the state and parastatal institutions carrying out research, the key issues are those of decentralization of decision making and of participation by interested parties in the definition of research priorities. Decentralization and participation are particularly important if research is going to address the problems of small farmers who generally operate under highly complex and heterogenous circumstances with minimal institutionalized representation. This problem has led to proposals by rural development advocates for participative research, farming systems approaches, and "farmer first and last" models (Chambers).

Also relevant as part of this fourth source of distortions in rate and bias are the role of international transfers of technology, the complementarity between public and private research, and the flow of international aid to agricultural research institutions. International transfers occur unevenly across crops, regions, and farms and transpose technologies with eventually optimum biases for the context where they have been developed but not for that where transferred. This is where the whole question of the role of international agribusiness as a vector of technology transfer to the third world comes about. These institutions are simultaneously a dynamic source of technological change and a source of exogenously determined distortions which have often had highly socially disruptive consequences.

Complementarity between public and private research is important because certain research areas cannot easily be carried out by private research. This is the case for fundamental research as well as research with long-term payoffs, substantial external effects, and results difficult to patent. Because of complementarity in research, underinvestment and instability in public research funding can lead to bottlenecks on investment in private research efforts.

Finally, international aid has been a major source of funding and support of national research initiatives. The level of international aid, its continuity over time, and its priorities are thus also important in determining the rate and bias of the actual supply of innovations.

SECTION 3

SIZE OF THE RESEARCH EFFORT: THE FACTS

3.1. Historical Overview

Prior to 1950, the developing countries had significant research programs aimed at the improvement of colonial trade crops such as sugar, tea, coffee, cocoa, and cotton along with a few small programs on rice and wheat. No significant research on root crops, oilseeds, pulses, sorghum, millets, and feed grains was undertaken.

In the 1950s and early 1960s, which was a period of decolonization and independence for many countries of Asia and Africa, high priority was given to industrial growth and to import-substitution policies while the agricultural sector was relatively neglected. Research on food crops was not given priority (Evenson, 1984, p. 357). Of the total investment in agricultural research in 1958, about 90 percent was in developed countries and only 10 percent in developing countries. The proportion of research on food crops necessary for the provision of cheap food to the increasingly urbanized population was only a fraction of that percentage.

During the 1950s and 1960s, a number of research institutions were built in the developing world on the model of the U. S. federal-state system, usually with international support. International aid financed the training of agricultural scientists and institutional buildup, but many national governments failed to fund and develop research facilities and other support.[3]

In response to that situation and following the successes of IRRI and CIMMYT, the international agricultural research system was developed during the 1960s, culminating with the creation of the CGIAR in 1971. These centers directed their attention to a limited number of crops and, given their international mandate, placed emphasis on wide adaptability of the genetic material. At the same time, national research centers were being transformed and developed. They were given an autonomous role and were distinct from their predecessors which usually were dependent on the Ministries of Agriculture (Pineiro and Trigo, 1983, pp. 126 and 127).

The initial success of international agricultural research was great, especially if one considers that in 1971 the IARCs accounted for only 0.1 percent of total expenditures for agricultural research. Dalrymple (1977, pp. 171-208) estimates that the technology derived from the work of the institutes added $1 billion (U. S.) in wheat and rice production in Asia alone during 1972-73.

As the new varieties spread into less-favored lands and as socioeconomic constraints to further advances in productivity began to appear, progress slowed. Evenson (1977, p. 261) suggests that the rate of return to investment might be declining as research moves into "second generation" technology in wheat and rice.

Moreover, progress has not been uniform. The return on investment in corn research at the IARCs has been realized more slowly than for wheat and rice, although private research on corn has been relatively profitable (Arndt and Ruttan, 1977, p. 14). There is a great variability in return to research on specific commodities as the work of Hertford and associates in Colombia has shown (Hertford et al., 1977, pp. 117-120). Rates of return for research on soybeans and rice were found to exceed 50 percent. Research on cotton, by contrast, yielded returns that were estimated to be negligible. This latter fact is surprising because cotton yield increases since the early 1950s have been spectacular. Hertford's explanation of this puzzle is that the main research activity, involving local testing of varieties imported from the United States, appears to have been unnecessary because there were only minimal yield differences in those imported varieties and they could just as well have been selected at random. The cotton research program of Colombia provides a good example of a state involved in agricultural research activated "from below" by powerful interest groups. Because of a change in exchange rate, the textile industry in Colombia--until then, accustomed to importing U. S. cotton--found itself compelled to buy Colombian cotton. Textile manufacturers then sponsored the research program which, for the most part, involved the importation, local testing, and distribution to farmers of high-yielding varieties.

Boyce and Evenson (1975, pp. 50 and 51) suggest that 40 percent to 50 percent of the total investment in agricultural research in low-income countries derived from international aid funds during the 1960s. By 1971, aid was at a low and probably accounted for less than 20 percent of the national system investment. New forms of funding--more complex than during the 1960s and involving a combination of public funds, international grants and loans, and participation of the private sector--were devised (Trigo and Pineiro, 1984). During the 1970s and early 1980s, it seems that foreign aid--although hard to quantify exactly--accounted for a larger share, doubling in Latin America between 1975 and 1980 (Oram, n.d., p. 7). It is possible that the crisis in most Latin American countries around 1981 and the international recession have affected this trend.

The inception in 1971 of the Consultative Group on International Agricultural Research (CGIAR) has introduced a new dimension in agricultural research for the third world. Originally established to help widen the basis of funding for the four existing IARCs, it was then used to create new centers to meet special needs, support national research efforts, and coordinate effort on an international basis. The CGIAR now has about 40 donors, mainly developed countries, multilateral organizations, the Ford Foundation and the Rockefeller Foundation, but also developing countries which finance the 13 institutions that make up the CG network.

The broad objectives of the system were defined by the Technical Advisory Committee (TAC) as follows: (1) increasing the amount, quality, and stability of food supplies in LDCs and meeting total food needs; (2) meeting the nutritional requirements of the less advantaged groups in the LDCs (Technical Advisory Committee Secretariat, 1979).

In the early 1970s, the CGIAR system had expanded considerably with a growth rate in financial support of nearly 20 percent per year. In the late 1970s and 1980s, there was a sharp levelling off of expenditures and the system has hardly expanded during the 1980s with a growth rate of only 1 percent per year in real terms since 1980. The 1980 level of funding was equivalent to 18.5 percent of donor funding of all agricultural research in the third world (Oram, p. 9).

More than 50 percent of the resources of the system go into plant breeding and related activities. The other major research area is the development of better systems of land and water management such as water conservation methods for the semiarid tropics, soil conservation projects, and farming systems.

In the aftermath of the Green Revolution, a global agricultural research system is emerging (Ruttan, 1984). Strong linkages between the various components of the system have been established, particularly between the international network of IARCs and the national research systems. Private research and private funding of public projects is increasing.[4] The private sector is becoming increasingly involved in agricultural research in Latin America, more so according to Oram (p. 14) than in any other developing region.

Agricultural research, by its very nature, is a long-term enterprise that requires not only adequate levels of investment but also a sustained investment program and qualified personnel over a period of years. Although there has been an increase in research expenditures measured in constant dollars over the past 20 years or so as well as an increase in the quality and quantity of the staff of research institutions, there is evidence of large year-to-year variations in the level of funding of research. The available data also reveal that resources are highly unevenly allocated among crops and regions, with certain crops receiving a disproportionate amount of funds, and countries--and regions within a country--being relatively more favored than others.

The generation and diffusion to farmers of a flow of the new technology are considered by all specialized agencies to be an essential component of the package of measures required for the elimination of the food gap projected until the end of the century (Food and Agriculture Organization, 1981, p. 77; World Bank, 1983, pp. 67-77; and Oram, Zapata, and Ray, 1979, p. 128). Most of the increase in agricultural productivity will come through larger and more efficient investments in applied research and extension services in developing countries. The possibility that it will come from some dramatic advance in basic research such as the one that gave rise to the Green Revolution cannot be excluded but is unlikely in the next two decades.

Global research expenditures for 1984 are of the order of $10 billion (U. S.) and involve about 200,000 scientists. About half that amount and twice that personnel are invested in extension. The CGIAR system represents only 2 percent of all agricultural research (and 15 percent of research expenditures in less-developed countries (LDCs). To fix ideas about the magnitude of foreign assistance, the World Bank over the past decade has loaned $1.5 billion (U. S.) for research support and $2 billion (U. S.) for extension.

The cost of research per scientist per year is $100,000 in industrialized countries and $60,000 in LDC which explains part of the difference (for extension services, the difference is even more striking--$33,000 and $3,000).

3.2. Level of Expenditures in 1980

The principal sources of data on research expenditures--the 1981 IFPRI/ISNAR study of Oram and Bindlish (OB), the 1983 data of Judd, Boyce, and Evenson (JBE) completing up to 1980 the Boyce-Evenson data (Boyce and Evenson, 1975), and the Trigo-Pineiro (1984) information for 1980 in Latin American countries--arrive at very different estimates. The JBE estimates, the result of a survey based on questionnaires, are based on a broad definition of research expenditures. They include public research and private industrial sector research and "agriculturally related" scientific research. One would therefore expect the OB estimates (which do not include private research and define narrowly agricultural research activities) to be lower.

In fact, as should be clear from Table 3.1, this is far from being the case. What is puzzling is that, in many important cases such as Argentina, Brazil, Mexico, Indonesia, the Philippines, etc., the OB figures are considerably larger than the JBE data. With the development of an international network of research and the existence of such organizations as CGIAR, one would have expected more accuracy in the data (for which times series covering at least two decades exist) as the data collection improves. The important discrepancies reflect the difficulties in measurement due to the fact that agricultural research activities are not easy to define with precision. The international component--bilateral and multilateral aid--of the funding cannot be evaluated with accuracy because (1) the disbursements are often made for a period of several years and (2) many development projects have "research components" which are hard to separate from the other components of the projects. Private research (which the OB data presumably omits) is also hard to quantify because of the variety of funding mechanisms ranging from contributions to specific public projects to independent institutes set up by producers' associations.

3.3. Growth Trend in Research Expenditures

Real spending on research increased nearly fourfold (3.68) between 1959 and 1980 but only by a factor of 1.4 between 1970 and 1980 according to the JBE data. These data apply to national (public) research systems (Judd, Boyce, and Evenson, 1983, p. 6) and do not include the IARCs expenditures.

According to the data of Oram, the overall annual rate of growth for the past decade was 12.9 percent (Table 3.2). Examining the data by region, it is clear that most of the research effort is still concentrated in developed countries. But important changes have taken place since 1959. Asia, Latin America, and Europe are increasing in importance. The share of Asia almost doubled between 1959 and 1980, mainly because of the expenditures of Japan and China--the latter having increased its research effort almost tenfold in the past 20 years. Europe's share increased slightly and Latin America's share doubled.

TABLE 3.1

Comparison of Estimates of Expenditures on Agricultural Research in Developing Countries, 1980

Country	JBE data	OB data	PT data
	1	2	3
	thousands of dollars (U. S.)		
Latin America			
Argentina	59,750	166,340	152,410
Chile	11,319	10,353	12,866
Paraguay	5,357	3,100	6,547
Uruguay	3,821	4,174	847
Bolivia	11,374	2,808	3,292
Brazil	174,012	245,000	142,317
Colombia	32,231	38,572	2,610
Ecuador	6,100	6,436	6,857
Guyana	2,678	2,428	419
Peru	8,163	8,912	4,355
Venezuela	34,885	39,172	39,171
Barbados	652	767	901
Costa Rica	2,168	2,082	2,083
El Salvador	2,391	4,974	2,875
Guatemala	5,332	4,700	5,785
Haiti	452	a	290
Honduras	1,047	978	979
Jamaica	935	772	770
Mexico	70,929	172,402	66,155
Nicaragua	2,211	1,999	1,815
Panama	2,482	3,200	2,255
Trinidad/Tobago	709		771
Dominican Republic	2,514	2,515	2,336
Middle East			
Morocco	8,026	19,981	
Sudan	13,600	14,634	
Egypt	23,717	23,717	
Tunisia	6,764	6,764	
Libya	2,793	2,793	
Cyprus	2,410	2,411	
Iran	45,163		
Israel	30,209		
Jordan	849	850	
Turkey	26,463	34,426	
Syria	4,963	5,293	

(Continued on next page.)

TABLE 3.1--Continued.

Country	JBE data	OB data	PT data
	1	2	3
	thousands of dollars (U. S.)		
Africa			
Cameroon	3,788	3,788	
Chad	1,602	1,602	
Benin	2,403	2,403	
Gambia	66		
Gabon	334		
Ghana	12,655	10,095	
Ivory Coast	12,771	24,370	
Liberia	394	394	
Mali	6,141	7,354	
Mauritania	284	284	
Nigeria	121,840	134,964	
Senegal	9,726	9,797	
Sierra Leone	698	698	
Upper Volta	1,105	1,105	
Zaire	5,095	5,098	
Burundi	3,608	3,610	
Ethiopia	3,400	3,400	
Kenya	22,712	24,052	
Madagascar	4,878	4,801	
Malawi	5,660	4,562	
Mauritius	7,879		
Rwanda	945	945	
Tanzania	7,214	7,219	
Uganda	7,452	7,452	
Zambia	5,202	5,205	
Botswana	4,977		
Lesotho	465	465	
Zimbabwe	10,560	10,560	
South Africa	64,519		
Swaziland	1,306		
Asia			
Bangladesh	27,613	26,616	
Sri Lanka	5,057	4,342	
Nepal	2,634	2,797	
India	120,167	154,781	
Pakistan	29,899	25,277	
Indonesia	33,200	44,485	
Malaysia	30,391	46,334	
Philippines	9,533	16,254	
Thailand	21,600	23,276	
China	643,555		

[a]Blanks indicate data not available.

Sources: Col. 1--Judd, Boyce, and Evenson, 1983; Col. 2--Oram and Bindlish, 1981; Col. 3--Pineiro and Trigo, ISNAR, 1984.

TABLE 3.2

Growth Rates of Agricultural Expenditures and Scientific Staff in Market Economies, 1970-80 (percent compound per annum).

	Ag. Research Expenditures			Ag. Research Scientists		
	1970-75	1975-80	1970-80	1970-75	1975-80	1970-80
Asia (except Middle East and China) (12)	5.4	6.3	5.9	5.2	9.3	7.2
Middle East and North Africa (9)	7.6	2.1	4.9	1.1	8.7	4.8
Sub-Saharan Africa (except South Africa) (25)	11.8	8.9	10.4	9.7	10.8	10.2
Latin America (21)	12.9	13.0	12.9	4.5	7.5	6.0
Total developing countries (67)	9.6	9.4	9.5	4.7	8.9	6.8
CGIAR Institutes	19.9	12.9	16.4	NA	NA	NA
Western Europe (17)	3.6	5.8	4.7	3.5	4.8	4.2
Canada, Australia, N.Zealand, Japan (4)	6.0	1.8	3.9	4.0	1.2	2.5
United States	1.6	2.4	2.0	0.0	1.0	0.5

Notes:
Figures in parenthesis in the first column indicate the number of countries included (The 67 developing countries are listed in table 3.3).
Source:
The table is taken from P. Oram, ISNAR, n.d.
References:
1) Developing countries: Oram, P. & Bindlish, V., IFPRI/ISNAR, 1981, and more recent information collected by P. Oram
2) CGIAR: Second Review of the CGIAR, November 1981.
3) Western Europe: unpublished data from R. Evenson (data are for 1968-74 and 1974-80).
4) United States: Assessment of the U.S. Food and Agricultural Research System, Congress of the United States, Office of Technology Assessment, 1981.

Expenditure Shares, 1959 and 1980
(percent of total)

Continent/Country	1959	1980
Europe	13.3	20.2
USSR and Eastern Europe	27.5	20.2
North America and Oceania	36.9	23.3
Latin America	3.9	6.3
Africa	5.8	5.7
Asia	12.7	24.3
(China)	(2.6)	(8.7)

Source: Judd, Boyce, and Evenson (1983).

This changing pattern and the different rates of growth by region reflect, of course, different initial conditions, the unequal financial effort of national systems, and the fact that the research that was previously carried out in developed countries now tends to be localized in the countries where most productivity gains and increase in arable land can take place.

When research and extension expenditures are presented as a percentage of the agricultural product, one observes that the relationship between more and less-developed countries has not changed much.

The more affluent countries tend to spend more on research and comparatively less on extension services than low-income countries. Within the developing countries group, however, clear differences appear. The effort of middle-income countries and semi-industrialized economies[5] has increased sharply since 1959 while low-income countries have increased research and extension expenditures at a slower pace, measured in percentage of agricultural GDP. This could be attributed to a lesser research effort or to a lower economic performance.

Research Expenditures
(as percent of value of agricultural product)

	1959	1970	1980
Low-income countries	0.15	0.27	0.50
Middle-income countries	0.29	0.57	0.81
Semi-industrialized economies	0.29	0.54	0.73
Industrialized economies	0.68	1.37	1.50
Planned economies (including China)	0.33	0.73	0.66
Planned economies (except China)	0.45	0.75	0.73

Extension Expenditures
(as percent of value of agricultural product)

	1959	1970	1980
Low-income countries	0.30	0.43	0.44
Middle-income countries	0.60	1.01	0.92
Semi-industrialized economies	0.29	0.51	0.59
Industrialized economies	0.38	0.57	0.62
Planned economies (including China)	a		
Planned economies (except China)	0.29	0.33	0.36

[a]Blanks indicate data not available.
Source: Judd, Boyce, and Evenson (1983).

As Table 3.3 for 67 developing countries (from Oram, ISNAR) shows, no clear pattern is recognizable. Two explanatory factors have been cited: size of the country and GNP per capita (Oram n.d., and Ruttan, 1984). The relationship between research expenditures and other economic variables is, in general, not significant. Oram (1978, 1979) estimated that developing countries spent approximately 0.3 percent of their agricultural product in 1975, a decade ago. This is considerably below the estimates of Boyce and Evenson for 1974 which are in most cases double or triple. One reason for the disparity is that Oram uses the agricultural GDP evaluated at current 1975 prices while Boyce and Evenson value agricultural GDP at 1971 prices. Due to the sharp increase in agricultural prices between 1971 and 1974, the difference can be sizable (Pinstrup-Andersen, 1982, p. 75).

TABLE 3.3

Agricultural Research in 67 Developing Countries, 1980.
(ranked by percentage of their agricultural GDP)

Country	GNP per capita (US $)	Ag. Res. Expend. (000 US$)	Ag. Res. as % of ag.GDP	Growth rate of ag. GDP (% per year) 1970-80	Number of Scientists in 1980	Costs per Scientist (US $)
EXPENDITURES OVER 1 PERCENT OF AG. GDP						
Panama	1730	3200	5.33	1.9	64	50,000
Zimbabwe	630	10560	2.42	-0.5	201	52,537
Guyana	570	2428	1.85	1.0	35	69,371
Argentina	2390	166340	1.64	2.6	1064	156,335
Mexico	2090	172402	1.36	2.3	1950	88,411
Barbados	1620	767	1.35	0.0	23	33,348
Venezuela	3630	39172	1.32	3.8	360	108,811
Mali	190	7354	1.24	4.4	68	108,147
Senegal	450	9797	1.21	3.7	105	93,304
Kenya	420	24052	1.19	5.4	400	60,130
Brazil	2050	245000	1.15	4.9	2957	82,854
Cyprus	1520	2411	1.12	1.1	55	43,836
Total/Mean		683483			7282	93,860
EXPENDITURES BETWEEN 0.5 AND 1 PERCENT OF AG. GDP						
Fiji	1150	2349	0.88	NA	22	106,773
Malaysia	1620	46334	0.82	5.1	822	56,367
Chile	2150	10353	0.81	2.3	281	36,843
Burundi	200	3610	0.81	1.8	41	88,049
Zambia	560	5205	0.30	1.8	109	47,752
Ivory Coast	1150	24370	0.78	3.4	212	176,594
Togo	410	1892	0.76	0.8	49	38,612
Malawi	230	4562	0.75	4.1	276	16,529
Nigeria	1010	134964	0.74	0.8	1084	124,505
Colombia	1180	38572	0.64	4.9	333	115,832
Morocco	900	19981	0.62	0.8	686	29,127
Lesotho	420	465	0.60	2.9	14	33,214
Papua N.G.	780	5052	0.59	NA	110	45,927
Benin	310	2403	0.59	NA	19	126,474
Uruguay	2810	4174	0.59	0.2	222	18,802
Sudan	410	14636	0.57	2.6	164	89,244
Chad	120	1602	0.56	-0.3	42	38,143
Tunisia	1310	6764	0.55	4.9	285	23,733
El Salvador	660	4974	0.50	2.8	116	42,879
Total/Mean		332262			4887	67,990
EXPENDITURES BETWEEN 0.25 AND 0.49 PERCENT OF AG. GDP						
Bangladesh	130	26616	0.48	2.2	1642	16,210
Egypt	580	23717	0.45	2.7	2724	8,707
Jordan	1420	850	0.44	NA	35	24,286
Libya	8640	2794	0.44	11.1	123	22,707
Pakistan	300	25277	0.41	2.3	2834	8,919
Sri Lanka	270	4342	0.41	2.8	422	10,289
Guatemala	1080	4700	0.39	4.6	158	29,747
Madagascar	350	4801	0.39	0.1	68	71,779
Tanzania	280	7219	0.35	4.9	256	28,199
Ecuador	1270	6436	0.35	2.4	276	23,319
Bolivia	570	2808	0.34	3.1	114	24,632
India	240	154781	0.33	1.9	7103	21,791
Peru	930	8912	0.33	NA	269	33,310
Turkey	1470	34426	0.28	3.4	937	36,741
Burkina F.	274	1105	0.28	1.2	123	20,463
Paraguay	1300	3100	0.28	6.9	63	40,206
Nicaragua	740	1999	0.27	3.1	63	31,730
Thailand	670	23276	0.26	4.7	1525	15,263
Indonesia	430	44485	0.26	3.8	1473	30,200
Total/Mean		381743			20208	18,890
EXPENDITURES UNDER 0.25 PERCENT OF AG. GDP						
Costa Rica	1730	2082	0.24	2.5	75	27,760
Syria	1340	5293	0.24	8.2	172	30,778
Korea Rep.	1520	29031	0.23	3.2	960	30,241
Jamaica	1040	772	0.23	0.7	40	19,300
Mauritania	440	284	0.22	1.1	8	35,500
Sierra Leone	280	698	0.21	2.2	35	19,943
Nepal	140	2797	0.20	0.5	226	12,376
Cameroon	670	3788	0.20	3.8	106	35,736
Domin. Rep.	1160	2515	0.20	3.1	99	25,404
Philippines	690	16254	0.20	4.9	1050	15,490
Zaire	220	5098	0.20	1.2	97	52,557
Rwanda	200	945	0.18	NA	24	39,375
Ethiopia	140	3400	0.18	0.7	155	21,935
Ghana	420	10095	0.17	-1.2	352	28,679
Honduras	560	978	0.16	1.5	60	16,300
Liberia	530	394	0.11	4.7	20	19,700
Uganda	300	7452	0.08	-0.9	175	42,583
Total/Mean		91876			3654	25,144

Source: P. Oram, ISNAR, n.d.

Notes: 1. GNP per capita and ag. GDP derived from World Bank data (World Development Report, 1982) and national data.
2. Ag. research expenditures and scientists: see references for table 3.2.
3. Costs per scientists include all research costs, not only salaries.

SECTION 4

COSTS AND BENEFITS OF AGRICULTURAL RESEARCH PROJECTS

From an economic perspective, the rate of technical change in agriculture depends on the level of investment in research. The internal rate of return (IRR) of a research project is the discount rate that equalizes benefits and costs of the project over its duration. The rule for optimal investment is that, as long as the IRR is greater than the opportunity cost of capital (OCC), it is profitable to increase the stock of knowledge by investing in research.

