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9. ABSTRACT

This first section of papers from the Airlie House conference focuses on the productivity of national research systems. In this section there are two papers on the organization and productivity of research systems in developed countries: the first (by Yujiro Hayami and Masakatsu Akino) describes the national-prefectural system in Japan; the second (by Willis L. Peterson and Joseph C. Fitzharris) discusses the federal-state system in the U.S. Two papers cover returns to investment in agricultural research in developing countries, one drawing upon the experience in Colombia (by Reed Hertford, Jorge Ardila, Andres Rocha, and Carl Trujillo) and one focusing on India (by A.S. Kahlon, P.M. Saxena, H.K. Bal, and Dayanath Jha). The final paper in this section (by Reed Hertford and Andrew Schmitz) reviews some of the theoretical foundations of, and empirical considerations involved in, the evaluation of returns to research.

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Resource Allocation and Productivity in National and International Agricultural Research

Thomas M. Arndt
Dana G. Dalrymple
and
Vernon W. Ruttan
Editors

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Preface

Within the last decade significant steps have been taken to narrow the agricultural technology gap among countries. New international agricultural research centers have been established, and a number of developing countries have made substantial progress in strengthening their national agricultural research capacities. It is estimated that world expenditures on agricultural research (in constant 1971 U.S. dollars) have risen from approximately $1.3 billion in 1959 to $3.8 billion in 1974. In the less developed countries of Latin America, Africa, and Asia, the estimated increase in research expenditures for the same period was from $141 million to $957 million.

The creation of two international agricultural research institutes in the early 1960s was an important factor in this surge of research investment. The establishment of the International Rice Research Institute (IRRI) in the Philippines in 1960 and the International Maize and Wheat Improvement Center (CIMMYT) in Mexico in 1966 signaled a wider contemporary refocusing on research as an essential instrument of agricultural productivity change in the less developed countries (LDC's).

The ensuing story is well known. CIMMYT and IRRI developed short-strawed, fertilizer-responsive, high-yielding wheat and rice varieties which were rapidly adapted and adopted in parts of Asia, Africa, and Latin America and which produced an upsurge in grain production popularly known as the "green revolution." By 1975, nine international research institutes and two other international programs were either in operation or in the process of being established in the LDC's (see Table 11-1).

The view that effective research capacity in developing countries is a primary means to raising agricultural productivity is now widely shared. The World Bank, the United States Agency for International Development (USAID), and other donors have begun to give agricultural research a higher priority for assistance. Investment in agricultural research in developing countries has grown rapidly in recent years. As the agricultural research system has continued to expand, research productivity and research resource allocation have become important issues for development planners and science managers.

In order to examine these issues, an international conference was held at Airlie House, Virginia, in January 1975. The conference had two main objectives: to examine recent evidence on the returns to investment in national and international agricultural research systems; and to explore the relevance of social and economic factors for the organization and management of national and international research systems. Technical issues related to the measurement of research productivity, the planning of research programs, and the management of research systems were also discussed.

The conference drew together over fifty natural scientists, social scientists, and administrators from national and international research agencies, some of whom wore more than one hat. The format of the conference was somewhat unusual. Individual papers were not read but rather circulated before the meeting and orally summarized at the conference by preselected discussants, several of whose commentaries proved so stimulating and original that they are included in this volume (chapters 26 and 27). Most of the conference, therefore, was devoted to what turned out to be a rich and vigorous discussion.

Following the conference, contributors were asked to review and revise their papers in the light of the discussions. The revised papers were then edited and returned to the authors for their further review, a painstaking process which was completed in November 1975. As they appear in this book, the twenty-eight papers have been organized into six sections. They are preceded by an introduction (by Thomas M. Arndt and Vernon W. Ruttan) which highlights the main issues discussed at the conference.

The first section of this book is devoted to a series of studies of the *productivity of national research systems* in both developed and less developed countries. There are two papers on the organization and productivity of research systems in developed countries: the first (by Yujiro Hayami and Masakatsu Akino) describes the national-prefectural system in Japan; the second (by Willis L. Peterson and Joseph C. Fitzharris) discusses the federal-state system in the United States. There are also two papers on returns to investment in agricultural research in developing countries, one drawing upon Colombian experience (by Reed Hertford, Jorge Ardila, Andrés Rocha, and Carlos Trujillo) and one focusing upon India (by A. S. Kahlon, P. N. Saxena, H. K. Bal, and Dayanath Jha). The final paper in this section (by Reed Hertford and

Andrew Schmitz), prepared after the conference, reviews some of the theoretical foundations of, and empirical considerations involved in, the evaluation of returns to research.

The second section includes three papers on the *productivity of international research systems*. The first paper (by Dana G. Dalrymple) documents the impact of the CIMMYT and IRRI varietal development programs on wheat and rice production in Asia. A second paper (by Robert E. Evenson) reviews the history of cycles in research productivity and in international diffusion patterns for three commodities: sugarcane, wheat, and rice. A third paper (also by Evenson) presents measures of the rates of return to the resources invested in research at IRRI and CIMMYT. In a fourth paper (by Yoav Kislev) an attempt is made to develop a theoretical model of applied research consistent with the historical experience reviewed in the earlier papers in the first two sections.