Some authors, notably Ruttan, have argued on the basis of numerous studies estimating the rate of return to investment in agricultural research that there is underinvestment in agricultural research. The argument runs as follows. All studies measuring the productivity of research starting with the path-breaking study of Griliches (1958) on hybrid corn come up with average rates of return to investment ranging between 30 percent and 60 percent per year (Table 4.1). The estimates vary greatly depending on the type of project, commodity, region, and methodology used for the evaluation. But the fact that average returns consistently exceed the OCC by a wide margin indicates that, as long as we are at a point on the marginal efficiency curve where the IRR exceeds the OCC, it is profitable to invest more in research. However one defines the opportunity cost--whether it is the rate of return to other types of agricultural investment; to conventional development projects such as road building, education, etc. (for which a 15 percent IRR is considered to be good); or simply the rate of interest in developing countries-there seems to be evidence that not enough resources are invested in research.[6]

The opponents of the underinvestment thesis have concentrated their criticisms on the methodology used to measure the IRR. Some authors, for instance, have pointed out that gross benefits were compared only to direct costs in most studies and that, if other costs of implementation were accounted for, estimated returns would be more comparable to those of infrastructure projects. As a counterargument, others have stated that there usually is underreporting of the benefits of the project as important indirect benefits, such as spillover effects beyond the country, are usually not taken into account.

The estimation procedure of the rate of return to research[7] involves three steps (Scobie, 1979): (1) measure the shift in the supply curve to estimate the output-increasing effect of technological change, and (given the shift) compute the gross annual research benefit (GARB); (2) compute the costs of the project; and (3) estimate the social profitability of the investment by a discounted cash flow analysis of the costs and benefits over time (typically, the internal rate of return is used as a measure of social return).

To measure the impact of the research-induced technical change on output, two methods are used: either an "index number approach" or a production function approach. The nature of the innovation involved determines in

TABLE 4.1

Summary Studies of Agricultural Research Productivity

Study	Country	Commodity	Time Period	Annual Internal Rate of Return (%)
Index Number:				
Griliches, 1958	USA	Hybrid corn	1940-1955	35-40
Griliches, 1958	USA	Hybrid sorghum	1940-1957	20
Peterson, 1967	USA	Poultry	1915-1960	21-25
Evenson, 1969	South Africa	Surgarcane	1945-1962	40
Barletta, 1970	Mexico	Wheat	1943-1963	90
Barletta, 1970	Mexico	Maize	1943-1963	35
Ayer, 1970	Brazil	Cotton	1924-1967	77+
Schmitz and Seckler, 1970	USA	Tomato harvester, with no compensation to displaced workers	1958-1969	37-46
		Tomato harvester, with compensation of displaced workers for 50% of earnings loss		16-28
Ayer and Schuh, 1972	Brazil	Cotton	1924-1967	77-110
Hines, 1972	Peru	Maize	1954-1967	35-40[a] 50-55[b]
Hayami and Akino, 1977	Japan	Rice	1915-1950	25-27
Hayami and Akino, 1977	Japan	Rice	1930-1961	73-75
Hertford, Ardila, Rocha, and Trujillo, 1977	Colombia	Rice	1957-1972	60-82
		Soybeans	1960-1971	79-96
		Wheat	1953-1973	11-12
		Cotton	1953-1972	none
Pee, 1977	Malaysia	Rubber	1932-1973	24
Peterson and Fitzharris, 1977	USA	Aggregate	1937-1942	50
			1947-1952	51
			1957-1962	49
			1957-1972	34
Wennergren and Whitaker, 1977	Bolivia	Sheep	1966-1975	44
		Wheat	1966-1975	−48
Pray, 1978	Punjab (British India)	Agricultural research and extension	1906-1956	34-44
	Punjab (Pakistan)	Agricultural research and extension	1948-1963	23-37
Scobie and Posada, 1978	Bolivia	Rice	1957-1964	79-96
Pray, 1980	Bangladesh	Wheat and rice	1961-1977	30-35
Regression Analysis:				
Tang, 1963	Japan	Aggregate	1880-1938	35
Griliches, 1964	USA	Aggregate	1949-1959	35-40
Latimer, 1964	USA	Aggregate	1949-1959	not significant

Source: Ruttan, pp. 242 and 243.

TABLE 4.1. *–Continued*

Study	Country	Commodity	Time Period	Annual Internal Rate of Return (%)
Peterson, 1967	USA	Poultry	1915-1960	21
Evenson, 1968	USA	Aggregate	1949-1959	47
Evenson, 1969	South Africa	Sugarcane	1945-1958	40
Barletta, 1970	Mexico	Crops	1943-1963	45-93
Duncan, 1972	Australia	Pasture Improvement	1948-1969	58-68
Evenson and Jha, 1973	India	Aggregate	1953-1971	40
Cline, 1975 (revised by Knutson and Tweeten, 1979)	USA	Aggregate	1939-1948	41-50[c]
		Research and extension	1949-1958	39-47[c]
			1959-1968	32-39[c]
			1969-1972	28-35[c]
Bredahl and Peterson, 1976	USA	Cash grains	1969	36[d]
		Poultry	1969	37[d]
		Dairy	1969	43[d]
		Livestock	1969	47[d]
Kahlon, Bal, Saxena, and Jha, 1977	India	Aggregate	1960-1961	63
Evenson and Flores, 1978	Asia– national	Rice	1950-1965	32-39
			1966-1975	73-78
	Asia– International	Rice	1966-1975	74-102
Flores, Evenson, and Hayami, 1978	Tropics	Rice	1966-1975	46-71
	Philippines	Rice	1966-1975	75
Nagy and Furtan, 1978	Canada	Rapeseed	1960-1975	95-110
Davis, 1979	USA	Aggregate	1949-1959	66-100
			1964-1974	37
Evenson, 1979	USA	Aggregate	1868-1926	65
	USA	Technology oriented	1927-1950	95
	USA	Science oriented	1927-1950	110
	USA	Science oriented	1948-1971	45
	Southern USA	Technology oriented	1948-1971	130
	Northern USA	Technology oriented	1948-1971	93
	Western USA	Technology oriented	1948-1971	95
	USA	Farm management research and agricultural extension	1948-1971	110

general the appropriate method. The first approach, which produces an estimate of average benefit from the whole project, is used when the source of technical change can be easily identified; it estimates the amount of resources saved by adopting modern varieties. This requires an assumption about yields that would have prevailed if the technology had not been adopted (usually using time series of yields of traditional varieties and simulating their time paths) and, as Scobie points out, depends heavily on the quality of the national data. The second approach, producing an estimate of marginal returns to increased investment, measures by econometric methods the contribution of inputs and of technical change to increased output. The classical problems of errors in measurement and specification bias can lead to biased estimates of the technological contribution, but there is "no clear presumption concerning the direction of the bias" (Scobie, 1979, p. 3).

Hertford and Schmitz point out that, regardless of the methodology employed, accurate estimation of the change in production attributable to research is the most critical step in any effort to measure productivity of research. The standard approach measures the social surplus resulting from a shift in the supply curve due to the technical change. Jarrett and Lindner note that accurate surplus measures depend on the shape and level of supply and demand functions and that parameters valued at equilibrium are not necessarily representative.

Bonig (1974) and Hertford and Schmitz (1977) note the necessity to use compensated demand curves to reduce the bias of surplus measures because uncompensated demand elasticities will tend to overestimate the benefits to consumers. Following the evaluation of research on cotton in Brazil by Ayer and Schuh (1972, 1974) there seems to be agreement that a unitary elasticity of demand curve is the relevant reference point to measure GARB (see Scobie, p. 5).

The level and shape of the supply curve constitute another area of disagreement. Griliches (1958) and Schmitz and Seckler (1970) in their work on the California tomato harvester assume perfectly elastic supply curves. Ayer and Schuh (1972), by using experimental cotton yield gains rather than actual gains observed among farmers, actually overestimate the shift in supply resulting from innovations. Two types of shifts have been mostly considered in the literature: a "pivotal" shift and a "parallel" shift. Lindner and Jarrett (1978) and Rose (1980, p. 834) have analyzed the effect on the type of curve chosen and of the intercept estimate on the measurement of GARB. They show that the estimates of GARB can vary sixfold depending on the nature of the shift.

As Scobie (1979) notes, econometric estimation is generally rendered difficult by the absence of observations for the estimation of the intercept. (Do farmers produce positive amounts if the price is zero?) As far as the shape of the curve is concerned, one possible assumption would be to postulate different curves depending on the type of technical change and how it affects different groups of producers, for example, producers of upland vs. irrigated rice (e.g., Scobie and Posada, 1978).

Several important methodological problems concerning the measurement of benefits have been noted, particularly by Lindner and Jarrett (1978), Scobie

(1979), and Rose (1980). In estimating GARB, typically the social loss were the new technology to be removed is calculated. But, as Scobie (p. 8) points out, other scenarios that might have prevailed in its absence are ignored. These omissions that are not taken into account in the measurement might very well dampen the bias and result in a net underestimation rather than overestimation of the benefits. For example, would the government have permitted imports at the higher price implied by the absence of technological change, and would it have introduced retail price fixing or rationing in an attempt to evade the consequences of higher prices? (Scobie).

Introducing trade and price policies and government intervention in general into the model to be estimated might alter the results considerably. The strength of the original Griliches model was its simplicity. By assuming a closed economy, he ignored the potential foreign exchange that might be earned through technical innovations. His model also assumes a price elasticity of demand of -1 and thereby abstracts from general-equilibrium and resource-adjustment problems.

Many of the studies listed in Table 4.1 have taken into account the possible distortions introduced by government policies and trade policies as well as the general-equilibrium effects arising from changes in resource productivity in one sector, thereby "freeing" resources that can be employed in other sectors. They have in general done so in the context of an analysis of the distribution between producers of the benefits from research.

For export commodities, demand elasticities will tend to be quite high. This means that, even for large changes in the quantity supplied, there will be fairly small changes in price; most benefits will go to producers unless the government judges it necessary to intervene. Some consumer groups, though, could benefit indirectly because the additional foreign exchange generated by increased exports can help finance a higher rate of growth. This sequence was pointed out by Castro and Schuh in their study of Brazil. Of the commodities included in the study, two (sugarcane and cotton) were traditional exports; another two were staple foods (beans and manioc).

Akino and Hayami (1975), in their study of the rice-breeding program of Japan, concluded that in the absence of trade producers would have been net losers from agricultural research. (During the period under study, Japan was a net importer of rice.) Evenson, Flores, and Hayami (1977), analyzing the rice program in the Philippines, have shown how imports have been used to maintain a stable price for consumers with sufficient rice imports to maintain a target domestic price.

In his famous paper on the returns to poultry research in the United States, Peterson (1967) takes general-equilibrium effects into consideration. The reduction in output if the new technology is withdrawn causes a reduction in net social benefits. But there is also a net gain because resources are moving out of that sector, a fact that should be subtracted from the estimate of net social benefits measured in the partial-equilibrium framework. Schmitz and Seckler (1970) proceed in a similar way in their analysis of the mechanical tomato harvester. They subtract from the benefits of the research on the harvester the returns foregone by farm workers who would have been employed were it not for technical change. As Schuh and Tollini (1978, p. 33) have noted, this procedure amounts to taking into account the adjustment costs associated with the technological change.

As these examples from the literature demonstrate, the theory is well developed on the benefit side; the accuracy of the estimates depends only on the availability of data in each relevant case. On the cost side, three problems seem to be of major concern for most authors. First, it has been argued that spillover effects originating in the public good character of the product of the research have not been internalized. For example, should part of the cost of the IRRI program be charged against the benefits of high-yielding varieties in Colombia or in the Philippines; does the fact that the IRRI is located in the Philippines explain why that country spent less than 0.25 percent of its agricultural product on research (Table 3.3.)? A second issue, raised by Dalrymple among others, is that of adoption and associated costs. In cost-benefit accounting, not only should the direct costs of the research program be entered against the benefits but, also, the costs of diffusion and assimilation by farmers of the new technology should be entered. Some authors have failed to do this and, therefore, have underestimated the costs of the program. In general, either because of the diverse nature of indirect costs or for lack of precise data, some costs might inevitably escape even a careful accounting. The third issue, already raised in the context of the evaluation of benefits, is that of price distortions. Do the costs of the inputs used reflect their true social scarcity value? For example, during the past decade, the price of chemical inputs (fertilizers, etc.) in developing countries was distorted by exchange rate policies and other measures aimed toward protecting the agricultural sector from the consequences of oil price increases.

Finally, in the context of our brief review of the methodology of evaluation of the project, it is important to mention the measurement bias that might exist because of an underestimation of the investment and adoption period. First, as Griliches (1957) had noted, not only should the lag in availability of technology be accounted for in the econometric estimation but the adoption lag should also be taken into account. A second problem is the correct measurement of depreciation costs during the investment period. As Scobie has pointed out (p. 9), because the lags are generally long in agricultural research, it can be argued that errors in GARB are damped rather than amplified by the fact that with high rates of returns (such as those reported in most studies) errors in future benefit streams are heavily discounted and more than offset the underreported costs.

In conclusion, none of the issues of methodology mentioned here seems to disprove the underinvestment hypothesis. Clearly, as we have seen, severe measurement problems exist at every step of the evaluation procedure. Although the accuracy of the estimates might be legitimately in doubt for the earlier studies, with the degree of sophistication displayed in the more recent studies incorporating earlier criticisms it is likely that the results actually underestimate rather overestimate returns to agricultural research. As we have seen from a methodological point of view, nothing presumes the direction that the estimation bias will take--neither optimism nor pessimism is justified. All that one can hope for is that the model will be sophisticated enough to take into account all of the relevant effects. To a great extent, the quality of the data will determine the results. It is possible that the average returns observed in many studies are too high. But if there exists a research production function with diminishing returns to marginal increments of investment, one wonders if IRRs ranging between 30 percent and 60 percent conceal marginal rates of returns so low that they would not justify more investment in agricultural research.

Pasour and Johnson (1982) have questioned the validity of ex post evaluations to measure potential returns. Their argument runs as follows. The fact that a particular investment performed well relative to the market average (a high ex post return) does not imply that it will be a good investment in the future (a high ex ante return). This is particularly true in the case of agricultural research because the (environmental, social, and institutional) conditions in which the innovation process takes place are crucial to the success of the project. This explains why, for example, the same varieties adapted to different regions or countries yield very different adoption rates. To conclude that there is underinvestment requires proof that the rate of investment in the current period is too slow and to use the term "underinvestment"--implying that the rate of investment is too slow--requires a normative judgment. "The economist cannot determine underinvestment or inefficiency by decision-makers in either the public or private sector--he can only provide information about past economic conditions" (Pasour and Johnson, 1982). Such a statement does not "prove" that the present level of investment is optimal or that investment opportunities in agricultural research have been exhausted; it merely shifts the debate from the positive to the normative terrain. Clearly, policy choices have to be made; but this does not disprove the point made by Ruttan and others that there is an economic rationale in making the choice of investing in research as long as there is evidence of high returns.

SECTION 5

UNDERINVESTMENT IN AGRICULTURAL RESEARCH

Plotting rates of return against investment-in-research data results in an unintelligible scatter of points. Studies examining the productivity of research in agriculture make a case for the underinvestment thesis, but they do not explain why investment in research activities is so low. They say very little about the policy choices involved in research-resource allocation, why there is investment in certain types of crops and/or types of innovations and why others are neglected, and why some research projects are successes and others failures.

The studies show that investment in agricultural research yields very high rates of return. They exhibit a great variance in returns ranging from a 10 percent to a 100 percent annual internal rate of return. Finally, they tend to analyze projects involving specific innovations in specific areas or crops. Failures are seldom documented. Behind these data are price/quantity relationships and institutional processes involving supply and demand curves and their interactions which generate those points. The great variance in returns observed in the studies can only be explained by identifying the variables determining demand and supply functions of research.

In this section we examine some of these variables and put forward some political-economic arguments that explain the low rate of investment in research. Before examining these arguments, we will comment on the boundary between private- and public-sector research in agriculture which has been a continuing area of concern and controversy. Participation of the public sector in agricultural research in both developed and developing countries has been justified on three grounds: research results are a public good, consumers should receive all the benefits from research, and spillover benefits from research create externalities that require government finance to internalize. Although they are related, we will examine these issues separately for convenience.

Neoclassical theory takes into account the possibility of market failure. The failure of markets to exist arises, for instance, because of the impossibility of excluding nonbuyers from the use of the product. In this case, pricing might be impossible or may require the use of considerable resources. In general, market failure occurs because transaction costs (including exclusion costs, information costs, etc.) which are attached to any market and indeed to any mode of resource allocation are so high that the existence of the market is no longer worthwhile. "The difference between transaction costs and production costs is that the former can be varied by a change in the mode of resource allocation while the latter depends only on technology and tastes and would be the same in all economic systems" [Arrow (1970), p. 68)].

Markets are the predominant form of social arrangement to allocate resources in a capitalist society, but they are not the only mode of resource allocation. One of the advantages of the price system over political bargaining or over planned allocation is usually stated to be the economy in costs of transaction; but in some cases such as usage of irrigation, the costs of transmitting and receiving a large number of price signals are very high, and there is a tendency not to differentiate prices as much as would be desirable from an efficiency point of view. In a price system, transaction costs drive a wedge between buyer's and seller's prices and thereby give rise to welfare losses. Removal of these losses can be achieved by switching to another mode of resource allocation such as allocation by the state on the basis of benefit-cost criteria. Of course, the advantages of such a mode of allocation compared to the market system must be weighed against a possible increase in transaction costs which could result, for example, in the case of agricultural research in the need for studies to determine demand functions without the benefit of observing a market.

Market failures are one of the reasons why the state has a special role to play in resource allocation. Given high transaction costs or given the existence of Pareto inefficiency in a free-market equilibrium, there is pressure to overcome it by some form of departure from the the free market, i.e., some form of collective action; but, other reasons have also motivated the state to intervene in the economy. Because of its relative autonomy, it was able in specific instances to effectuate important structural changes in agriculture--through land reform and investment programs--against the will of the dominant classes in society basing its action on efficiency or equity considerations. The state, historically, has played a privileged role in replacing the market for allocating resources because it has the coercive power (and, in some cases, the legitimacy) required to economize on transaction costs.

The state is not the only social institution which can serve as compensation for the failure of the market. Institutions, such as producers' associations and other types of coalitions, can organize themselves in order to internalize the externalities created by the process of production of research. In Section 3 we have seen, for example, that the association of textile producers of Colombia has financed research on cotton in that country, thus, appropriating most of the benefits of the operation.

The spillover argument addresses the issue of externalities that are present in most research projects. Spillover effects result from the lack of congruence between costs and benefits of agricultural research. Research in certain domains, such as improved varieties, can be expected to have an impact on productivity growth in agriculture for others than those who have borne the costs. Therefore, some mechanism is required to internalize the externalities and, thus, improve efficiency.

Another dimension of spillover effects is the transfer of gains from producers to consumers (Ruttan, 1982, p. 257). The way in which the gains from technical change are partitioned between producers and consumers of a particular commodity depends on the slopes of the demand and supply curves for the product and on the rate of technical change and of demand change, i.e., that rate at which the two curves shift to the right over time. If the product is characterized by highly elastic demand and/or by rapid growth in demand, such as for most export crops, producers are able to retain large gains from technical change. By contrast, if demand is inelastic and/or if the rate of growth in demand is slow, as is the case for many food crops consumed by the poor in developing countries, most of the gains from technical change are passed on to consumers in the form of lower prices if no intervention, such as price support programs for farmers, takes place. The treadmill mechanism limits the economic motivation of farmers for support of agricultural research to a small population of early adopters of the new technology. The early adopters also tend to be the most influential and politically articulate. As Ruttan (1982, ibid.) points out, it may explain why agricultural research has not been able to achieve as broad a base among the farm population as support for commodity price programs.

Some authors have objected to public agricultural research on the grounds that centralization of decision making at the level of the state creates inefficiencies. To the structuralist market-failure argument, these authors respond with a nonmarket-failure argument (see Pasour and Johnson, 1982); but the centralization argument is historically incorrect in the case of agricultural research. Pineiro and Trigo (1983) have documented the evolution of Latin American research institutions and shown that, as a response to the problems associated with centralized research under the aegis of the ministries of agriculture, decentralized and autonomous institutions emerged during the 1960s in most Latin American countries.

Other authors have expressed doubt about the public-good nature of research. They argue that a large proportion of new technology has been in the form of improved seeds, machinery, chemicals, etc., rather than "information" (such as farming practices) which has a public-good element. Even information, say, about planting density, which may appear to have a public-good character, in fact, must be modified and adapted to individual microecological circumstances on each farm (Grant Scobie, personal communication). Whether agricultural technology is actually a public good is highly relevant for a policy debate if one considers that the state should intervene in the financing and conduct of the research process only in cases where private initiative fails.

There are two distinct aspects to the question of what is the appropriate boundary between public and private research. In some instances where research benefits are not appropriable by the private sector and where market mechanisms or private coalitions fail to produce research (market failure), public intervention is required. The private sector will neglect research in instances where benefits are not appropriable because private transaction costs are too high. In such uncontroversial instances, most authors agree that public financing is in order and that the state should have a role in determining research priorities. This would be, for instance, the case of basic scientific research; but in those situations where private mechanisms of appropriation can be devised, the question becomes: Should the private sector appropriate all the benefits from research? If the answer is negative (because one considers, for example, that the state should use the surplus to finance development projects), how should the surplus be distributed? In practice, the answer given to this question depends largely on the nature of the state and of its relationship with various groups in civil society.

Such difficult questions can only be answered on a case-by-case basis based on an ex ante evaluation. Some general principles, though, can be derived from already existing studies. Innovations in mechanization have mostly the effect of displacing labor and do not profit society at large. Therefore, financing of such cost-saving but not ouput-increasing innovations should be left to the private sector. Binswanger, for instance, in his study of tractorization in South Asia (1980, p. 73) concluded that "the tractor surveys fail to provide evidence that tractors are responsible for substantial increases in intensity, yields, timeliness, and gross returns on farms in India, Pakistan, and Nepal. Such benefits may exist but are so small that they cannot be detected and statistically supported even with massive survey research efforts. This is in sharp contrast to new varieties or irrigation where anybody would be surprised if he failed to find statistically significant yield effects, even in fairly moderate survey efforts." Biological innovations are beneficial to larger groups in society than mechanical innovations, and the problem then becomes to devise mechanisms to make beneficiaries pay for the research according to their share of benefits via taxation or other public allocation schemes.

The growing importance of the private sector in the process of technical innovation, including the role of transnational corporations and national farmer associations, and the decentralization of national research systems are the most important features of the global research system that has emerged in recent years. During the 1960s, there was strong expansion in national research backed by international support. The momentum was provided by the early successes of IRRI and CIMMYT. But as technology moved into the "second generation" phase, latent problems began to appear; there were signs that the institutions built during the 1960s were facing a crisis because they were not adapting to new developments taking place in the economies of Latin America.

Before the Second World War, institutional change in agricultural research was induced in response to specific crises such as a cotton crisis in Canete, Peru, an outbreak of sugarcane mosaic disease in Palmira, Colombia, and changes in export markets (cacao and rubber) as a result of the war in Ecuador (Trigo, Pineiro, and Sabato).

During the 1950s, as a result of the process of import-substituting industrialization (ISI) which induced changes in the structure of demand for food because of population growth and urbanization, there was increasing awareness of the importance of agricultural technology and of institutional changes to modernize agriculture and counteract the trend of stagnation of the agricultural sector that was generating balance-of-payments problems and domestic excess demand.

The agricultural sectors of Latin America were transformed by a set of interrelated reforms: (1) changes in the production structure through agrarian reforms; (2) increasing use of agroindustrial inputs, which implied a change in orientation in the development of agriculture and, as such, was resisted at first by several social groups but in time led to the appearance of new agrarian interest groups; and (3) institutional changes in research and technology. During this period, Latin American states acting "from above" assumed responsibility for technological change. Autonomous semipublic institutions were set up in many countries (INTA in Argentina in 1957, INIAP in Ecuador in 1959, FONAIAP in Venezuela in 1959, INIA in Mexico in 1960, SIPA in Peru, ICA in Colombia, INIA in Chile, etc.). The basic model around which these institutes were constructed was that of a technological converter to facilitate the adoption and dissemination of the technologies available at the international level (see Trigo, Pineiro, and Sabato, p. 132). The national institutes were based on the concept of broad adaptability (encompassing a wide range of regions and types of farms) for major crops.

5.1. Political-Economic Dimension of the Demand for Research

At the beginning of the 1970s it became clear that the available technologies on which the modernization strategy was based were quite successful in some cases but were not neutral in their effects on production and in their social impact.

Public research policy when the state is in the "planning mode" can be viewed as a process of "explicitly creating the demand for research of certain types rather than simply responding to existing demand through estimates of market forces and their effects" (Mellor, p. 479). The case studies analyzed by Trigo and Pineiro show the successes of strategies in which the government, in response to stagnation in production or foreign exchange shortages, pushes for a negotiated solution and mediates the interests of industrial urban classes with more specific interests of farmers' groups (rice in Colombia or maize in Argentina). In these cases, the state, acting from above, is able to articulate the demand for new technology originating from various groups, which appears in an ex ante evaluation to be in the interests of the society at large, and to produce a "package" of policies combining adaptation of improved varieties available internationally to local conditions with economic policies protecting specific groups from the effects of technical change (price stabilization, subsidies, and protectionism). These processes of "articulation" presuppose that the state must be strong enough, once the need for the society as a whole to increase production is recognized, to implement public policies consistent with "progress" and technical change.

In other types of successful technological processes, the social articulation was generated from within the agricultural sector. The examples of sugar in Colombia and milk production in the Ecuadorian highlands show that, when it takes the initiative, the agrarian sector acquires considerable influence and participation in the institutional mechanisms. In these cases, specific social classes were able to negotiate with the government on a series of policies (price policies, credit, etc.) that served their specific interests and activated the state "from below." The economic policies implemented were in all cases designed to solve particular problems obstructing the development of the productive sector. The social groups that took the initiative in the change controlled the sector and were able to appropriate a good part of the benefits of technical change. Moreover, they created organizational mechanisms that gave them a certain amount of control over the supply of technology.

According to the findings of the PROTAAL studies, such processes of technical change, although successful, had moderate effects on yields and resulted in considerable expansion of area. They resulted in important changes in work organization toward more concentration and vertical integration of production. By contrast, when the state mediated the interests of conflicting groups from above, the results were significant increases in production and yields and minor modifications of the work organization (see Pineiro and Trigo, 1983).

There are also examples of relative failures resulting either in stagnation of the sector affected or in insignificant increases in yield but in accelerated social differentiation (e.g., potato production in the Mantaro Valley in Peru). In these examples, either public policies backing up the process of technical innovation were not adequately designed or no existing social class linked to production was capable of mobilizing and coordinating government action in its favor. This remark applies particularly to the crops that are produced by the campesino sector (potatoes, beans, etc.) or by specific regions. In Latin America the rural poor tend to be concentrated in less-fertile regions or regions with reduced access to water; regional differences are often correlated with class differences (see Scobie and Posada, p. 386). The difficulties of the poorest producers to mobilize research efforts in their favor may explain, for example, why upland, nonirrigated rice has received less attention than has irrigated rice. Concentrating research on the former "would presumably have entailed foregone benefits to the numerous urban poor without guaranteeing that small upland producers would have benefitted in the long run" (Scobie and Posada).

These comments show that potential demand for research will be translated into actual demand either when some products are important for the state, which sees in the process of technical change a means of finding a solution to a specific agrarian problem (e.g., rice in Colombia), or when products are important for some specific groups and producers' associations capable of mobilizing the state which will then engineer the change in active collaboration with those groups.

5.2 The Supply of Research and Its Determinants

The rate of technical change is affected by the conditions under which institutions supplying research in agriculture operate. As explained above, from an institutional point of view, research efforts are mainly centered around the national research institutes organized in the 1960s, but one of the most significant recent trends is the growing participation of the private sector in some areas of research.

The setting of priorities and allocation of resources of the national research institutes have been affected during the 1970s by changes in the national and international context in which they operate. The institutional model adapted from the U. S. federal-state Agricultural Experiment Station system (in which states compete against one another in the provision of research) has become increasingly inadequate to deal with those changes. The decentralized institutions of Latin America, organized along the lines of the U. S. system, were set up with the function of serving as public converters of technology available internationally into technology adapted to local conditions. Although there was a marked increase in budgetary and human resources coinciding with initial successes in some areas, available data show that, since the early 1970s, the overall trend in Latin America is toward a loss of institutional strength. The signs of crisis identified in some institutions and the regional differences noticeable among different systems (Southern Zone, Andean region, Central America, and the Caribbean) reflect mainly the different characteristics of the economic development and of the process of social change generated by technical change specific to each country (Table 5.1).

Aside from region or country-specific developments, which we will examine further in the context of the instability of financial resources, certain developments common to all countries may explain the failure of the present system to adapt to the new situation.

The "converter model" was suited to a situation characteristic of the early stages of institutionalized research. The technology of the Green Revolution was available from international centers, on the one hand; and, on the other hand, it had all the characteristics of a public good. It was well suited for involvement of the public sector as the technology in most cases did not induce benefits that could be easily appropriated by private groups and, therefore, the state could mediate among various urban and rural groups to adopt successfully new technologies within the framework of the development plan. Although the original model was based on the idea of complementarity between international and national centers, in practice, the internal dynamics of the IARCs led them to become a practical alternative and a competitor (in terms of human resources, for example) for the national institutes. As the example of rice in Colombia shows, ICA has lost much of its initiative as a result of work conducted at the centers.

Parallel development at the national level also resulted in a loss of influence of the national systems. Direct participation in the process of generation of technology by private associations (such as CENICAÑA and FEDEARROZ in Colombia) corresponds to an increasing involvement of the private sector in research. The increasing role in the development of agriculture of firms producing inputs in the development of agriculture has created new opportunities for the private sector, and the identification of benefits suitable for private appropriation has encouraged private firms to participate in the generation and dissemination of technology. These tendencies indicate that research is increasingly becoming a private good and that institutions are viewed not as instruments for broad agrarian change reflecting a national consensus but, rather, as organizations serving particular interests in the agricultural sector (see Pineiro and Trigo, pp. 332-333).

Within the context outlined above, national institutes must develop programs under severe shortages of skill supply. Although the data indicate an increasing trend in terms of professional personnel from 1970 to 1980 (as a result of a conscious strategy aimed toward developing human resources for agricultural research), the sector is plagued by outmigration of highly qualified personnel, a high rate of turnover of trained personnel which is detrimental to the development of long-term research programs, and a weakening of the training programs of the institutes (see Trigo, Pineiro, and Ardila).

TABLE 5.1

Budgetary Resources Allocated to Agricultural Research in Latin America and the Caribbean, between 1960 and 1980, Selected Years (Constant Value of 1975; Official Money Exchange Rate: National Currency/US dollars, for Year Selected)*

SUBREGION[1]	1960	1965	1970	1974	1980
Southern zone (excluding Brazil)	31,446[2]	31,298	32,594[3]	44,702[4]	42,559[5]
Brazil	8,280[6]	15,533[7]	24,178[8]	32,879[9]	116,797
Andean Zone	15,631[10]	20,003[11]	43,056[12]	57,393[13]	60,541[14]
Panama and Central America (excluding Mexico)	4,412[15]	4,967[16]	4,904[17]	5,961[18]	10,215
Mexico	4,666[19]	5,218	9,723	14,637[20]	48,357[21]
Caribbean (excluding Dominican Republic)	1,530[22]	1,530[23]	3,280[24]	2,940[25]	2,128[26]
Dominican Republic	441[27]	496[27]	490[27]	2,278[28]	1,642
Latin America and the Caribbean (total)	66,406	79,045	118,225	160.790	282,239

*Preliminary figures, currently being adjusted (Trigo and Piñeiro, 1981: Appendix 1).

[1] Southern Zone includes Argentina, Uruguay, Paraguay, and Chile. Andean Zone includes Bolivia, Peru, Ecuador, Colombia and Venezuela. Central America includes Costa Rica, Nicaragua, Honduras, El Salvador, and Guatemala. Caribbean includes Guyana, Suriname, Jamaica, Haiti, Barbados, Grenada, Trinidad and Tobago.
[2] Information for Chile is from 1961.
[3] Information for Paraguay is from 1971.
[4] Information for Chile and Uruguay is from 1973; for Paraguay from 1972.
[5] Information for Argentina is from 1979.
[6] Information is from 1962.
[7] Authors' estimate, based on figures supplied by Boyce and Evenson.
[8] Information is from 1972.
[9] Information is from 1973.
[10] Information for Bolivia, Venezuela and Peru is from 1962; for Ecuador from 1965.
[11] Information for Bolivia is from 1962.
[12] Information for Bolivia and Venezuela is from 1972 and 1969 respectively.
[13] Information for Bolivia and Ecuador is from 1973; for Venezuela and Peru from 1976.
[14] Information for Colombia is from 1979.
[15] Information for Nicaragua and Guatemala is from 1962; for Honduras from 1963.
[16] Information for El Salvador is from 1966; for Guatemala from 1962 and Panama from 1961.
[17] Information for Honduras and Nicaragua is from 1965; for Guatemala from 1973; for Panama it was estimated as US$600,000.
[18] Information for El Salvador is from 1973; Honduras from 1976 and Panama from 1975; for Nicaragua it was estimated as US$1,000,000.
[19] Information is for 1962.
[20] Information is for 1972.
[21] Information is for 1979.
[22] Information for Barbados, Jamaica, Suriname, Grenada, Trinidad and Tobago is from 1965; for Guyana it was estimated as US$250,000.
[23] Same information as 1960.
[24] Information for Barbados, Jamaica, Suriname, Grenada, Trinidad and Tobago is from 1972; for Guyana from 1973 and for Haiti from 1976.
[25] Information for Barbados and Haiti is from 1976; for Jamaica Trinidad and Tobago from 1972.
[26] Information for Haiti is from 1978; for Suriname and Grenada from 1974, and for Guyana from 1978.
[27] Information was estimated on the basis of 10 per cent of the totals for Panama and Central America.
[28] Information is for 1977.

Source: Pineiro and Trigo (1983).

In terms of human resources (Table 5.2), it seems that progress can be expected at the level of the Master's degree in the training of personnel in developing countries but that it will be very slow at the level of the doctorate degree (Evenson and Evenson, p. 227). The availability of foreign training fellowships from granting agencies will not increase substantially. A few countries are using loans from the World Bank to support graduate studies in the United States by their students (Evenson and Evenson).

The phenomenon of migration and the highly fragmented market for scientists (with low wages for lower ranking personnel and higher wages for personnel trained abroad) is even more preoccupying. National salaries are low relative to those paid by international agencies that are willing to pay a high wage for short-term consulting services. Such developments in which the quantity of personnel is increasing but the quality remains inadequate represent a preoccupying trend for the development of a stable research effort

The market mechanism performs poorly in the allocation of research funds to research. This is mainly because a large part of research produced by national institutes (such as basic knowledge) is a public good with its characteristics of nonrivalness and nonexcludability (free use for anyone once it becomes available except in some specific--patentable--instances), and it induces "free riding" (people will wait for somebody else to incur the cost of research before doing it themselves). Therefore, market signals cannot be used to allocate resources and administrative mechanisms have to be used.

Some forms of technologies that do not have the characteristics of a public good are more easily appropriated by the private sector. In what other instances can the private sector be expected to participate in agricultural research? Improved machinery and other forms of technology (mechanical and chemical) that can be protected by patents permit selective access to research findings to those who finance (or buy) the product. Because the risk is too high or because the costs cannot be covered by the benefits associated with the new technology the farmer is able to capture, the private sector has been unwilling in the past to finance research in areas such as biological innovations. Crop varieties with high-yield capacity, disease and pest resistance, etc. for developing countries were generally developed by international research institutes and adapted to local conditions by national research institutes. But introduction of this new technology had a considerable impact on the demand for fertilizers and other agricultural inputs, and firms supplying such inputs acquired large economic gains derived from investment in agricultural research through its effect on the demand for their product (pesticides and fertilizers).

The greater importance of the private sector in agricultural research in developed countries results in part from the greater use of purchased inputs by the agricultural sector--although this is not the only explanatory factor. The use of fertilizer and other chemical inputs is higher in some developing countries than in the United States for export crops such as cotton.

A clear correlation exists between the proportion of agricultural research by the private sector and the national income of the country (Table 5.3). In developed countries, according to 1974 data (Boyce and Evenson), the private

TABLE 5.2

Human Resources (Professional Personnel) in Agricultural Research in Latin America and the Caribbean, from 1960 to 1980 (Selected Years)*

SUBREGION[1]	1960	1965	1970	1974	1980
Southern Zone (excluding Brazil)	365[2]	816	1,045[3]	1,196[4]	1,364
Brazil	200[5]	500[6]	764	2,000	2,935
Andean Zone	387[7]	643	1,294	1,694	1,843[8]
Panama and Central America (excluding Mexico)	144[9]	305[10]	283[11]	333[12]	383
Mexico	190[13]	279[14]	551	1,000	1,079
Caribbean (excluding the Dominican Republic)	64[15]	96	157[16]	228[17]	198[18]
Dominican Republic	3[19]	5	12[20]	35[21]	99
Latin America and the Caribbean (total)	1,353	2,644	4,106	6,486	7,901

*Preliminary information, still being analyzed (Trigo and Piñeiro, 1981: Appendix 2).

[1] Southern Zone includes Argentina, Uruguay, Paraguay, and Chile. Andean Zone includes Bolivia, Peru, Ecuador, Colombia and Venezuela. Central America includes Costa Rica, Nicaragua, Honduras, El Salvador and Guatemala. Caribbean includes Guyana, Suriname, Jamaica, Haiti, Barbados, Grenada, Trinidad and Tobago.

[2] Information for Argentina, Chile and Paraguay is from 1959.

[3] Information for Paraguay is from 1971.

[4] Information for Chile is from 1973; for Paraguay it was estimated at 37.

[5] Information is for 1959.

[6] Information is for 1967.

[7] Information for Bolivia, Ecuador and Peru is from 1959.

[8] Information for Colombia is from 1979.

[9] Information for Honduras and Nicaragua is from 1959; for Guatemala it was estimated at 20.

[10] Information for El Salvador and Guatemala is from 1966.

[11] Information for Honduras, Nicaragua and Panama is from 1971; for Guatemala, from 1972.

[12] Information for El Salvador is from 1973; for Costa Rica and Guatemala it was estimated at 64 and 58 respectively.

[13] Information is for 1959.

[14] Information is for 1966.

[15] Information is for 1959.

[16] Information is for 1971.

[17] Information for Trinidad and Tobago is from 1971.

[18] Information for Trinidad and Tobago is from 1978.

[19] Information is for 1959.

[20] Information is for 1971.

[21] Estimated.

Source: Pineiro and Trigo (1983).

TABLE 5.3

Percentage of Total Agricultural Research by the Private Sector: Selected Continent/Country, 1974, and Income Level, 1971

	Percentage of total agricultural research
Continent/country	
North America and Oceania	25.4
Western Europe	10.8
Eastern Europe and USSR	8.3
Latin America	5.1
Africa	2.9
Asia	2.2
Income (GNP per capita)	
Less than $150	5.2
$ 150-$ 400	2.8
$ 400-$1,000	7.4
$1,000-$1,750	7.0
$1,750 and more	24.0

Source: Boyce and Evenson.

sector accounts for about 25 percent of total research while in resource-poor countries of Africa it accounts for less than 3 percent. The proportion of purchased industrial inputs used by farmers is much lower than in the United States or Japan and makes benefits from research much less attractive.

When agricultural production is oriented toward rural consumption or toward the domestic market, the private sector may be unwilling to invest in research that would increase productivity and induce a fall in food prices. Resource substitution may be induced by new technologies, such as laborsaving mechanization, and lead to a reduction in costs. For the private sector to be willing to pay for the research, the resource substitution effect must be sufficient to cause a decrease in total costs that would exceed research costs and the induced fall in farm income. This is why the participation of the private sector can be expected only when the elasticity of demand for the good is high (export crops, for example) or when the state is willing to take measures such as price subsidies.

Participation of the private sector can also be expected in cases where the crop is grown by a limited number of producers who can easily appropriate the benefits from research. Research programs successful from the point of view of the private sector have been carried out by producer groups such as the Colombian Federation of Cotton Growers (see Hertford, et al). In general, producers are not able to identify the potential benefits to research or may not be able to capture the benefits; their participation in research investment in developing countries is limited.

The changes that have occurred at the international level during the past several years have considerably altered the parameters of agricultural research. Along with the creation of an international network of public or semipublic institutions under the umbrella of CGIAR, there is evidence of a private internationalization of the technological process whereby transnational corporations operating in developing countries transfer technologies developed by their research and development departments. The international trade of technological inputs defines the type of technology to be supplied at the national level.

These international transfers of technology, rather than responding to a demand originating from within a country, respond to the investment programs of these firms. To quote Pineiro and Trigo, "The participation of private industry in the generation of agricultural technologies is increasing faster than the conditions in each country would seem to merit." This is the product of changes in the world market and of the faster growth of commercial agriculture and agroindustrial activities than peasant agriculture. It suggests that the state has not been able to control the technological process effectively. Evenson and Evenson, in their study of the legal incentive systems in Latin America, suggest that developing countries have tended to develop legal systems of patents and other forms of protection of intellectual property that do not foster creativeness in the private sector but create, instead, excessive reliance on the technology developed in richer countries. Brazil, Mexico, and a few other countries, by adopting "codes of conduct" for transnational corporations and "petty patents systems" more adapted to inventions of their countries, could foster more autonomous private research in Latin

America. Evenson and Evenson (p. 211) suggest that "combinations of public sector research, public sector contracts with private firms, and imaginative patent systems are optimal."

SECTION 6

INSTABILITY OF FINANCIAL RESOURCES

One of the most preoccupying trends in agricultural research is the highly variable nature of funding observed in the past decade. The annual variations in budgetary resources for agricultural research in Latin America, expressed in constant (1975) local currency, are shown in Tables 6.1-6.3 and Figures 6.1-6.14.

The data plotted in Figures 6.1 through 6.14 are taken from Table 6.1 published by ISNAR. It is the most complete source of information on Latin American research expenditures. However, there is reason to have doubts about the quality of the data. Eduardo Venezian did a careful study of Chile for the Impact Study in which he reports that total research expenditures in real terms have doubled from 1970 to 1975 while the ISNAR data indicate an opposite trend (Grant Scobie, personal communication).

Index of Real Research Expenditures, Chile, 1960-1980

Year	From table 6.1	From E. Venezian
1960	100	100
1965	99	181
1970	300	283
1975	191	529
1980	242	721

Variability of expenditures is not limited to Latin American countries.

The IFPRI/ISNAR data for 41 developing countries (Oram et al., 1979) indicate that the problem is shared by almost all countries with coefficients of variation[8] ranging from 10 percent to 90 percent over the 1970-1980 period but mostly between 20 percent and 50 percent. Countries that exhibit a rapid growth rate in research expenditures (12 percent or higher) also tend to exhibit a high coefficient of variation (45 percent or higher). On a regional basis, Asian and African countries have 67 percent and 50 percent, respectively, of their countries exceeding 25 percent of variation; and South America and the Middle East have 80 percent and 100 percent, respectively. These aggregate data indicate the serious nature of the problem, given the long-run nature of agricultural research programs. Since, on the average, 70 percent of all institutional costs are absorbed by personnel costs (which in the short term can be considered as fixed costs), a decline of 10 percent in the resources available to research institutes implies a cut of 40 percent to 50 percent in operating capacity and, in practice, jeopardizes future research programs.

The funding of agricultural research activities comes from three major sources:

TABLE 6.1

Latin America and the Caribbean: Budgetary resources for agricultural research from 1960-1980. Values expressed in constant 1975 currency (in thousands).

	1960	1965	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
North Zone:													
Costa Rica (Colones)	3,565.1	5,210.6	4,637.5	13,521.9	14,387.5	9,235.3	7,081.0	8,972.8	9,937.9	10,839.5	10,329.1	12,525.9	12,143.7
El Salvador (Colones)	1,177.5	1,072.5[3]	1,280.3	1,552.2	1,812.5	2,295.1	2,570.0	2,500.0	4,530.4	4,095.8	5,077.2	4,409.2	3,906.3
Mexico (Pesos)	58,325.0	65,237.0	30,900.0	41,912.5	65,812.5	109,337.5	116,812.5	173,437.5	199,912.5	166,612.5	450,600.0	510,750.0	579,487.5
Nicaragua (Cordobas)	—	5,545.8	7,209.5	7,469.3	7,729.0	6,430.3	6,830.5	7,855.4	8,494.2	9,343.6	7,848.4	8,508.2	9,168.1
Guatamala (Quetzales)	1,840.0[1]		—	—	1,911.0	1,578.9	2,330.7	2,380.0	2,293.7	2,668.8	2,841.2	3,426.7	3,484.9
Panama (Balboas)	417.0	—	1,176.0	1,437.0	1,698.0	1,649.0	1,600.0	1,218.0	850.0	989.9	1,014.2	1,709.8	1,622.3
Caribbean Zone:													
Barbados (BB Dollars)	—	480.0	1,179.7	1,258.5	1,100.9	943.3	843.4	747.4	735.3	735.3	850.4	1,149.4	1,012.0
Jamaica (J Dollars)	—	137.5	138.0	769.0	814.0	1,257.3	1,360.7	1,301.3	1,340.9	1,178.1	841.5	504.9	554.4
Guyana (G Dollars)	—	—	—	—	—	1,218.7	1,131.8	1,543.4	1,094.9	583.5	—	—	—
Andean Zone:													
Bolivia (Pesos)	10,820.0[1]	—	30,980.0	31,360.0	25,080.0	25,620.0	26,140.0	24,820.0	23,520.0	41,240.0	46,020.0	42,080.0	36,680.0
Colombia (Pesos)	213,751.2	234,312.0	667,944.0	764,755.0	750,562.0	760,766.0	701,984.0	711,454.0	747,173.0	641,682.0	807,461.0	739,899.0	697,114.0
Ecuador (Sucres)	—	42,850.0	72,628.0	96,552.0	125,806.0	137,143.0	126,025.0	128,825.0	131,600.0	132,880.0	109,321.0	124,156.0	99,666.0
Venezuela (Bolivares)	19,850.6[1]	31,757.6	—	—	—	—	—	—	85,207.7	96,647.0	99,330.8	84,387.4	97,699.8
Peru (Soles)	76,948.8[2]	114,933.6	351,818.0	271,279.2	289,353.6	308,937.6	297,962.4	415,711.2	376,852.0	211,028.0	188,975.0	174,644.0	161,188.0
Southern Zone:													
Argentina (Pesos)	1,099,976.4	1,066,998.8	1,113,000.0	936,000.0	1,028,000.0	1,283,000.0	1,534,000.0	1,222,000.0	1,145,000.0	1,165,000.0	1,218,000.0	1,209,000.0	1,301,000.0
Brazil (Cruzeiros)	67,316.4	—	—	—	196,569.0	237,608.0	—	—	700,307.0	713,405.0	758,027.0	945,240.0	949,561.0
Chile (Pesos)	13,701.7[2]	13,554.4	41,173.8	45,711.6	46,787.1	26,745.3	28,690.1	26,151.1	33,252.4	32,957.7	31,283.1	32,373.3	33,208.2
Paraguay (Guaranies)	—	—	—	68,164.0	75,982.0	—	—		—	208,232.0	205,767.0	213,733.0	441,135.0
Uruguay (Pesos)	215.0	484.5	372.3	399.0	425.7	525.6	584.1	730.2	573.6	663.3	585.3	773.4	817.8

Source: Oram and Bindlish, 1981; Piñero and Trigo 1983.