The third section is devoted to the *organization and development of the international agricultural research institute system*. The first chapter (by J. G. Crawford) traces the development of a system for organizing, funding, and managing the new institutes, spearheaded by the Ford and Rockefeller foundations and now guided by the Consultative Group on International Agricultural Research. The programs that have been developed to achieve closer articulation of the research programs of the international and national systems are outlined by the director of IRRI (Nyle C. Brady) and the director of CIMMYT (Haldore Hanson). The problem of establishing effective working relationships between the international and national agricultural research systems is then reviewed (by Sterling Wortman). The final paper in this section (by Burton E. Swanson) presents a comparison of the impact of the IRRI and CIMMYT training programs on the career patterns and effectiveness of young scientists who have studied at these two institutes.

The fourth section is devoted to issues bearing directly on the *organization and management of agricultural research systems*. The first paper (by Albert H. Moseman) outlines the evolution of coordinated national research projects for improving food crop production. Two papers focus on the problem of reorganizing and reforming national research systems: in the United Kingdom (by Tilo L. V. Ulbricht) and in Brazil (by José Pastore and Eliseu R. A. Alves). Next, the contribution of private sector international agricultural research is described (by S. M. Sehgal), based on the experience of Pioneer Hi-Bred International. A systems approach to research resource allocation is then outlined and evaluated (by Per Pinstrup-Andersen and David Franklin). The final chapter in this section (by C. Richard Shumway) presents a review and evaluation of the literature on formal models and methods for allocating resources in research.

The fifth section examines the role of *economic and social factors in re-*

search resource allocations. The first paper (by Martin E. Abel and Delane E. Welsch) outlines a theoretical model for exploring the relative effects of environmental constraints and commodity mix on research resource allocation. The second paper (by John W. Mellor) is devoted to an empirical evaluation of the effects of efforts to relate research resource allocation to alternative goals such as labor absorption. In a third paper (by J. P. Ramalho de Castro and G. Edward Schuh) the use of an economic model to establish research priorities, based on Brazilian data, is illustrated. The role of resource endowments and relative prices in inducing the choice of alternative paths of technical change – that is, labor saving versus land saving – is documented (by Hans P. Binswanger). The final paper in this section (by Alain de Janvry) presents a theoretical model of dialectical interaction between technical and institutional change in agriculture which suggests important directions for future research.

The final section is devoted to discussion of the research strategy and management issues that will affect *the future of the international research system* and the productivity of national research systems. The first paper (by A. T. Mosher) is devoted to a discussion of unresolved issues in the evaluation of the international system. A second essay (by Theodore W. Schultz) focuses on the role of economic policy in influencing the prospects for gains from agricultural research. In the final paper (by J. G. Crawford) the policies and problems facing the Consultative Group on International Agricultural Research and its Technical Advisory Committee in their efforts to strengthen national and international research are reviewed.

The papers included in this volume cannot, of course, reflect fully the excitement and challenge of the Airlie House conference. Particularly significant contributions to the discussions were made also by Richard Baldwin of Cargill Inc.; Joel Bernstein of the U.S. Agency for International Development; John K. Coulter of the Consultative Group on International Agricultural Research; George Darnell, James M. Fransen, Raj Krishna, and Montague Yudelman of the World Bank; M. McDonald Dow of the National Academy of Sciences; Walter L. Fishel of the U.S. Department of Agriculture; Lowell S. Hardin of the Ford Foundation; W. David Hopper of the International Development Research Centre; Richard Nelson of Yale University; Peter Oram of the Food and Agriculture Organization of the United Nations; S. J. Webster of the Ministry of Overseas Development of the United Kingdom; A. M. Weisblat of the Agricultural Development Council, Inc.; and F. R. Wittnebert of the Parker Pen Co.

The Airlie House conference was given considerable impetus and background by the materials presented and discussed at an earlier symposium on Resource Allocation in Agricultural Research held at the University of Minne-

sota in February 1969. The results of the Minnesota conference, which focused on many of the same issues considered at Airlie House but from a domestic (United States) viewpoint, were published in a book edited by Walter L. Fishel and entitled *Resource Allocation in Agricultural Research* (Minneapolis: University of Minnesota Press, 1971).

Both the Minnesota and Airlie House conferences were oriented to formal research carried out at nonprofit institutions and supported primarily with public or philanthropic funds and, to a lesser extent, to research conducted by private firms. It is recognized, however, that significant technical improvements may also result from informal research by farmers themselves or by small, local firms. Simple selection of improved varieties of seeds has traditionally been an important source of varietal development and yield increase. In the field of mechanical technology, simple but effective mechanical devices invented by farmers or mechanics, such as small irrigation and cultivation equipment, continue to provide many of the models for equipment engineered, manufactured, and marketed by larger firms. The work of both national and international research programs in many cases builds on this indigenous technology. Thus while little is said about informal research in this volume, its potential importance should not go unrecognized.