Notes: A Hyphen (-) signifies that the data was not available.
[1] Corresponds to 1962
[2] Corresponds to 1964
[3] Corresponds to 1966

TABLE 6.2

Latin America and the Caribbean: Annual variations in budgetary resources for agricultural research. 1970 – 1980

	1971/1970	1972/1971	1973/1972	1974/1973	1975/1974	1976/1975	1977/1976	1978/1977	1979/1978	1980/1979
Northern Zone										
Costa Rica	2.91	1.06	0.64	0.76	1.27	1.11	1.10	0.95	1.21	0.97
El Salvador	1.21	1.17	1.26	1.12	0.97	1.80	0.90	1.24	0.62	0.88
Mexico	1.36	1.57	1.66	1.07	1.48	1.15	0.83	2.70	1.13	1.13
Nicaragua	1.04	1.03	0.83	1.06	1.15	1.08	1.10	0.84	1.08	1.07
Guatemala	–	–	0.82	1.47	1.02	0.96	1.16	1.06	1.20	1.02
Panama	1.22	1.18	0.97	0.97	0.76	0.70	1.16	1.02	1.69	0.95
Caribbean Zone										
Barbados	1.07	0.87	0.86	0.89	0.88	0.98	1.00	1.16	1.35	0.88
Jamaica	5.57	1.06	1.54	1.08	0.96	1.03	0.88	0.71	0.60	1.09
Guyana	–	–	–	0.93	1.36	0.71	0.35	–	–	–
Andean Zone										
Bolivia	1.01	0.80	1.02	1.02	0.95	0.09	1.75	1.12	0.91	0.87
Colombia	1.14	0.98	1.01	0.92	1.01	1.05	0.86	1.26	0.92	0.94
Ecuador	1.33	1.30	1.09	0.92	1.02	1.02	1.01	0.82	1.13	0.80
Venezuela	–	–	–	–	–	–	1.13	1.03	0.85	1.16
Peru	0.77	1.06	1.07	0.96	1.39	0.91	0.56	0.89	0.92	0.92
Southern Zone										
Argentina	0.84	1.10	1.25	1.20	0.79	0.94	1.02	1.05	0.99	1.08
Brazil	–	–	1.21	–	–	–	1.02	1.06	1.25	1.00
Chile	1.11	1.02	0.57	1.07	0.91	1.27	0.99	0.10	1.03	1.03
Paraguay	–	1.11	–	–	–	–	–	0.99	1.04	2.06
Uruguay	1.07	1.07	1.23	1.11	1.25	0.78	1.16	0.88	1.32	1.06

Source: Table 6.1
Note: A hyphen (–) means that the data was not available.

Data refer to absolute variations from previous year.

TABLE 6.3

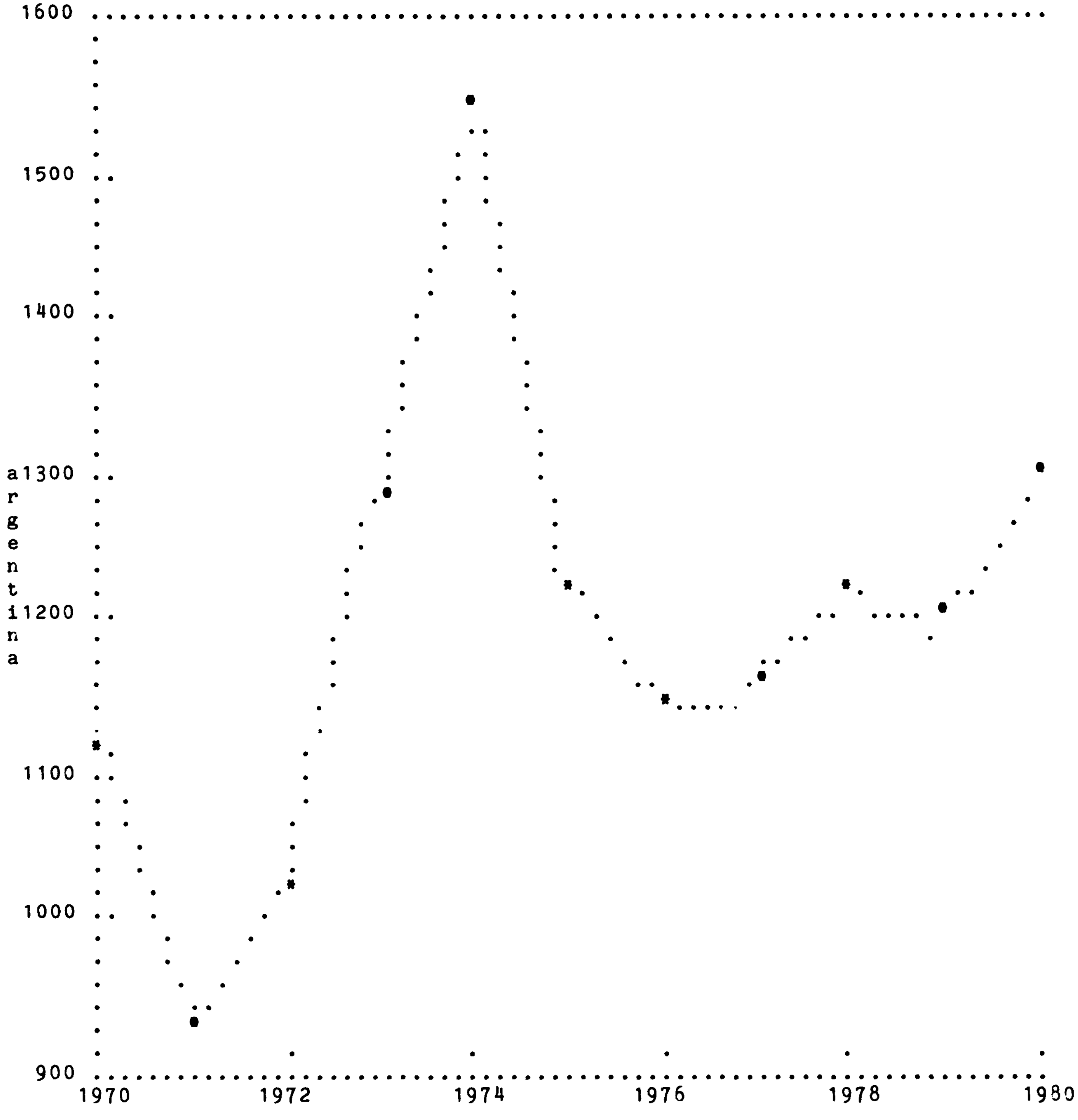
1970-1980 Indicators for 21 Latin American Countries
(Countries in order of ag. GDP growth rate)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Paraguay	6.9	11.7	63.3	0.28	1.0	1300	0.61	25.6	1.6	7.4	-3.5
Brazil	4.9	20.2	53.5	1.15	2.0	2050	0.51	5.7	4.0	1.4	7.0
Colombia	4.9	3.3	14.5	0.64	1.5	1180	0.22	17.0	6.8	1.1	16.2
Guatemala	4.6	9.1	29.7	0.39	0.6	1080	0.25	11.6	2.6	1.7	16.2
Venezuela	3.8	12.1	45.0	1.32	2.5	3630	0.25	10.4	10.4	0.7	18.7
Nicaragua	3.1	2.5	11.6	0.27	0.7	740	0.55	24.1	1.3	0.6	9.8
Bolivia	3.1	4.2	25.1	0.34	0.5	570	0.61	29.6	0.8	4.2	3.2
Dom. Rep.	3.1	NA	NA	0.20	0.4	1160	0.21	65.4	2.0	0.8	15.2
Salvador	2.8	25.3	70.9	0.50	1.0	660	0.15	6.3	6.9	1.4	12.0
Argentina	2.6	7.9	47.4	1.64	6.2	2390	1.30	33.1	4.8	0.5	1.2
Costa Rica	2.5	0.5	17.2	0.24	0.9	1730	0.22	6.5	4.2	0.0	7.3
Ecuador	2.4	6.7	25.8	0.35	0.8	1270	0.33	9.5	2.5	0.2	7.7
Mexico	2.3	33.5	88.4	1.36	2.5	2090	0.33	12.0	7.4	0.1	9.5
Chile	2.3	-2.9	21.7	0.81	0.9	2150	0.50	19.7	1.9	1.3	-1.0
Panama	1.9	11.4	29.1	5.33	1.7	1730	0.30	9.0	5.6	0.6	11.0
Honduras	1.5	-6.8	32.5	0.16	0.3	560	0.48	7.8	0.6	1.4	6.7
Guyana	1.0	NA	NA	1.85	2.7	570	0.43	10.9	6.4	0.2	-1.0
Jamaica	0.7	-4.5	33.8	0.23	0.4	1040	0.12	7.8	2.9	0.6	-5.5
Uruguay	0.2	7.5	25.6	0.59	1.4	2810	0.65	8.6	2.2	0.3	4.4
Barbados	0.0	-2.3	20.0	1.35	2.9	1620	0.14	1.4	23.2	0.0	-6.5
Peru	NA	4.5	32.5	0.33	0.5	930	0.19	12.6	2.6	2.0	5.9

Explanation of columns:
(1) growth rate of ag. GDP 1970-80 (percent)
(2) growth rate of ag. research expenditures 1970-80 (percent)
(3) coefficient of variation in ag. research expenditures (percent)
(4) ratio of ag. res. exp. to ag. GDP 1980 (percent)
(5) ag. research expenditures per capita 1980 (US $)
(6) GNP per capita 1980 (US $)
(7) man/land ratio (arable area per capita, in ha)
(8) arable area per scientist (ha)
(9) ag. research expenditures per ha (US $)
(10) growth rate of arable area 1970-80 (percent)
(11) growth rate of fertilizer use 1968-78 (percent)

Source: P. Oram, ISNAR.

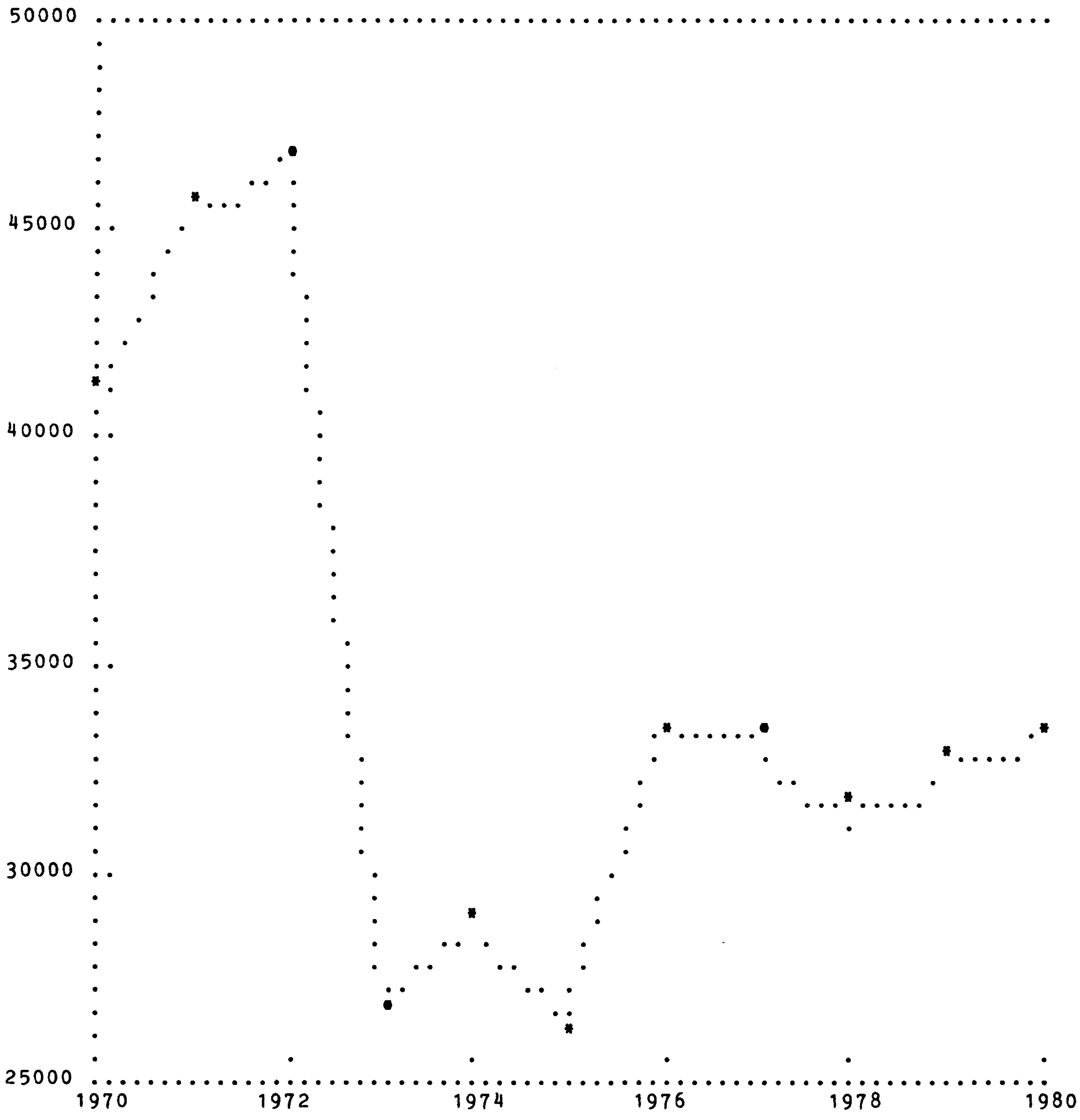
EXPENDITURES ON AGRICULTURAL RESEARCH



Argentina 1970-1980 (in mill. constant pesos)

FIGURE 6.1

Expenditures on Agricultural Research



Chile 1970-80 -- in constant 000 pesos

FIGURE 6.2

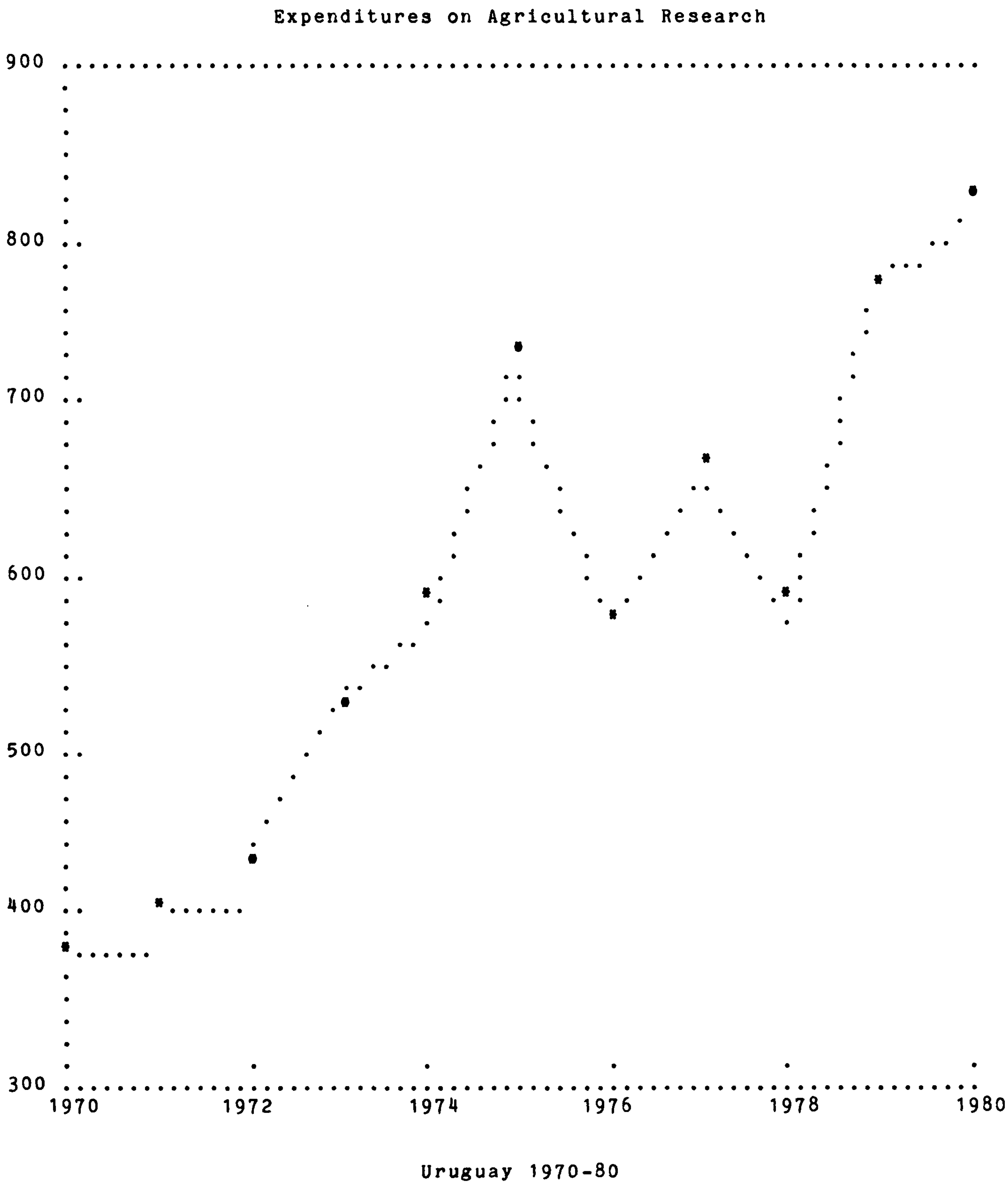
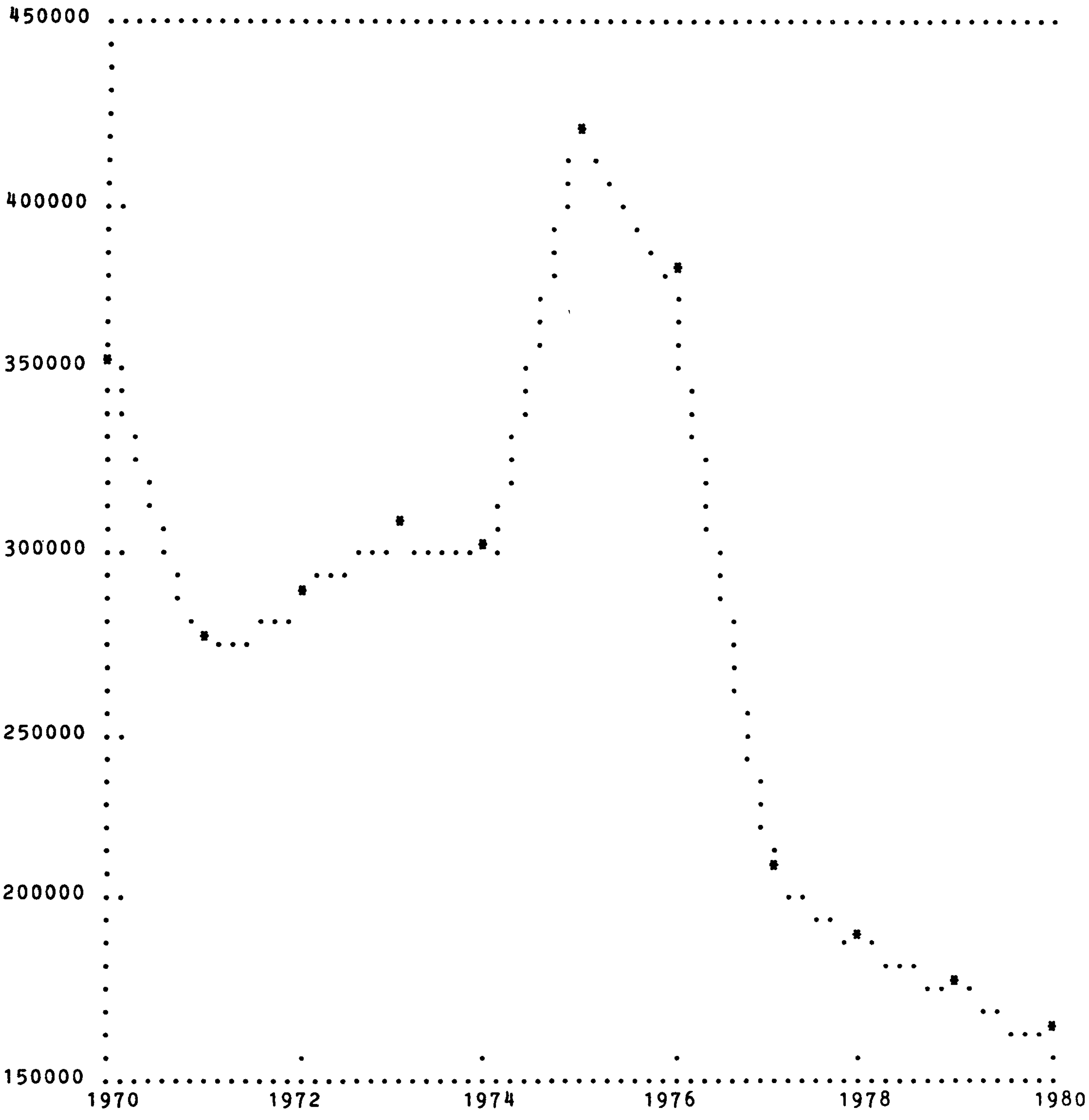

Expenditures on Agricultural Research
900
800
700
600
500
400
300
1970
1972
1974
1976
1978
1980
Uruguay 1970-80

FIGURE 6.3

Expenditures on Agricultural Research



Peru 1970-80

FIGURE 6.4

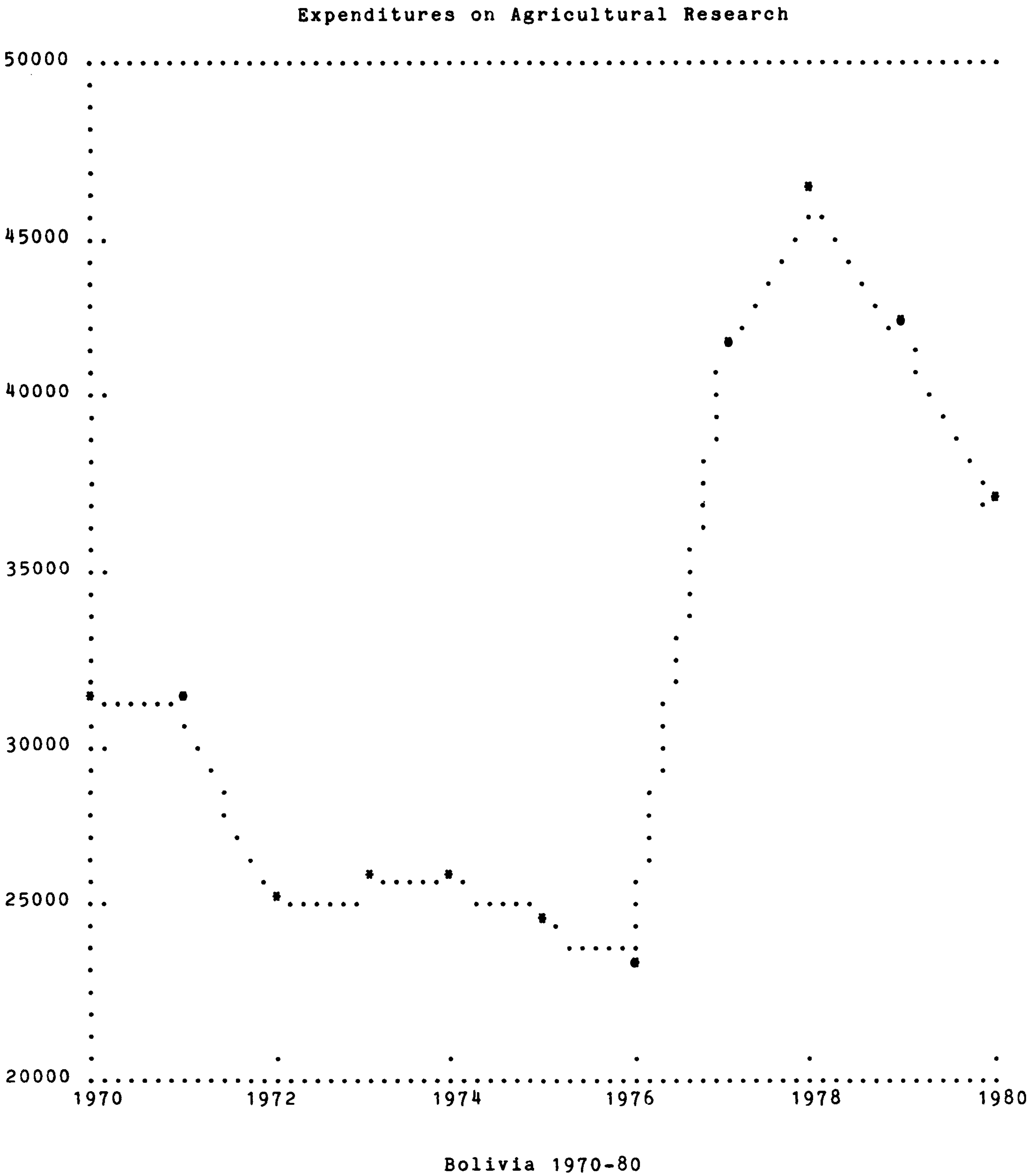

Expenditures on Agricultural Research
50000
45000
40000
35000
30000
25000
20000
1970
1972
1974
1976
1978
1980
Bolivia 1970-80

FIGURE 6.5

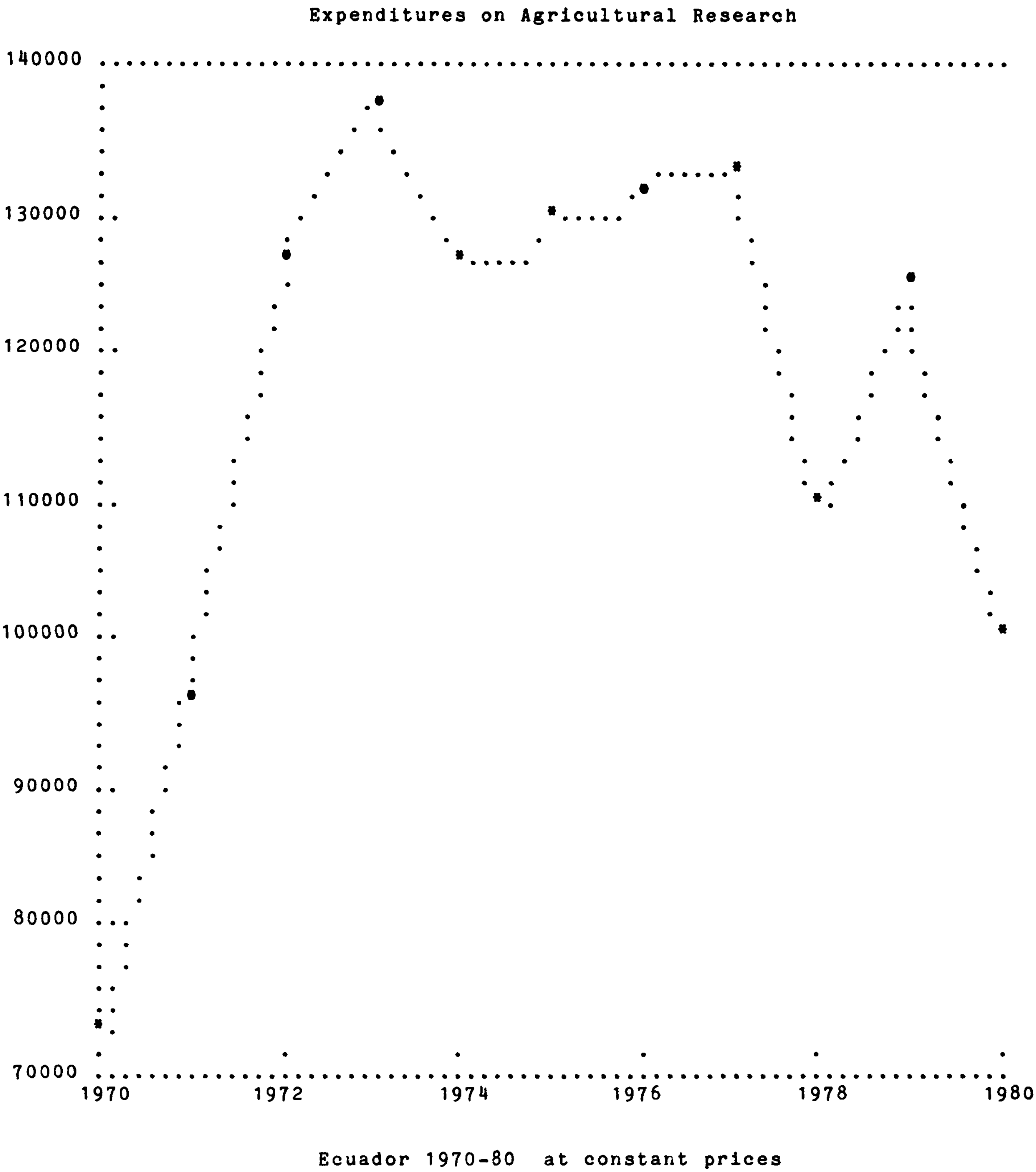

Expenditures on Agricultural Research
140000
130000
120000
110000
100000
90000
80000
70000
1970
1972
1974
1976
1978
1980
Ecuador 1970-80 at constant prices

FIGURE 6.6

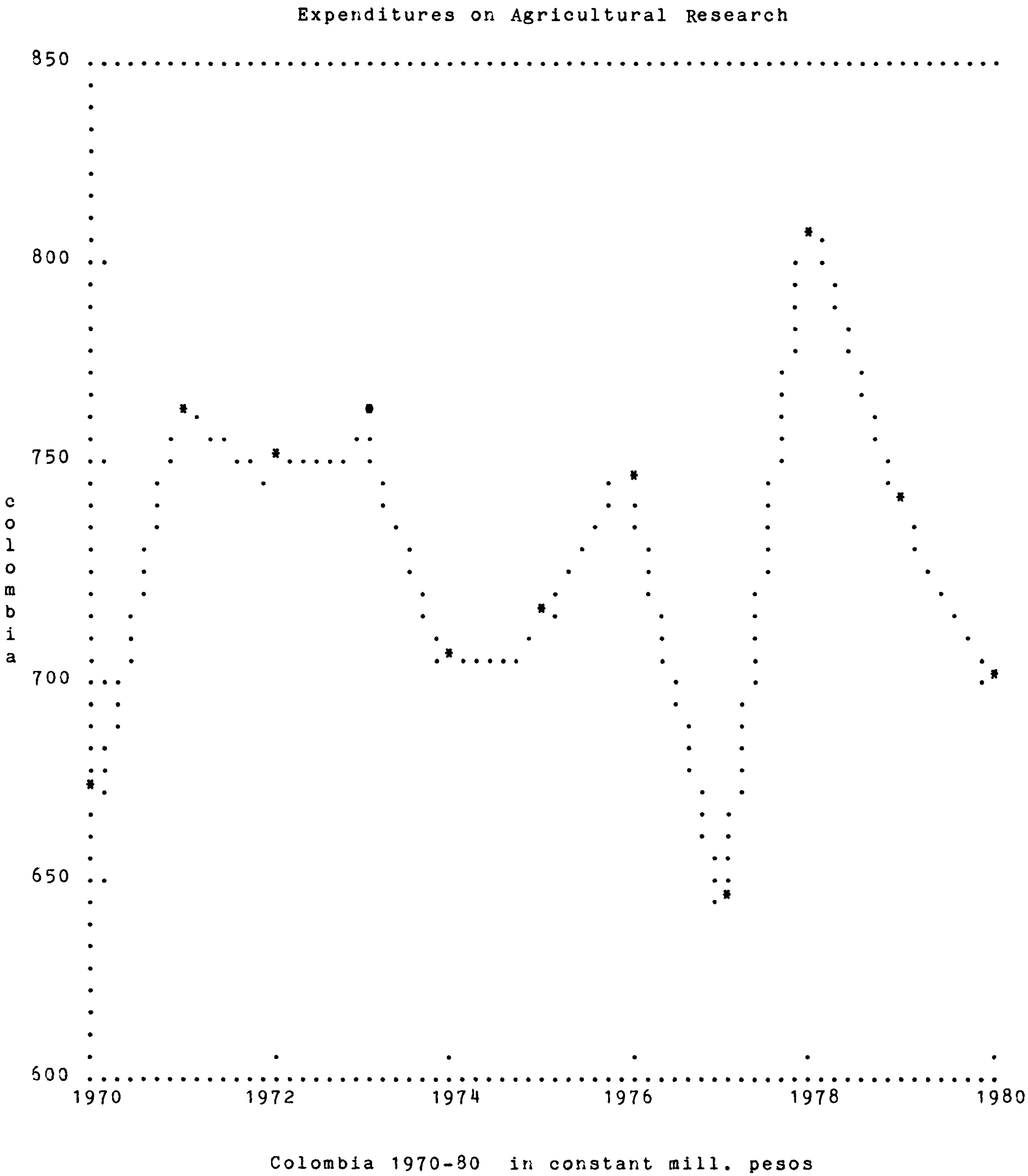

Expenditures on Agricultural Research
850
800
750
700
650
600
Colombia
1970
1972
1974
1976
1978
1980
Colombia 1970-80 in constant mill. pesos

FIGURE 6.7

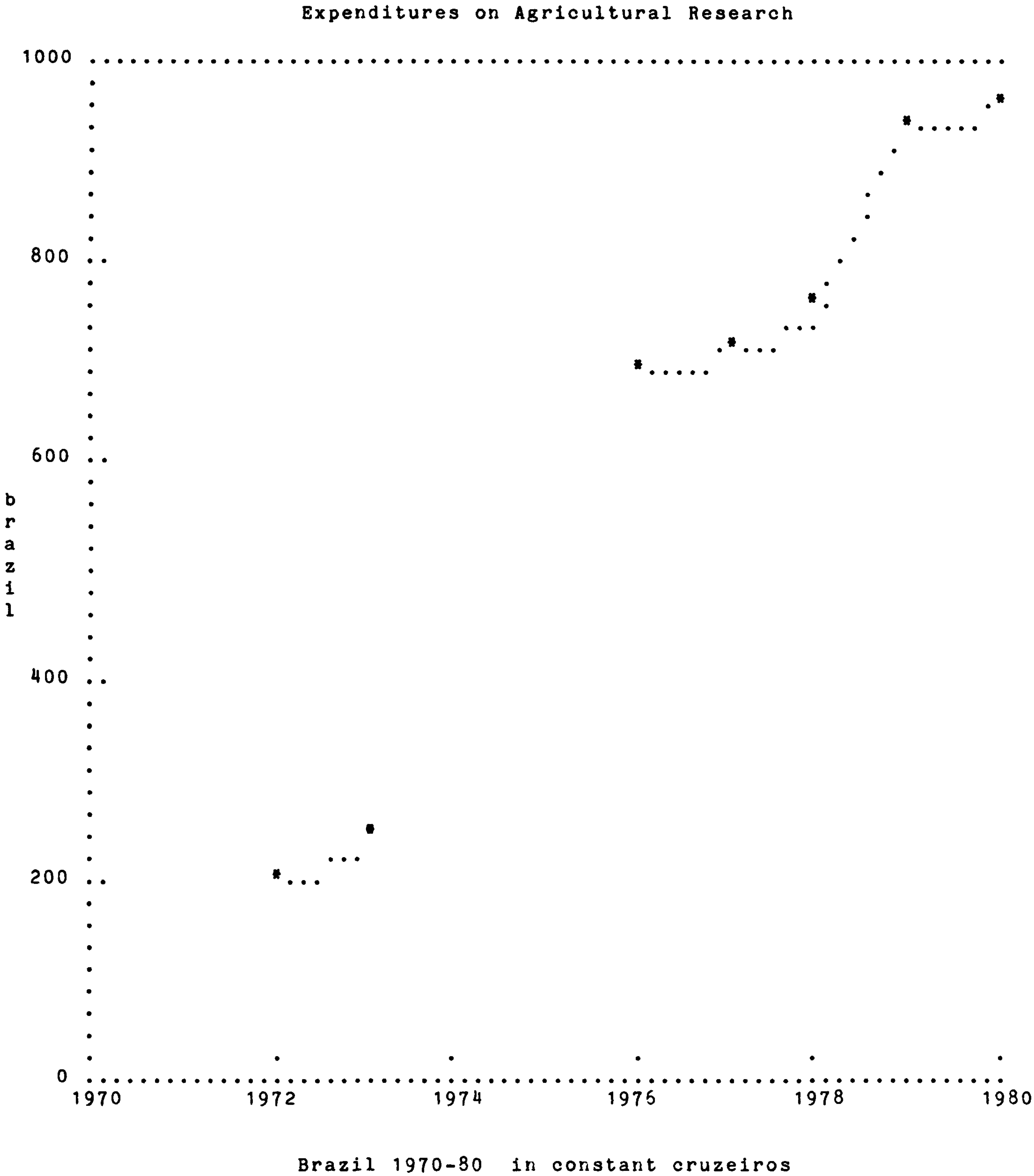

Expenditures on Agricultural Research
1000
800
600
400
200
0
b r a z i l
1970
1972
1974
1976
1978
1980
Brazil 1970-80 in constant cruzeiros

FIGURE 6.8

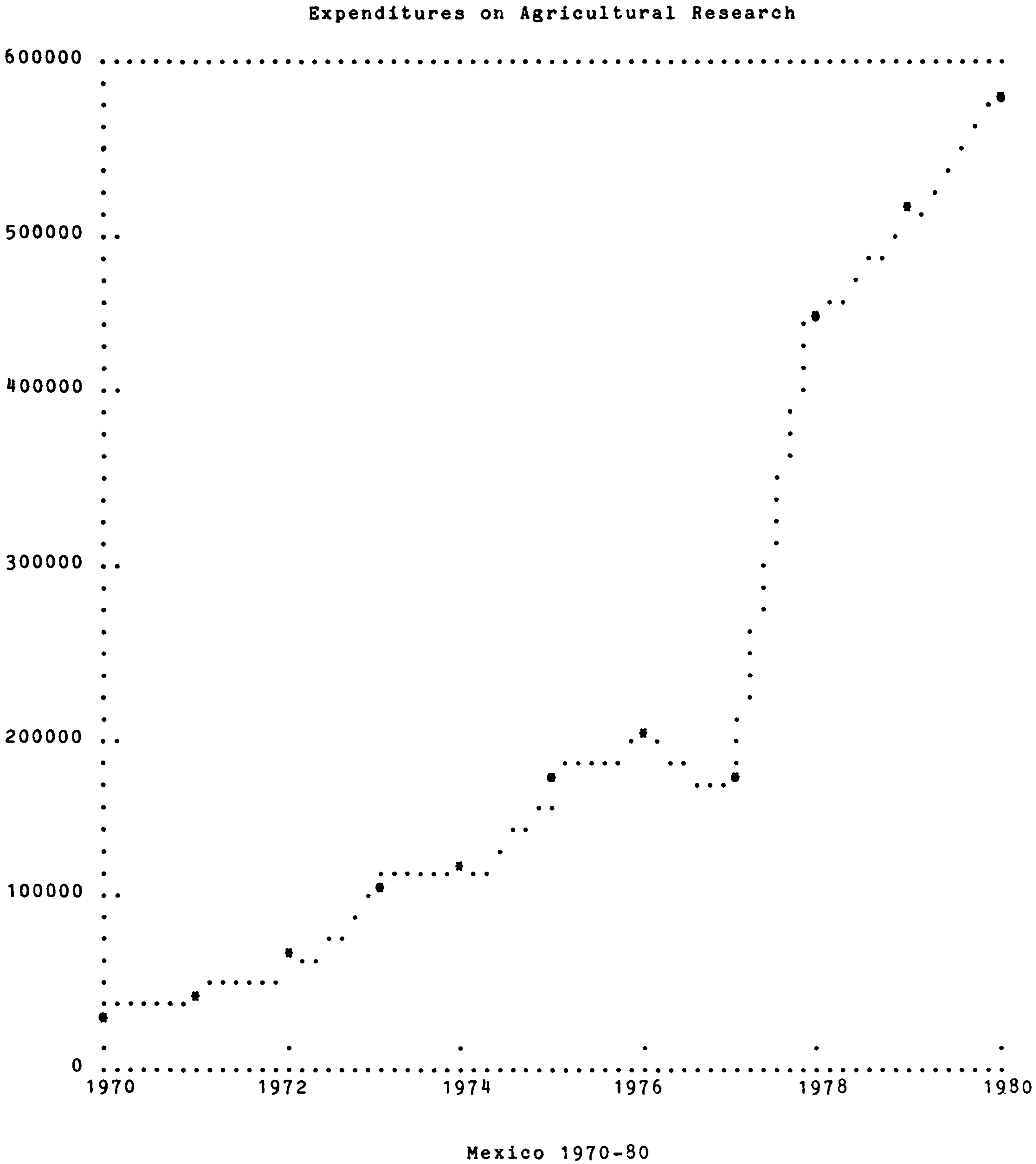
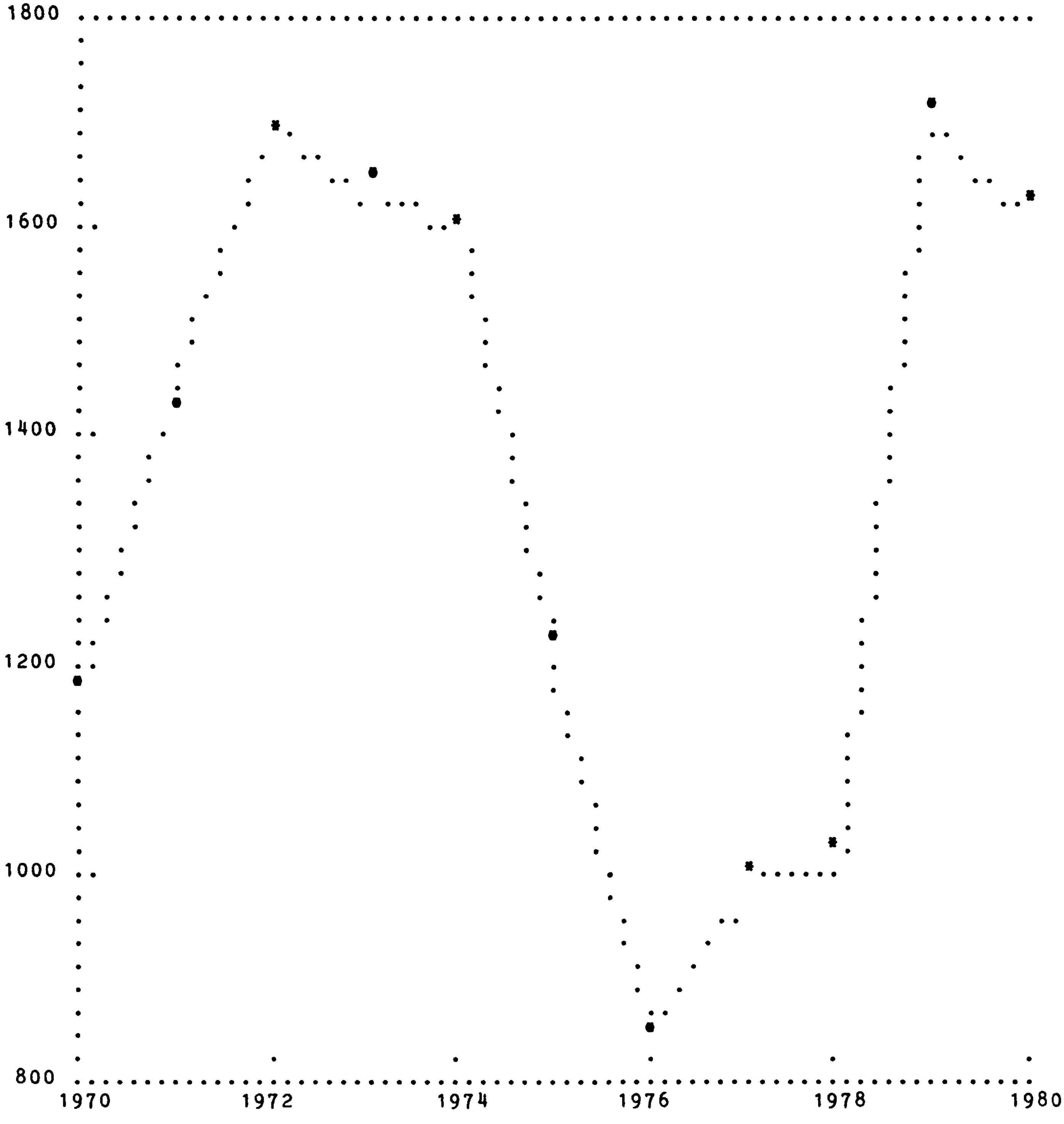

Expenditures on Agricultural Research
600000
500000
400000
300000
200000
100000
0
1970
1972
1974
1976
1978
1980
Mexico 1970-80

FIGURE 6.9

Expenditures on Agricultural Research



Panama 1970-80

FIGURE 6.10

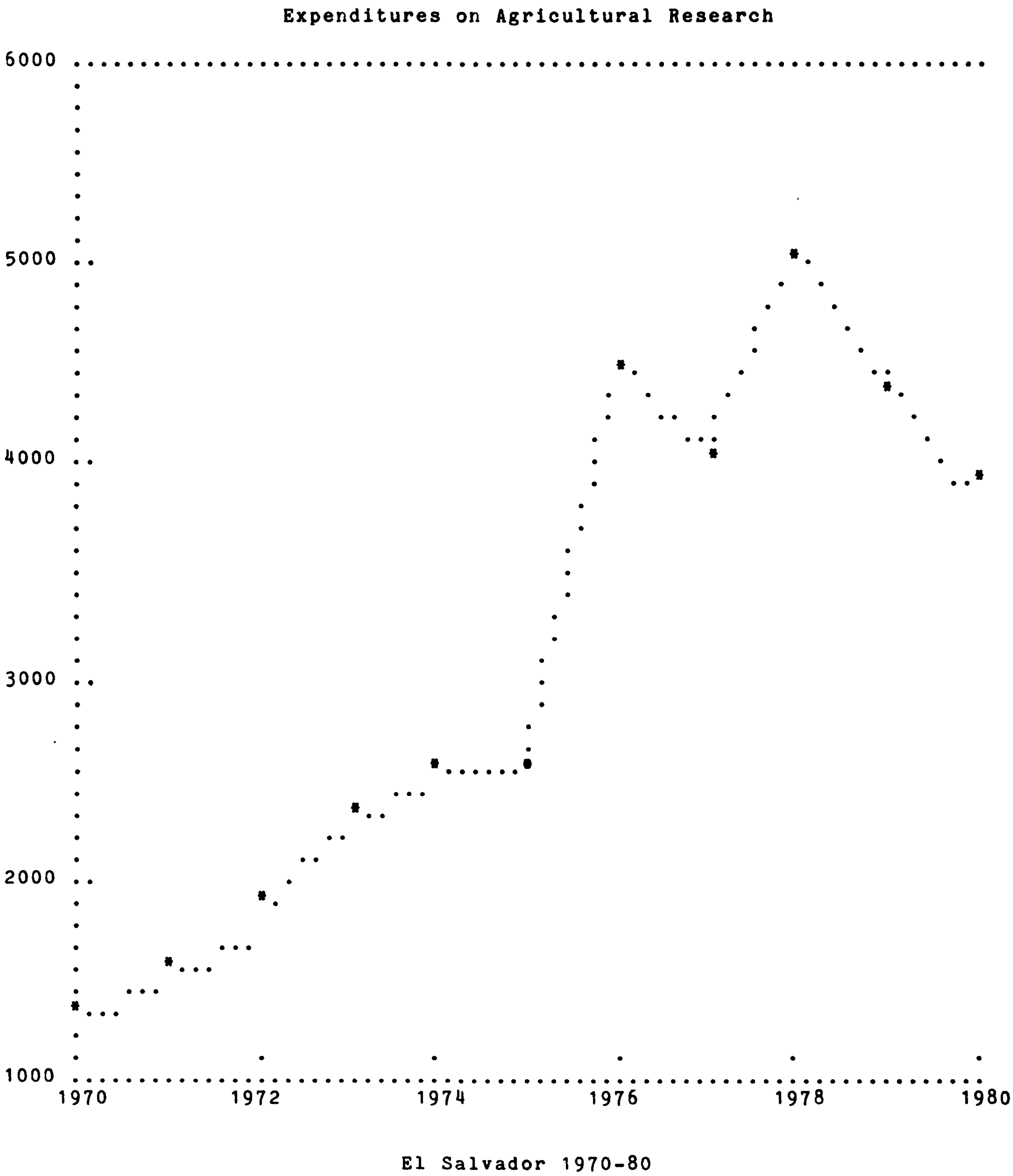
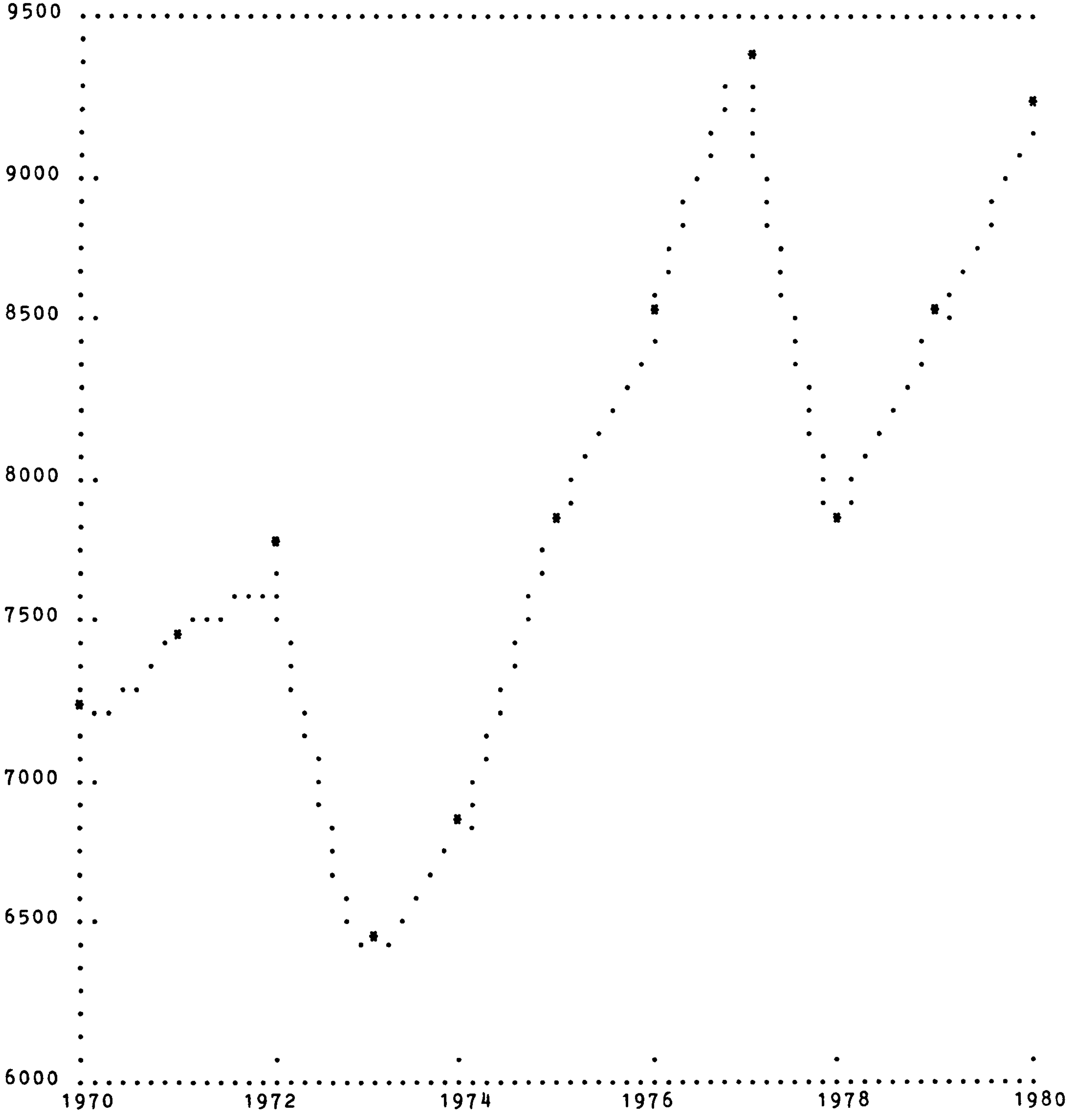

Expenditures on Agricultural Research
6000
5000
4000
3000
2000
1000
1970
1972
1974
1976
1978
1980
El Salvador 1970-80

FIGURE 6.11

Expenditures on Agricultural Research



Nicaragua 1970-80

FIGURE 6.12

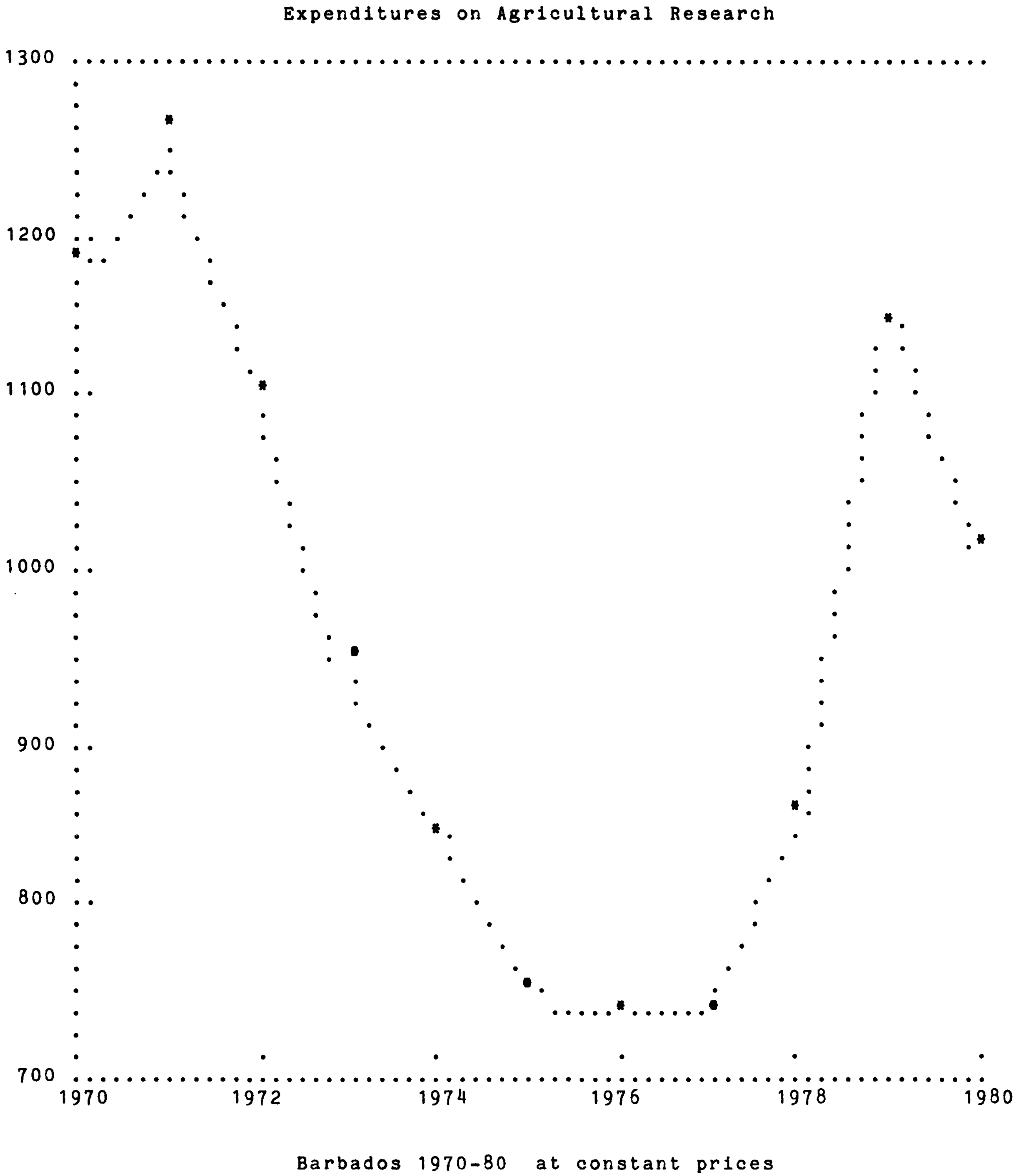
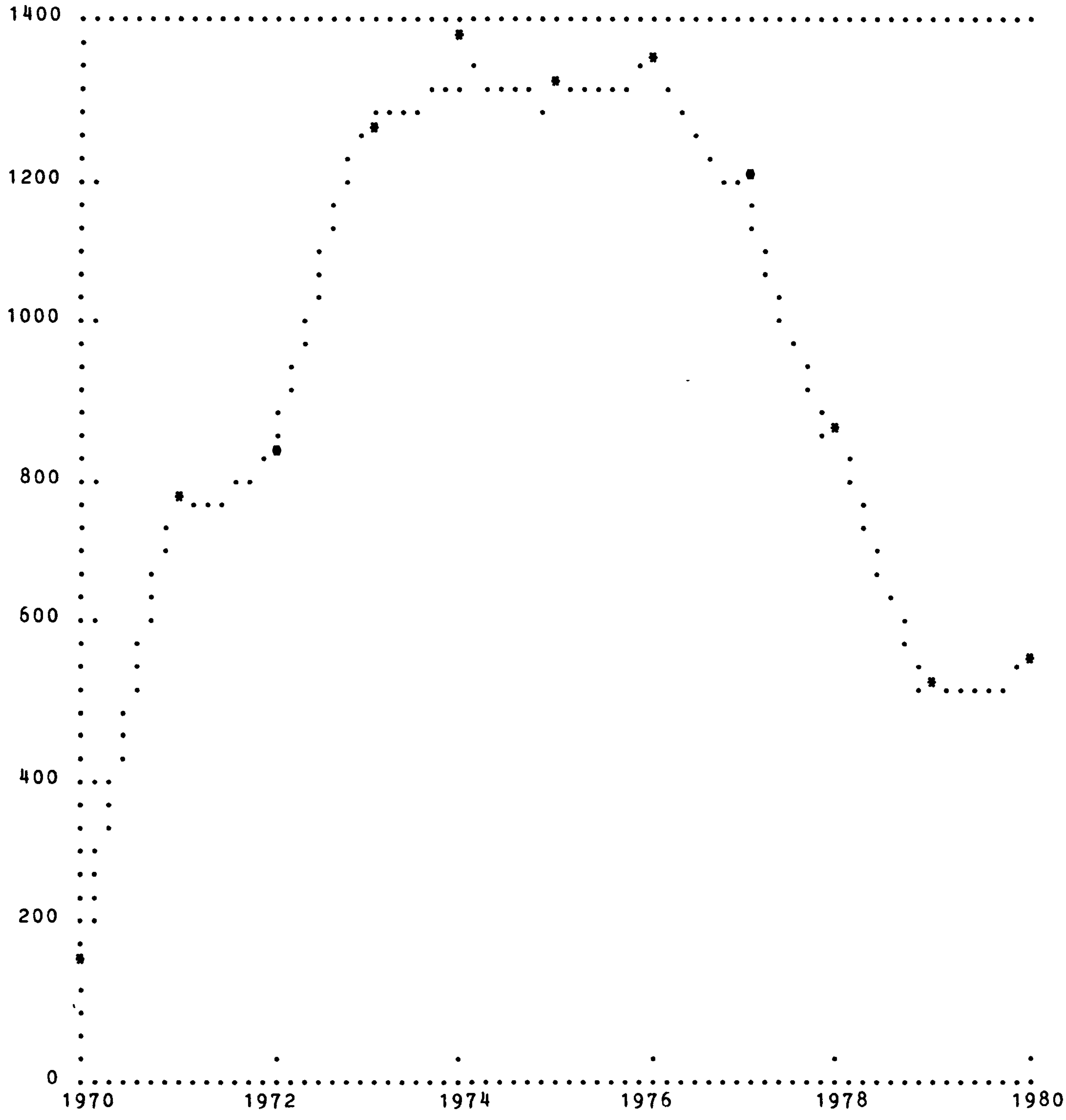

Expenditures on Agricultural Research
1300
1200
1100
1000
900
800
700
1970
1972
1974
1976
1978
1980
Barbados 1970-80 at constant prices

FIGURE 6.13

Expenditures on Agricultural Research



Jamaica 1970-80

FIGURE 6.14

1. Annual allocations from the national budget.
2. International grants and loans from bilateral and multilateral sources.
3. Channeling a fraction of the proceeds from agricultural exports towards agricultural research which provides an alternative to the traditional mechanism of budget appropriation.

The INTA of Argentina, until recently, received budgetary resources from a tax on agricultural exports; and in Brazil (CEPLAC, for research on cacao) and Colombia (FEDERACAFE, for coffee) research on specific commodities is supported by levying a tax on such exports. In Colombia, CENICANA receives financing through a formula based both on sugar exports and on the differential between domestic and foreign sugar prices (Trigo and Pineiro, 1984, p. 77).

The above trend seems to indicate a shift away from institutional allocations from the public sector supported by international grants. As Trigo and Pineiro (1984, p. 80) remark, events point to growing acceptance of the principle, "whoever benefits pays," indicating the diminishing role of the state and of its ability to set priorities and the growing influence of private interests. In Brazil, for instance, a number of research programs for sugarcane are financed by COPERSUCAR (the sugar producers' cooperative) and by ANDA (the association for the use of fertilizer) for cotton, beans, corn, soybeans, and wheat. Similarly, in Ecuador, the research program on pasture underway at INIAP is financed by the Highlands Livestock Association. The trend toward increasing privatization and particularization of research should be of serious concern because:

1. Nothing indicates that there is any inherent mechanism capable of setting national priorities and allocating funds to neglected areas of research; it leaves the market with its distorted signals as the sole mechanism of allocation so that there is a lack of congruence between the research budget and the economic importance of specific products.

2. It might place excessive value on research programs producing "quick" results and lead to an exaggerated reliance on transfers of technologies that some producer groups are able to obtain.

Nevertheless, it points toward new approaches in the attempt to coordinate research at the national level. Recent developments in some Latin American countries should be viewed in this light. In Chile, for instance, the INIA combines two forms of financing: core funds originating in the national budget and international aid which meets the basic operating costs while specific project fundings are covered by contracts and agreements with the interested parties. In Colombia the coordination of research programs is carried out in the framework of a National Agricultural Research Plan which is the tool used to govern the use of available financial resources (Departamento National de Planeacion, 1981). Agricultural Research Councils in which all parties interested in research would be represented (consumers and producers by farm size, region, etc.) have also been proposed in Colombia as mechanisms of coordination. In spite of the increasing role of supplementary sources of funding, the causes of financial instability in agricultural research are to be found mainly in the factors that affect national budgets and international disbursements.

External funding to national research systems is subject to political vagaries and to the financial difficulties experienced by the funding agencies themselves. There are no available data after 1980 when major lending agencies such as the World Bank and its affiliates (IDA in particular) had to reduce their lending program due to the unwillingness of the United States to contribute to an increase in resources. Prior to 1980, external multilateral assistance, mainly from IDB and from the World Bank, was increasing rapidly. Until the mid-1970s, multilateral funding was relatively insignificant (Oram, n.d.). After 1975, when it was estimated to be roughly equal to bilateral funding, it increased three times as fast. This shows that multilateral and bilateral aid often supplement each other. From 1971 to 1980, the IDB granted 13 loans to eight countries in Latin America for a total of $138 billion (U. S.). It also provided nonreimbursable grant aid for technical cooperation to 20 projects in 13 countries. The World Bank granted two research loans totaling $96 million (U. S.) in Latin America (Trigo and Pineiro, 1984, p. 80). Multilateral money has gone mainly to larger countries (Brazil, Colombia, Peru, Bolivia, Ecuador, and Mexico); but Jamaica, Honduras, and Costa Rica among the smaller nations received significant sums. With the increasingly blurred distinction between long-term and short-term development programs in the context of the shared responsibilities of the IMF and the World Bank and the increasingly active role played by those institutions in the economic management of Latin American countries, one can expect that conditionality programs will affect research programs in the future. Nicaragua, for instance, although it has significantly increased its expenditures on research (Figure 6.12) has not received loans from the World Bank since 1981. Bilateral aid, mainly from the United States, Canada, and Western European countries, has been generally smaller than multilateral funds and more evenly distributed among countries (Oram, n.d.). Political motivations affect the granting of fundings more directly than in the case of multilateral aid.

Budgetary appropriations for agricultural research can be expected to fluctuate according to the economic situation in the country. Given that such funds are paid out of general revenues and that they have to compete with other priorities in the budget, the variations in the research budget can be expected to follow the fluctuations observed in the highly unstable economies of Latin America and to be more affected than other budgetary items. Given the "double bias" existing against agricultural research (an urban bias against agriculture and a tendency to underinvest in agricultural research), expenditures on research are probably more affected by the current recession than other budgetary items. Government revenues fluctuate mainly because of variations in tariffs and other international trade taxes (which typically make up from 25 percent to 50 percent of total revenues in LDC) and in domestic taxes on goods and services. The current recession affects both.

In his analysis of the determinants of government expenditures in the agricultural sector, V. Elias (1981, p. 27) found that the sources of variations in the share of government expenditures on agriculture in the GDP depend more on the variations of the share of expenditures on agriculture in agricultural value added than in changes in the share of the agricultural sector in the total GDP. In other words, the major determinant of change in the share of government expenditures on agriculture in national income is the fluctuations in the share of expenditures on agriculture by the government in the total budget. This implies that political decisions concerning the allocation of funds between agriculture and other budgetary items and not economic and structural factors are the most important factors explaining variations in the research budget. In the case of many important countries (Mexico, Brazil, Argentina, and Peru), the repayment of the foreign debt has clearly become, in recent years, the most important priority for the short term. Some of these countries have the oldest research infrastructure and are most affected by budgetary instability in research.

SECTION 7

THE COMMODITY BIAS IN AGRICULTURAL RESEARCH

In this section we turn to the issue of bias of technical change and examine why many commodities of major economic importance are receiving virtually no research attention.

The evidence on the subject is scant. The relationship between research expenditures and the value of commodities is a key question in determining whether resources are allocated correctly and in what direction the bias of technical change has occurred. Unfortunately, data on investment by commodity are limited because of the difficulty in disaggregating data on research expenditures and staff on a commodity basis.

Estimates published by the U. S. National Research Council indicate that cotton, livestock and dairy products, wheat, rice, sugarcane, and maize (in decreasing order of importance) rank among the best-funded agricultural commodities in terms of expenditures in 1976 (Table 7.1). In terms of percentage of the commodity value, though, cotton is ahead with 3.5 percent while all other commodities represent less than 1 percent of the value of the product. Some important staple foods of low-income population groups, such as cassava, receive hardly any attention, while export crops, such as coffee, have been the object of research programs in many tropical countries since the beginning of the century and continue to be abundantly financed. Research in tropical crops and export crops expressed as a percentage of the value of the commodity is in many instances more important than it is for food crops.

Judd, Boyce, and Evenson have presented data on research expenditures by commodity for 1972 through 1979 which also use the frequency of publications on each commodity as an indicator (Table 7.2). Although this indicator has been criticized, mainly on the grounds that it does not account for the geographical origin of the research (many researchers publish in foreign journals) and that basic research (rather than applied research) finds its way into journals and other scientific publications, it provides a rough measure of the emphasis placed on specific commodity programs.

The trend favoring export crops and underfunding staple crops does not seem to vary greatly, except for cotton, comparing the data in Table 7.1 and in Table 7.2. The declining world demand for cotton (competing with synthetic fibers) and the fact that technological innovations may have reached an upper limit may be factors accounting for the slowing down of expenditures in cotton-related research. By contrast, "new" export crops, such as soybeans and vegetables, receive a good deal of research attention.

Research in food crops must be judged on the basis of their importance in national consumption. Some tentative conclusions can be drawn on the basis of the data put together by Oram, et al. relating expenditures and scientific man-years by geoclimatic region to the share of the total population and to the main staple commodities. From these data, it is concluded, very

TABLE 7.1
ESTIMATES OF INTERNATIONAL AND NATIONAL RESEARCH INVESTMENT BY MAJOR COMMODITIES, 1971 CONSTANT DOLLARS

Commodity, in Order of Value of Production	*Value of Commodity in All Developing Nations ($ billions)*	*Estimated Research Investment*		
		International Centers (1976)[a] ($ millions)	*National Centers (1976)[b] ($ millions)*	*National Investment as Proportion of Product Value (percentage)*
1. Rice	Over 13	7.9	34.7	0.26[d]
2. Wheat	5–6	3.8	35.9	0.65
3. Sugar cane	5–6	0	30.2	0.50
4. Cassava	5–6	1.9	4.0	0.07
5. Cattle	5–6	7.9	54.8	0.88
6. Maize	3–4	4.1	29.6	0.75
7. Coconuts	3–4	0	2.0	0.06
8. Sweet potatoes	3–4	0.6[c]	3.4	0.09
9. Coffee	2	0	8.5	0.40
10. Grapes	2	0	6.9	0.35
11. Sorghum	1–1½	1.2	12.2	0.77
12. Barley	1–1½	0.5	9.4	0.62
13. Groundnuts	1–1½	0.5	4.0	0.13
14. Cotton	1–1½	0	60.1	3.50
15. Dry beans	1–1½	1.5	4.0	0.25
16. Chick peas	1–1½	1.2	3.0	0.18
17. Chilies and spices	1–1½	0	4.0	0.25
18. Olives	1–1½	0	5.0	0.33
19. Grain legumes	1	1.6	(25.3)	(2.00)
20. Potatoes (white)	1	2.0[c]	8.2	0.68

SOURCE: Reproduced from *Supporting Papers, World Food and Nutrition Study, Vol. 5* (1977), 51, by permission of the National Academy Press, Washington, D.C.

[a]Centers and programs sponsored by the Consultative Group on International Agricultural Research.

[b]Rough estimate derived by allocating total research expenditures by country according to the proportion of standardiz .: publications. Standardized publications are converted into constant scientist-years.

[c]Additional funds also were spent on these crops at the Asian Vegetable and Research Development Center.

[d]The proportion varied sharply by type of rice: shallow water, 0.40; upland rainfed, 0.16; intermediate, 0.16; and deep water, 0.05. The international center investment was principally in the first two types.

TABLE 7.2

Research as a Percent of the Value of Product, by Commodity, Average 1972-79 Period, 26 Countries

COMMODITY	REGION Africa	Asia	Latin America	All Countries	International Centers
Wheat	1.30	.32	1.04	.51	.02
Rice	1.05	.21	.41	.25	.02
Maize	.44	.21	.18	.23	.03
Cotton	.23	.17	.23	.21	-
Sugar	1.06	.13	.48	.27	-
Soybeans	23.59	2.33	.68	1.06	-
Cassava	.09	.06	.19	.11	.02
Field Beans	1.65	.08	.60	.32	.04
Citrus	.88	.51	.57	.52	-
Cocoa	2.75	14.17	1.57	1.69	-
Potatoes	.21	.19	.43	.29	.08
Sweet Potatoes	.06	.08	.19	.07	-
Vegetables	1.56	.41	1.13	.73	-
Bananas	.27	.20	.64	.27	-
Coffee	3.12	1.25	.92	1.18	-
Groundnut	.57	.12	.60	.25	.005
Coconut	.07	.03	.10	.04	-
Beef	1.82	.65	.67	1.36	.02
Pork	2.56	.39	.60	1.25	.02
Poultry	1.99	.32	1.12	1.64	-
Other Livestock	1.81	.89	.42	.71	-

Sources: M. Ann Judd, James K. Boyce, and Robert E. Evenson, "Investing in Agricultural Supply" (Discussion Paper No. 442, Yale University, Economic Growth Center, 1983); and USDA, Indices of Agricultural Production, various issues.

tentatively, that "wheat and perhaps barley, millet, sorghum, and groundnuts receive a fair share of research resources in relation to their importance as staple food and that rice, starchy crops, and pulses probably do not. For maize, the shares in South America are relatively high and those for Central America and Africa relatively low. Ruminant livestock research in the Middle East, semiarid tropics, and South America may be adequately funded" (Oram, et al., 1979, pp. 129-130 and Table 44).

There is also some evidence indicating a positive correlation on a commodity basis between the expenditures of IARCs and the national expenditures for wheat, maize, white potatoes, sweet potatoes, rice, and sorghum. Both types of expenditures are less strongly correlated in the case of groundnuts, beans, millet, and cassava (see CGIAR Impact Study Newsletter). The determinants of investment of specific crops have never been clearly elucidated. They fall into two categories: variables affecting the demand for research and variables affecting the supply of research.

The mechanisms through which demand for technical innovations is articulated tend to exclude peasants and other groups unable to voice their demand at the level of the state. This may explain why minimal research attention relative to the importance of the crops as a source of nutrients is paid to some crops. Beans are a case in point. This crop traditionally has been a small farm sector activity in Latin America. Beans represent an important source of protein for many Latin Americans, and there is a great potential for increasing yields of beans through improved seeds and farming practices, but the social context in which they are grown limits the possibilities of development of new technology. Beans are almost exclusively a crop of the small farm sector grown mainly for local market consumption. Because they are considered a high-risk crop, they often receive less cultivation and care than do other, surer market crops such as maize and coffee. Farmers planting beans tend to be resource poor and do not have access to credit for fertilizer and chemical control agents. In every country except Venezuela, the majority of farmers is not using improved seed and replants traditional seeds from one harvest to the next.

The beans program of CIAT is relatively new, and many countries have not yet released varieties developed with material developed by that organization because of the general difficulty of matching a particular type of beans with the required resistance characteristics for a particular environment. Climatic conditions vary considerably, and the conditions and types of diseases found at CIAT are not found in many countries.

Most countries of Latin America are currently importing beans to meet their needs. Because many countries have set a goal of becoming self-sufficient in beans, there is increasing pressure to abandon the small farm sector and focus attention on large farms where beans could be produced as a single crop (intercropping of beans is a widespread practice in most countries) with full mechanization. This policy is in effect in Costa Rica; and there is increasing interest in mechanization in Honduras, Guatemala, Panama, Venezuela, Paraguay, Argentina, and Brazil (Iowa State University, p. 240).

Being unable to articulate their atomistic demand through public channels, growers of beans who are marginal producers are losing control over this crop which would require considerable investment in on-farm research, farming practices, and development of disease-resistant varieties.

The supply of technological innovations for some commodities has often been limited by the fact that research has a relatively low productivity in early years. As Evenson (1978) points out, it may take several years to collect and classify germ plasm and to create physiological and pathological studies to develop the basis for a productive breeding program.

The time lag between investment and actual payoff for neglected commodities will be longer than for those crops, such as rice, on which research has been in progress for many years. It is not necessarily true that the internal rate of return to investment in research on neglected crops in the early years is lower than it is on the more established crops (Evenson, p. 231). The longer gestation period does provide an explanation for the observed tendency to invest relatively little in the neglected crops such as root crops. This, combined with the fact that the state and the private sector tend to value short-term gains most highly (i.e., that their discount rate is high), explains why there are few incentives to invest heavily in programs that have uncertain payoffs.

Another element of explanation is provided by the nature of the commodities neglected by research. Many such crops, such as cassava, tend to be grown for home consumption of small farmers, are not consumed widely in urban areas, and have no known industrial use (except at an experimental level). Some countries, such as Thailand, where cassava ranks fifth in terms of investment in research, export that crop (Suthad Setboonsarng, personal communication), but these are isolated cases.

SECTION 8

PATHS OF TECHNOLOGICAL INNOVATION

It is useful to look at different paths through which technological innovations have occurred in order to identify the conditions that have been associated with success and to learn from them. There are basically two broad paths that can be contrasted. The first is when the private sector is the generator of technology. This includes producer associations organizing private research institutes with a specialized commodity focus. Examples are the Sugarcane Growers Association and the Rice Growers Association in Colombia which have organized private research institutes to solve particular problems through research and manage international transfers of technology. Strong producer organizations of this type tend to emerge when production of a particular commodity occurs in specialized regions with a high degree of homogeneity of production conditions and farm types, most likely medium-sized, owner-operated commercial farms.

A second private initiative is when the agribusiness sector--in particular, seed, chemical, and machinery companies--engages in research and international transfers. This has been the dominant path in farm machinery where most innovations have originated in small independent firms and where international transfers require minimal, if any, adaptation. This path has also been important in the production of new seed varieties, and the recent developments in the patentability of biogenetic inventions should further stimulate private research activity in this field. The result will be enhanced competition between public and private sectors, a desirable feature to stimulate the articulation of the public sector with its farm sector clientele. This occurs because private self-interest firms tend to have a better perception of market demands and more institutional flexibility in organizing research, including organizing cooperative ventures with public research institutions. They, however, tend to confine their activities to low-risk, short-run, high payoff technological advances.

We concentrate here on the paths of technological innovations which occur through the public sector. Following the discussion in Section 2, we distinguish three cases.

8.1. State Acting From Above

A good example of a successful technological path that originated in the state acting from above is the development of new rice varieties in Colombia. It also shows how a state initiative was coordinated with research by international centers (CIAT) and commodity organizations (FEDEARROZ)

During the 1950s, the production of food grains in Colombia was rapidly falling behind domestic demand. This occurred as a result of a program of import substitution industrialization that induced rapid urbanization and large income effects in consumption. Excess demand for food was pushing prices upward and adding to inflationary pressures. In addition, it forced the government to divert part of foreign exchange earnings away from essential imports of capital and intermediate goods for industry toward food imports. In the mid-1950s, 10 percent of the domestic consumption of rice was imported. The Ministry of Agriculture was thus drawn into a campaign to induce import substitution in rice through the promotion of technological change. Having witnessed the success of the public research system in the United States, it was obvious that the state had to play an active role in stimulating technological change. The institutional formula was going to be uniquely original. This focus on rice technology was triggered by a virus infestation transmitted by insects that destroyed nearly half of the rice acreage in 1956 and 1957. Since the use of insecticides was deemed impossible due to the wide range of the insect vector of the disease, the search for resistant varieties appeared as the only solution. This led to the organization of a national rice program (PNA) in 1957 under the direction of the Agricultural Research Bureau (DIA). In 1962, the DIA was reorganized to create the Institute Colombiano Agropecuario (ICA) under the direction of the Ministry of Agriculture, and in 1967 the International Center for Tropical Agriculture (CIAT) was established. This led to a reorganization of the national rice program as a cooperative tripartite arrangement between ICA, CIAT, and the National Federal of Rice Growers (FEDEARROZ). The latter is a powerful commodity association that had been created in 1947 as a lobby to oppose the unfavorable rice policies promoted by the government. This federation rapidly assumed important functions in the technical assistance to rice growers and was subsidized by the government for as long as Colombia was importing rice. In 1963, a law was passed that levied a duty on all rice milled to provide a development fund to FEDEARROZ.

The Colombian rice program was thus initiated by the state in response to economic problems of national significance. It was organized as a triangular arrangement between (1) CIAT, charged with the responsibility of importing dwarf varieties from IRRI and of multiplying them for the region; (2) ICA, engaged in the local adaptation of these varieties and then crossing them with domestic varieties to insure grain characteristics compatible with national tastes (long grains as opposed to the short grains imported from Asia); and (3) the Federation which organized local trials and the transfer of technology to local farmers. This triangular arrangement proved to be highly flexible and effective in successfully unleasing a technological revolution in rice production in Colombia.

As Scobie and Posada and Balcazar et al. have shown, the impact of technological change was dramatic. Between 1967 and 1978, the area planted increased by 50 percent and yields doubled, transforming Colombia into a rice exporting country. Real prices declined by 40 percent allowing poor landless and urban consumers to become the main beneficiaries. Scobie and Posada thus conclude that "as rice is disproportionately consumed by the lower income groups who make limited tax contributions, the net benefits of the research program were strongly biased toward them in both absolute and relative terms. While the lower 50 percent of Colombian households received about 15 percent of household income, they captured nearly 70 percent of the net benefits of the research program" (p. 383). The extent of the proconsumer bias was, however, closely monitored by government intervention in price formation. Prices were allowed to fall but not sufficiently rapidly as to transfer away from producers all the gains from technological change. This monitoring by the state of the price-cost relation allowed prices to fall by only 28 percent between 1965-1969 and 1970-1974, while costs fell by 30 percent. This relation illustrates the importance for the state of coordinating technological and economic policies for successful technological sequences to result.

The rice research program contained two other sources of bias. One was a factor bias toward a deepening of the capital-labor ratio. The new technologies implied a sharp increase in the use of fertilizers, herbicides, fungicides, and pesticides. At the same time, labor requirements per ton of rice produced fell by 50 percent. The aggregate result for Colombia was a fall in labor use from 15.2 million person/days in 1965 to 13.2 million person/days in 1978 in spite of large increases in area planted and output levels (Pineiro and Trigo, p. 141).

Another bias is among production systems. Since technological change was motivated by a production crisis (and not, for example, an income crisis among small farmers), the research strategy naturally focused on "building on the best," i.e., concentrating on the production conditions where the greatest yield increases could be obtained per unit of research cost. This led to focus on irrigated rice production--a production system for which significant technological advances were available in Asia. As the new varieties diffused in the medium/large irrigated farms, output increases forced rice prices downward. The result was detrimental to small dryland rice producers for whom no new cost-reducing technological options were available. Their share in national output thus fell from 50 percent in 1966 to 10 percent in 1974.

Information is very incomplete, but it seems that dryland producers shifted to the next best alternative as rice prices declined. The assumption of perfect substitution between upland rice and irrigated rice used in the original study by Scobie et al. may have been too strong. Small upland farmers on the north coast produce different qualities of rice for own or local market consumption. There is a certain degree of substitutability with the high-quality rice from irrigated regions over 1500 km away in the Tolima Valley but not perfect substitutability (G. Scobie, personal communication).

Whatever the case may be, the Colombian rice program is an excellent example of a technological path induced by the state acting from above to deal through the instrument of technology with a problem of national significance. It shows the importance of coordinating international, public, and private organizations in managing the process of transfer, research, adaptation, trial, and diffusion. It also shows the key role of coordinating technological with economic policies. Equity issues in agriculture could, however, have been minimized had the participation of rice growers to decision making not been confined to the medium/large producers represented by FEDEARROZ. If no easy technological option was available for upland rice farmers, compensation could at least have been paid under the form of research programs for the next best alternative available to them.

8.2. State Activated From Below

Agricultural technology is, to a large extent, an imperfect public good--that is, a good the benefits from which no individual can be excluded but where the benefits vary sharply across individuals by region, crops, farm types, sources of income, income levels, and consumption patterns. The result is that different groups in civil society have markedly different demands for technological innovations and that different groups have a differential ability to induce a public sector response to their demands. The organization of the public sector also has an impact on its response to interest group demands for technology, in particular the degree of decentralization of research institutions, their degree of autonomy in the management of research budgets, and the existence or not of formal mechanisms of consultation with interest groups.

The pattern of technological change in the production of sugarcane in Colombia is a good example of the state being activated from below in response to a strong commodity association (Pineiro *et al*.). Sugarcane production in Colombia is regionally concentrated in the Cauca Valley. Over time, a few large sugar mills have dominated the industry. During the 1940s and 1950s, these mills expanded output by horizontal expansion and managed independently an effort to improve the technology of sugarcane production. The limited size of the domestic market was an effective bottleneck to output growth, and the mills were competing for market shares with technology as one instrument of competition.

Sugar is the single most important form of calories in the Colombian diet, especially for low-income consumers; but sugar production for industrial use and, especially, for export was limited before 1960.

Sugar Disappearance, Colombia, 1960-1977 (Thousands of Tons)

Year	Direct consumption	Industrial use	Exports
1960	180.6	107.3	0.1
1961	205.8	115.0	48.7
1962	245.2	124.1	65.5
1963	212.9	127.8	40.8
1964	227.1	140.4	25.7
1965	250.2	139.3	94.6
1966	259.0	150.7	113.9
1967	252.7	140.7	200.3
1968	292.2	149.9	238.7
1969	312.3	171.7	171.3
1970	339.3	164.5	129.4
1971	357.2	180.8	165.2
1972	387.1	193.1	202.8
1973	414.5	213.1	142.5
1974	437.3	223.7	128.6
1975	457.6	229.5	197.8
1976	489.7	246.0	100.2
1977	509.0	254.0	59.1

Source: Pineiro *et al*., p. 92.

With the Cuban Revolution in 1959 and the consequent possibility of exporting a fixed quota to the United States under highly favorable price conditions, the Colombian sugar industry entered into a boom period. This induced the sugar mills to cooperate in the organization of a cartel that would regulate the distribution of export quotas in the highly concentrated industry and block entry of new competitors. Thus was created ASCOCAÑA, the Association of Colombian Sugarcane Producers. With excellent ecological conditions for sugarcane production and the possibility of incorporating additional land in production throughout the 1960s, the main focus of the Association was not technological improvement but the promotion and regulation of exports, the negotiation of internal prices fixed by the state, and wage bargaining with the local labor unions. As can be expected of a national cartel with no international competitive pressures, the Association thus concentrated its power on the price, market, and income conditions of production and not on the modernization of production itself.

By 1970, the conditions of production changed sufficiently to force the association to deal more squarely with technological issues. Horizontal expansion became severely limited, labor shortages began to occur among cane cutters, and reinforcement of the union movement led to significant increases in labor costs. The public research agency (ICA in Palmira) had no particular interest in developing technological programs to increase exports. At the same time, Colombia was promoting a new institutional model for the generation and diffusion of technological change based on a shared responsibility between the public and private sector for the commercial sectors of agriculture, while the public sector only retained full responsibility for rural development activities directed at the traditional and marginal sectors. For sugarcane, this led in 1977 to the organization of a National Sugar Commission integrated by representatives of key public sector institutions (Ministry of Agriculture, price-fixing agency, agricultural bank, etc.) and representatives of ASCOCAÑA. The Commission was charged with the responsibility of recommending to the national government policies for the production, marketing, export, credit, and development of the sugar sector. The Commission was endowed by law with a national fund for sugarcane based on a tax levied on sugar prices. This fund was used to create a specialized regional research institute, CENICAÑA (Colombian Research Center for Sugarcane), managed jointly by public sector (ICA) and private sector (ASCOCAÑA) representatives. Strongly organized private sector interests thus mobilized the state into organizing a specialized agency with very broad policy and technological mandates over which they had a substantial degree of control and which was financed by public revenues.

The institutional model that characterizes research on sugarcane in Colombia is thus one that evolved from a central role of the state acting with relative autonomy (ICA) to one where the state was increasingly captured from below by powerfully organized interest groups. This occurred in the context of both an increasing weakening of the state due to fiscal crises and neoliberal philosophies and a strengthening of the agribusiness sector, a process which characterized most of Latin America in the 1970s and which is reinforced by the crisis of debt and austerity policies in the 1980s. If state programs for the underrepresented sectors of civil society are insufficient to compensate for their exclusion from agribusiness interests, the bias in research in favor of the commercial sector will likely be increased.

CENICAÑA actively engaged in a broad program of technological research. It assisted in the definition and diffusion of a number of innovations such as seed control, introduction of new varieties, biological control, and cultural practices. This resulted in a 35 percent increase in yields between 1970 and 1978. Technological change also allowed horizontal expansion by making productive lands of inferior quality. The technologies introduced were capital intensive and led to an increase in the capital/labor ratio greater than justified by relative factor price changes. These technological improvements allowed the sugar mills to increase their share of the total product at the expense of both labor and independent producers of sugarcane. They also allowed them to consolidate the sugarcane cartel and create barriers to the entry of potential competitors.

We see, in conclusion, that technological change in sugarcane production in Colombia occurred as a result of strong initiatives of producer organizations. They were able to activate the state from below into creating a mixed research program over which they retained strong control. This path of technological change is, of course, most effective for commodities with powerful lobbies and relatively little importance for the macroeconomy. It, consequently, tends to be biased in favor of agroindustrial and agroexport crops and to neglect the problems of the more disorganized sectors in agriculture, typically small farmers and farm workers.

8.3. State Activated From Within

The state is internally divided, and agents of the state belonging to particular groups of bureaucrats or politicians or acting individually influence the course of state actions in directions that do not necessarily correspond either to the logic of the state acting from above or to the logic of the state activated from below by pressure groups in civil society. This is particularly evident in the case of research on agricultural technology where perception of the potential gains from technological innovations (the expected payoffs matrix) is often difficult to achieve for both the state at large and civil society, while scientists and research administrators can more easily do this. The result is that narrow control by outside interests over the course of research is difficult to achieve and that scientists and research administrators generally have a considerable degree of initiative in establishing research priorities. In their study of the U. S. Agricultural Experiment Station system, Kaldor and Paulsen thus conclude that "the internal decision-makers (station directors, department chairpersons, and scientists) decide the program and the external decision-makers (the U. S. Congress and state legislatures) appraise the program and decide how much support to give it" (p. 10). Similarly, in a study of how research projects are selected, Ramsdale and Paulsen find that, because scientists are the initiators of proposals, they have the greatest short-run influence on the choice of topics. It was found that the strongest source of signals for them were departmental colleagues, journals, and conventions--not interest groups--and only secondarily sources of funding.

In the study of the performance of public agricultural research in Argentina (INTA), Colombia (ICA), and Peru (UNA), Pineiro and Trigo found that the main source of research inefficiency was pervasive "social disarticulation," i.e., the lack of connection between the demand for new technology and the research effort. What they found is that scientists tend to be motivated by peer recognition, especially in international scientific circles, and by the challenge of the research effort more than by a demand originating in the sector or at the level of the state. The cases of rice and sugar are, by contrast, cases where social articulation was effective in demand guiding the research effort.

An example where research scientists had an important role in initiating a research program is the case of the mechanization of tomato harvesting in California. Mechanization came about as a response to the end of the Bracero Program in 1964 (through which Mexican farm workers had been imported seasonally into the United States) and successful unionization of farm workers that pushed wages upward dramatically. The role of the University of California, a public University, was essential due to the difficulty of mechanizing the harvest of tomatoes that required simultaneously biological and mechanical research. Also essential was the continued interaction within public and private sectors throughout the process of technological development.

The initial momentum was provided by specific scientists of the University of California who perceived during World War II the recurrence of future labor shortages. They initiated the search for tomatoes with properties suitable for machine harvesting as well as the design of a mechanical harvester. The first tomato varieties adapted to mechanical harvesting were released in the late 1940s, and it is only in 1956 that the California Tomato Growers Association started to fund research at the University of California. The first harvesters were built in 1958 by Michigan State University, the University of Florida, and Purdue University. In 1959, the University of California patented a harvester and licensed a private agricultural machinery company to start large-scale production.

With some of its scientists having taken the lead, the University of California's role as an integral part of the process of technological innovation was crucial. The University provided practically all the scientific research capability including the new tomatoes that were the necessary prerequisites to success of the overall strategy. It was a focal point through which all segments of the industry could interact--hosting seminars and demonstrations. Finally, the University was involved in all phases of the development and diffusion of the harvester system and the necessary associated cultural practices.

All segments of the California canning tomato industry were also involved. For example, some large and progressive growers were important in testing the new machines and new cultural practices and in speaking in favor of them at growers' meetings. The Tomato Growers Association, a group of canners, and the Blackwelder Manufacturing Company all donated funds to the University in support of its work. Canners would run "peelability" and "solids" tests for seed companies on new strains, and some seed companies worked with the University to select new tomato strains and were among the first to adopt the harvester. University engineers, Blackwelder Manufacturing Company, and some large growers all worked together on the machine. The canners' decision to accept machine-harvested tomatoes was also essential. This decision implied conversion of tomato-receiving facilities to handle bulk containers, expanded washing and sorting operations, greater expenses for quality control, different hours of operation, and many other costly adaptations. Since almost all tomatoes were grown under contract and since every contract specified the type of seed to be used and quality limitations, adoption could not have occurred without the consent of processing firms. Once the processors decided to switch to machine-harvested tomatoes, adoption of the harvester was accomplished quickly.

The percent of the crop harvested by machine increased from 3.5 percent in 1964 to 80 percent three years later and reached 100 percent in 1970. The shift from hand- to machine-harvested methods implied drastic changes in the system of production--with seeds, cultivation, machinery, labor requirements, chemical inputs, handling, processing, product mix, and marketing all deeply affected.

The cost savings to growers who adopted the technology were significant (Schmitz and Seckler). These savings arose largely because the harvester was a once-through-the-field operation, whereas hand harvesting required three to six passes through the field and because the female machine sorters, who replaced the male field pickers, were paid 15 to 25 percent less per hour.

The innovation was, of course, seriously biased toward large farms and against labor. Due to economies of scale in machinery, smaller growers were rapidly eliminated and production became concentrated in the large farms. In 1964, there were 1,072 farmers with tomatoes with an average area of 132 acres; by 1975, there were 845 growers left with an average area of 354 acres. While male hand-picking crews were displaced by the machines, new jobs were created in sorting (unskilled women) and for drivers and mechanics as well as in manufacturing and processing (skilled labor). There was thus a simultaneous process of deskilling and skilling of the labor force involved, increasing the polarization of wages among farm workers.

This path of technological development where particular members of the state play an active promotional role shows the importance of effectively linking these institutions with the potential clientele for technological innovations. The objective of this linkage is to overcome three tendencies in the process of technological innovations. One is the difficulty for civil society of perceiving the expected payoffs from research which places the scientist in the position of having to create the demand for his future work. This requires the existence of institutional mechanisms that allow scientists and potential beneficiaries to maintain a constant dialogue on the potential gains of technological innovations. The second is the tendency for scientists to seek peer recognition through scientific achievements instead of seeking maximum impact on civil society through technological advances. This also requires carefully designing the rules of the game in research institutions to overcome the resulting tendency of disarticulation between research effort and latent demand. And the third is the tendency for scientists to link up with the groups in civil society with the greatest financing capacity, typically the more aggressive producer associations. The result is biases against the weaker sections, typically small farmers and farm labor.

SECTION 9

CONCLUSIONS AND IMPLICATIONS FOR THE INTERNATIONAL CENTERS

The thrust of this paper has been to show that there has been a remarkable increase in the size of the research effort on agricultural technology in the third world, pushed by the need to substitute yield increase for area expansion as the dominant source of output growth. Yet, this effort remains generally underfunded relative to the equilibrium rates of technological change, distorted relative to optimum biases dictated by shadow prices, non-Pareto optimum in its social impacts, and highly unstable over time. In addition, there has been a nuclearization of the research effort with the emergence of a number of new actors. No longer are the Ministries of Agriculture or the large polyvalent agricultural research institutes the main sources of technological innovations. Strong producer associations in particular commodities, usually geographically concentrated in medium-to-large farms with linkages to agroindustry, have taken the initiative of organizing the generation and diffusion of technological change either in fully privately funded programs, or by activating the state from below in the development of joint ventures and in project funding in public research institutions. With increasing possibilities of patenting innovations and of developing monopolistic or oligopolistic control over markets, private agribusiness firms have become important in seed, fertilizers, agrochemicals, and machinery. Pushed by the profit motive, these firms are well prepared to address technological problems that require applied research and that promise short-run payoffs. Transnational agribusiness firms have, in particular, become major agents of technological change, commonly fully controlling through contracts and vertical integration the technological decisions made by farmers. Finally, the network of international agricultural research centers, coordinated by the Consultative Group for International Agricultural Research and funded by foundations and bilateral and multilateral aid agencies, has also emerged as a key actor on the technological scene. While fundamentally oriented toward research on staple food crops, these centers have been more effective in addressing the problems of global food supply than the problems of who produces food and thus who derives an income from this activity.

There is no question that this multiplicity of research efforts has had a high economic payoff and that continued increase in investment in research will be needed for the foreseeable future. Insuring this will be all the more difficult in the current context of stabilization policies that many countries have to implement to face up to their debt crisis and inflationary pressures. Our concern is in identifying some avenues to decrease underinvestment in research, decrease the social bias that research contains, and reduce instability in the funding of the research effort. The thrust of our analysis has been to show that market forces alone are inadequate in providing a solution to these problems and that greater attention, instead, must be given to the dominant role of institutional forces. Some proposals in that direction, which derive from the evidence reviewed, are the following.

1. Coordination of the Research Effort. With the current nuclearization of the research effort, there is an increasing need to insure proper

coordination among research initiatives as well as between generators, users, and beneficiaries of research. We have seen how some of the more successful technological paths have involved the combined efforts of international, national, and private institutions with a clearly defined and flexible division of labor between them. Also, we have seen how scientists have a unique role to play in identifying the potential payoffs from research. Stronger contacts consequently need to be institutionalized between researchers and research users. And we have seen how both underinvestment in specific research areas and biases in technological innovations result from the lack of representation of specific social sectors (especially resource-poor farmers and landless workers) in the process of definition and budgeting of research priorities. As of today, coordination among research efforts and communication among generators, sellers, users, and beneficiaries of research remain woefully inadequate. It is consequently essential that national research councils be promoted that allow a broad participation of international, public, and private interests in the definition and funding of research priorities. These institutions should give a voice to the socially marginal sectors as well, i.e., provide representation not only in terms of the relative economic importance of commodities and the relative economic importance of producers but also in terms of numbers of individuals affected by the course of technology.

2. Taxing the Beneficiaries. One of the main reasons for which there has been underinvestment in public agricultural research is the difficulty of taxing part of the benefits of research away from its beneficiaries. Land taxes are notably difficult to impose on agriculture due to the political power of landlords; and taxes on consumers are equally difficult to impose due to their dispersion, disorganization, and the small size of the benefits they each derive from technological progress. Yet, the system of export tax to finance INTA in Argentina and of tax on milling to finance FEDEARROZ in Colombia are examples of the successful financing of research and diffusion programs by taxing beneficiaries. What is required for this is a much more clear identification of the ex ante payoffs from research and a broad mobilization of future beneficiaries in accepting to share the costs. This requires both greater decentralization of research and greater participation of future beneficiaries to the definition and budgeting of the research efforts. It also requires the availability of research loans in order to finance the research efforts until latent payoffs become taxable actual payoffs. Not all research can, however, be financed by taxing the beneficiaries, and research that benefits the weaker segments of the population should remain the financial responsibility of the public sector.

3. Coordination Between Technological and Economic Policies. The examples of successful technological paths demonstrate the importance of coordinating technological and economic policies. In particular, the downward pressure on prices exercised by output-increasing technologies must be carefully monitored to allow for technological treadmill effects that will extract from agriculture some of the benefits of technological innovations without stifling the profitability and, hence, the inducement to invest in agriculture. If technological innovations are cost saving but not output increasing, the benefits of technological change need to be extracted from agriculture through

land taxes. The economic policies that affect the success of technological change in agriculture must be understood in terms of macroeconomic forces including the valuation of the exchange rate, trade policies, credit terms, etc. Here, again, a broad consultative mechanism is needed that can reconcile the conflictive pressures which underlie the definition of technological economic policies.

4. Ex Ante Analysis and Participatory Research. It is evident that very little information and analysis goes into the definition of research priorities. The result is that the socially more vocal and powerful sectors unduly dominate the course of technological change. Needed to counteract this tendency is a greater collaboration between natural and social scientists and a greater participation of research beneficiaries (and affected sectors) in the definition of research priorities. This is not to say that all technological progress must be Pareto optimum but that compensatory programs or research lines should be considered simultaneously with the definition of programs with clear negative payoffs for weak segments of the population. Since these payoffs are extremely difficult to anticipate, a broadly participatory process with continued evaluation of the impact of research advances seems to be the best guarantee that the biases of technological change can be promptly corrected by complementary technological and institutional innovations.

5. Implications for the International Centers

Recognizing the role of institutional forces in influencing the rate and bias of technical change in agriculture has several implications for the CGIAR system.

To a certain extent, the analysis of the state activated from below/above/within can apply, by analogy, to the behavior of the International Centers. There are, however, fundamental differences between National Institute and IARCs. Being supranational institutions, the IARCs have a greater degree of autonomy from local interest groups than national institutions in terms of the definition of their research priorities and programs; but, they also face serious limitations in their action.

a. First of all, they depend on the countries with which they cooperate to obtain "signals," i.e., information on the latent demand for innovations. The distortions that are present at the national level are, therefore, translated at the international level.

b. To the extent that they are able to formulate independently a research program filtering the information received from their various contacts with NRIs, they can claim to represent the interests of social groups that are underrepresented at the national level.

For instance, donors have stressed repeatedly that the work of the IARCs should focus on increasing the prosperity of resource-poor farmers. These demands have also been expressed by the TAC. Several programs have focused on the development of technologies that will require low amounts of purchased inputs for millet, sorghum, and cassava which are common crops among poor farmers. There are also several programs on legumes, such as beans, to improve the quality of nutrition among the poor. However, one of the obstacles that such programs have to face is the congruence between the priorities established by CGIAR and those of the national strategies where priorities are often given to quick payoffs in more productive areas and to cash crops for foreign exchange.

c. A major obstacle to increasing agricultural productivity occurs at the level of translation of the latent demand for innovations into a budgeted demand. The symptoms of underfunding and instability that we have noted in relation to national systems are also present at the level of CGIAR. Real growth of expenditures during the 1980s has sharply dropped (1 percent since 1980 as compared to 20 percent in the first five years of CGIAR according to Oram). Personnel costs form an increasing proportion of the budget of the centers. Maintenance, equipment replacement, and other operating costs are being cut back. Thus, as noted by Oram, paradoxically, the system becomes less operational just when its potential multiplier effect is nearest to realization.

An additional dimension of the financial crisis of the system is that the CGIAR must compete for funds with the national institutes that it is supposed to support resulting in competing rather than collaborative behavior. The percentage of donor funding to agricultural research being channeled to the CGIAR has dropped from 26 percent in 1971-72 to about 18.5 percent in 1980.

d. In terms of supply of research, the support provided by the CGIAR to national systems poses a problem for a worldwide system that includes countries and regions with highly variable resources and levels of development. As a result, measurable progress has been quite unevenly distributed.

Some countries have strong research systems and are capable of undertaking basic, applied, and adaptive research and of training staff up to the Ph.D. level. They are able to complement and cooperate with the IARCs in most respects. Other countries are still at a level of development of their agricultural research system where they need the assistance and expertise of the IARCs at all stages of their training and research efforts.

Carrying out research with countries with different needs and different degrees of complexity in their research system poses serious problems of priority setting and coordination in a period where the growth rate in funding is declining.

e. By mandate, the IARCs are required to direct their research toward those food crops that will meet the nutritional requirements of the less advantaged groups in the LDCs (TAC Secretariat, Review of priorities, 1979); but, research on crops such as sorghum, millet, tropical roots, and tubers initiated less than 10 years ago does not yet produce results that it is possible to adapt to different microecological situations. Increased long-run commitment on the part of the donors is required in order to ensure that such programs aimed at reaching resource-poor farmers that are underrepresented at the national level be allowed to continue without being affected by financial restrictions at the international level.

Footnotes

[1]Reca estimates a long-run supply elasticity for Argentina agriculture between 0.42 and 0.52; Chibber, for Indian agriculture between 0.29 and 0.46; and Esfahani, for Egyptian agriculture of 0.09 (see Mohan Rao).

[2]V. Ruttan (1982, pp. 249-251) defines articulation as the "systematic interrelation of parts to form an integrated whole" referring to public agricultural research in the United States. He notes that articulation can be seen in the multidisciplinary orientation of experiment stations; in the association between experiment stations and extension services; and in the connections and communications that are to be found among theoretical research, practical research, and farm production. He also notes, quite interestingly, that "decentralization (of the agricultural research system) strengthened the articulation between science and farming."

[3]On the development of national research systems, see Ruttan, 1982 (United States, Japan, India, Brazil, Malaysia); Trigo, Pineiro, and Ardila, 1982 (Colombia, Argentina, Peru); and Pray, FRI Studies, XIX-1, 1982 (Pakistan/Punjab).

[4]See Ruttan (1982); Trigo and Pineiro, ISNAR (1984); and Pinstrup-Andersen (1982).

[5]This classification of countries refers to the World Bank's World Development Report, 1982.

[6]In their study of research benefits in Brazil, Castro and Schuh assume that the OCC is 10 percent.

[7]For a survey of models used for the evaluation of costs and benefits of research, see Schuh and Tollini (1978).

[8]The coefficient of variation is the standard deviation divided by the mean.

REFERENCES

Ahmad, S. "On the Theory of Induced Invention," Economic Journal, Vol. LXXVI (June, 1966), pp. 344-357.

Ahn, C., I. Singh, and L. Squire. "A Model of an Agricultural Household in a Multi-Crop Economy: The Case of Korea," Review of Economics and Statistics, Vol. LXIII, No. 4 (November, 1981), pp. 520-525.

Akino, M., and Y. Hayami. "Efficiency and Equity in Public Research: Rice Breeding in Japan's Economic Development," American Journal of Agricultural Economics, Vol. 57 (February, 1975), pp. 1-10.

Arndt, T. M., and V. W. Ruttan. "Valuing the Productivity of Agricultural Research: Problems and Issues." In T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan (eds.), Resource Allocation and Productivity in National and International Agricultural Research. Minneapolis: University of Minnesota Press, 1977.

Arrow, K. "The Organization of Economic Activity: Issues Pertinent to the Choice of Market versus Nonmarket Allocation." In R. Haveman and J. Margolis, Public Expenditures and Policy Analysis. Markham Publishing Co., Chicago, 1970.

Ayer, H. W., and G. E. Schuh. "Social Rates of Returns and Other Aspects of Agricultural Research and Reply," American Journal of Agricultural Economics, Vol. 56 (November, 1974).

Badhuri, A. The Structure of Backward Agriculture. London: Academic Press, 1983.

Balcazar, A., O. Marulanda, H. Rojas, and D Roldan. Cambio Tecnico en la Produccion de Arroz en Colombia, 1950-1979. IICA, Publication No. 239. Bogota, Colombia, July, 1980.

Binswanger, H. P. The Economics of Tractors in South Asia: An Analytical Review. New York: Agricultural Development Council and Hyderabad, India, ICRISAT, 1980.

Bonig, W. "Social Rates of Returns and Other Aspects of Agricultural Research: A Comment," American Journal of Agricultural Economics, Vol. 56 (February, 1974).

Boyce, J. K., and R. E. Evenson. Agricultural Research and Extension Programs. New York: Agricultural Development Council, Inc., 1975.

Castro, J. P. Ramalho, and G. E. Schuh. "An Empirical Test of an Economic Model for Establishing Research Priorities: A Brazil Case Study." In T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan (eds.), Resource Allocation and Productivity in National and International Agricultural Research. Minneapolis: University of Minnesota Press, 1977.

Cheung, S. The Theory of Share Tenancy. Chicago: University of Chicago Press, 1969.

Chibber, A. "Dynamics of Price and Non-Price Response of Supply in Agriculture." Stanford: Food Research Institute, 1982 (mimeographed).

Dalrymple, Dana G. "Evaluating the Impact of International Research on Wheat and Rice Production in the Developing Nations." In T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan (eds.), Resource Allocation and Productivity in National and International Agricultural Research. Minneapolis: University of Minnesota Press, 1977.

Departamento Nacional de Planeacion, "Bases para el Plan Nacional de Investigaciones del Sector Agropecuario." Quoted in Trigo and Pineiro, 1981.

de Janvry, A. "Inducement of Technological and Institutional Innovations: An Interpretative Framework." In T. Arndt, D. Dalrymple, and V. Ruttan (eds.), Resource Allocation and Productivity in National and International Agricultural Research. Minneapolis: University of Minnesota Press, 1977.

Diamond, P. "Disembodied Technical Change in a Two-Sector Model," The Review of Economic Studies, Vol. 32(2), No. 90 (April, 1965), pp. 161-168.

Elias, V. "Government Expenditures on Agriculture in Latin America," IFPRI Research Report No. 23. Washington, D. C., 1981, p. 27.

Esfahani, H. "A System-Wide Analysis of the Impact of Policy on Agricultural Performance in Egypt." Unpublished Ph.D. dissertation, Department of Economics, University of California, Berkeley, 1984.

Evenson, R. "Benefits and Obstacles in Developing Appropriate Agricultural Technology." In C. K. Eicher and J. M. Staatz (eds.), Agricultural Development in the Third World. Baltimore: Johns Hopkins University Press, 1984.

_______. "Comparative Evidence on Returns to Investment in National and International Research Institutions." In T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan (eds.), Resource Allocation and Productivity in National and International Agricultural Research. Minneapolis: University of Minnesota Press, 1977.

_______. "The Organization of Research to Improve Crops and Animals in Low-Income Countries." In T. W. Schultz (ed.), Distortions of Agricultural Incentives. Bloomington, Indiana University Press, 1978.

Evenson, D., and R. Evenson. "Legal Systems and Private Sector Incentives for the Invention of Agricultural Technology in Latin America. In M. Pineiro and E. Trigo (eds.), Technical Change and Social Conflict in Agriculture: Latin American Perspectives. Boulder, Colorado: Westview Press, 1983.

Evenson, R. E., P. M. Flores, and Y. Hayami. "Costs and Returns to Rice Research." International Rice Research Institute, Resource Paper No. 11, for the Conference on Economic Consequences of New Rice Technology. Los Banos, Philippines, 1977.

Food and Agriculture Organization. Agriculture: Towards 2000. Rome, 1981.

Griliches, Zvi. "Hybrid Corn: An Exploration into the Economics of Technical Change," Econometrica, Vol 25 (October, 1957).

______. "Research Costs and Social Returns: Hybrid Corn and Related Innovations," Journal of Political Economy, Vol. 66 (October, 1958).

Hertford, R., J. Ardila, A. Rocha, and C. Trujillo. "Productivity of Agricultural Research in Colombia." In T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan (eds.), Resource Allocation and Productivity in National and International Agricultural Research. Minneapolis: University of Minnesota Press, 1977.

Hertford, R., and A. Schmitz. "Measuring Economic Returns to Agricultural Research." In T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan (eds.), Resource Allocation and Productivity in National and International Agricultural Research. Minneapolis: University of Minnesota Press, 1977.

Iowa State University/Inter-American Development Bank. Analysis of Cooperation and Coordination Between the International Research Centers and the National Centers of Latin America. Inter-American Development Bank, Project No. ATN/TF-1798-RE (4), 1982 p. 240.

Judd, M. A., J. K. Boyce, and R. E. Evenson. "Investing in Agricultural Supply: The Determinants of Agricultural Research and Extension Investment," Economic Development and Cultural Change (forthcoming).

______. "Investing in Agricultural Supply." Economic Growth Center, Discussion Paper No. 442. Yale University, 1983.

Kaldor, D., and A. Paulsen. "Choice Criteria in Planning Agricultural Research." Paper presented at a seminar of Station Directors on Research Resource Allocation. Ames, Iowa, 1979.

Lau, L., and D. Jorgenson. "An Economic Theory of Agricultural Household Behavior." Paper presented at the Far Eastern Meeting of the Econometric Society. Tokyo, June, 1969 (mimeographed).

Lau, L., P. Yolopoulos, E. Chou, and W. Leu. "The Microeconomics of Distribution: A Simulation of the Farm Economy," Journal of Policy Modeling, Vol. 3, No. 2 (1981), pp. 175-206.

Lindner, R. K., and F. G. Jarrett. "Supply Shifts and the Size of Research Benefits," American Journal of Agricultural Economics, Vol. 60 (February, 1978).

Mellor, J. "Relating Research Resource Allocation to Multiple Goals." In T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan (eds.), Resource Allocation and Productivity in National and International Agricultural Research. Minneapolis: University of Minnesota Press, 1977.

Oram, P. "Current and Projected Agricultural Research Expenditures and Staff in Development Countries." IFPRI Working Paper No. 30. Washington, D. C., November, 1978 (mimeographed).

______. "Support for Agricultural Research in Latin America: Progress Since 1970 and Some Suggestions for Future Policy." The Netherlands: ISNAR, n.d. (mimeographed).

Oram, P., and V. Bindlish. Resource Allocations to National Agricultural Research: Trends in the 1970s (a review of Third World systems). The Netherlands: ISNAR-IFPRI, 1981.

Oram, P., J. Zapata, G. Alibaruho, and S. Ray. Investment and Input Requirements for Accelerating Food Production in Low-Income Countries by 1990. IFPRI Research Report No. 10. Washington, D. C., September, 1979.

Pasour, E. C., and M. A. Johnson. "Bureaucratic Productivity: The Case of Agricultural Research Revisited," Public Choice, No. 39 (1982).

Peterson, W. L. "Returns to Poultry Research in the United States," Journal of Farm Economics, Vol. 49 (August, 1967).

Pineiro, M. E., and E. J. Trigo. Procesos Sociales e Innovacion Technologia en America Latina. San Jose, Costa Rica: IICA, 1983.

Pineiro, M., R. Fiorentino, E. Trigo, A Balcazar, and A. Martinez. Articulacion Social y Cambio Tecnico: La Produccion de Azucar en Colombia. San Jose, Costa Rica: IICA, 1982.

Pineiro, M., and E. Trigo (eds.). Technical Change and Social Conflict in Agriculture: Latin American Perspectives. Boulder: Westview Press, 1983.

Pinstrup-Andersen, Per. Agricultural Research and Technology in Economic Development. London: Longman, 1982.

Pray, Carl E. "Underinvestment and the Demand for Agricultural Research: A Case Study of the Punjab," Food Research Institute Studies, Vol. XIX, No. 1 (1983).

Ramsdale, J., and A. Paulsen. "Entrepreneuring Scientists Influence Research Program as They Select Research to Propose," Evaluation of Agricultural Research. Minnesota Agricultural Experiment Station, Miscellaneous Publication 8-1981. University of Minnesota, Minneapolis, 1981.

Rao, M. "Agriculture in Recent Development Theories." Paper presented at the conference on New Directions in Development Economics, Massachusetts Institute of Technology, January, 1985.

Reca, L. "Argentina: Country Case Study of Agricultural Prices and Subsidies." World Bank, Staff Working Paper No. 386. Washington, D. C., 1980.

Rose, R. N. "Supply Shifts and Research Benefits," American Journal of Agricultural Economics, Vol. 62 (November, 1980).

Ruttan, Vernon. Agricultural Research Policy. University of Minnesota Press, Minneapolis, 1982.

______. "The Changing Role of Private and Public Sectors in Agricultural Research, Science (1982).

______. "Towards a Global Agricultural Research System" (1984) (mimeographed).

Schmitz, A., and D. Seckler. "Mechanical Agriculture and Social Welfare: The Case of the Tomato Harvester," American Journal of Agricultural Economics, Vol. 52, No. 4 (November, 1970), pp. 569-578.

Schuh, G. E., and Helio Tollini. "Costs and Benefits of Agricultural Research: State of the Art and Implications for CGIAR," CGIAR, October, 1978.

Schultz, T. W. Distortions of Agricultural Incentives. Bloomington: Indiana University Press, 1978.

Scobie, G. "Variation in the Rates of Return to Agricultural Research." Ford Foundation Workshop, 1979 (mimeographed).

Scobie, G., and T. Posada. "The Impact of Technical Change on Income Distribution: The Case of Rice in Colombia," American Journal of Agricultural Economics, Vol. 60, No. 1 (February, 1978), pp. 85-92.

Technical Advisory Committee Secretariat. Review of Priorities for International Support to Agricultural Research, UNFAO, Rome, 1979.

Trigo, E. J., and M. E. Pineiro. "Funding Agricultural Research." In Selected Issues in Agricultural Research in Latin America. The Hague, Netherlands: ISNAR, March, 1984.

Trigo, E., M. Pineiro, and J. Ardila. Organizacion de la Investigacion Agropecuaria en America Latina. San Jose, Costa Rica: IICA, 1982.

Trigo, E., M. Pineiro, and J. Sabato. "Technology as a Social Issue: Agricultural Research Organization in Latin America." In M. Pineiro and E. Trigo (eds.), Technical Change and Social Conflict in Agriculture: Latin American Perspectives. Boulder, Colorado: Westview Press, 1983.

Trimberger, E. Revolution from Above: Military Bureaucrats and Development in Japan, Turkey, Egypt, and Peru. New Brunswick, N. J.: Transaction Books, 1978.

U. S. Department of Agriculture. Indices of Agricultural Production, various issues.

U. S. National Research Council. Supporting Papers, World Food and Nutrition Study, Vol. 5. Washington D. C.: National Academy Press, 1977.

World Bank. World Development Report, 1982. Oxford: Oxford University Press, 1983.

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