The structure of public agricultural research differs somewhat between the developed and the less developed nations. In the developed countries, research is conducted both by ministries (or departments) of agriculture and by colleges and universities. In the developing nations, research has traditionally been much more strongly concentrated in specialized arms of the ministries of agriculture or in autonomous, commodity-oriented research institutes. Colleges of agriculture in developing countries have usually concentrated on teaching, although in some cases they have done significant research (the popular rice variety C4-63, for instance, was developed by the College of Agriculture at the University of the Philippines) and may well play a larger role in the future. A paper on "Articulation of the International System with Other Regional Organizations: Ministry and University," by Jose Drilon was originally scheduled for the conference, but unfortunately Dr. Drilon, for reasons beyond his control, was unable to prepare the paper or to participate in the discussions.

We would also like to emphasize that, while this volume focuses on the importance of improved technology in the process of agricultural development, we are quite aware that it is not the only factor. A host of other forces—social, institutional, economic, and technical—both influence the adoption of technology and set the stage for the complex of other changes which must take place in the process of agricultural and economic development. Although improved technology may be the key factor in some societies, in others it may

not. Improved technology alone is clearly not tantamount to agricultural development. But if the proper forms of technology can be efficiently generated through research, the development process can often be facilitated. It is our hope that this volume will contribute to a better understanding of the role of research in the process of technical change and of the role of technical change in agricultural development.

The conduct of the Airlie House conference and the preparation of this volume have been possible only through the help of many individuals and several institutions. The conference planning committee consisted of Robert E. Evenson, Walter L. Fishel, and Vernon W. Ruttan. The conference was sponsored by the Agricultural Development Council under its Research and Training Network Program, a program which, in turn, is funded under a contract with the United States Agency for International Development. Additional support for international participation in the conference was provided by the World Bank.

Turning a set of conference papers by an international cast into a book is, as we learned, far from a quick or simple job. Our task was facilitated by the cooperation and forbearance of the individual authors, most of whom found their carefully revised papers further edited and trimmed. Virginia O. Locke played a key role in the copy editing; her professional skills and contributions were of great assistance. We would also like to express our appreciation to Willis L. Peterson for his review of technical portions of the final page proofs and to Raymond D. Vlasin for his very helpful review and evaluation of a preliminary draft of the conference proceedings manuscript.

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and Andrew Schmitz

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and V. W. Ruttan

2

Organization and Productivity of Agricultural Research Systems in Japan[1]

Yujiro Hayami and Masakatsu Akino

Agricultural growth in Japan since the Meiji Restoration (1868) is unique in that it was achieved without disrupting Japan's traditional rural structure even though there were strong constraints on the land. Data indicate that Meiji Japan inherited a man/land ratio from the feudal Tokugawa period which was even more unfavorable than that in South and Southeast Asia today (Table 2-1). However, it appears that the unfavorable endowment of land relative to labor was compensated for by higher land productivity. Because of this, labor productivity in agriculture in Meiji Japan was at the level prevailing in Asia today.

From this initially low level, Japanese agriculture has grown to a level of agricultural output per male worker which exceeds Asian standards by a wide margin. A major component in this growth of output per worker was the increase in yield per unit of agricultural land. Meanwhile, there has been little change in rural structure; Japan remains a nation of small farms (Table 2-2).

This clearly indicates that technical innovations in Japanese agriculture were consistent with both its resource endowments and its rural organization. Central to these innovations was the development of biological technology in the form of fertilizer-responsive high-yielding varieties of major cereal crops, especially rice, complemented by improvements in land infrastructure.

The agricultural research system that developed the land-saving and yield-increasing biological technology was essential to the growth in output and

Table 2-1. Agricultural Productivity and Man/Land Ratios in Japan and Selected Asian Countries

Country	Agricultural Output per Male Farm Worker[a] (wheat units per worker)	Agricultural Output per Hectare of Agricultural Land[b] (wheat units per hectare)	Agricultural Land Area per Male Worker[c] (hectares per worker)
Japan			
1878-82	2.5	2.9	0.9
1898-1902	3.4	3.6	0.9
1933-37	7.1	5.5	1.3
1957-62	10.7	7.5	1.4
Asia, 1957-62			
Ceylon	3.9	2.9	1.3
India	2.1	1.1	1.9
Pakistan	2.4	n.a.	n.a.
Philippines	3.8	1.9	2.0

Source: Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore and London: Johns Hopkins Press, 1971), pp. 70 and 328. Japan's time series revised to accord with presentation in Yujiro Hayami, in association with Masakatsu Akino, Masahiko Shintani, and Saburo Yamada, *A Century of Agricultural Growth in Japan. Its Relevance to Asian Development* (Minneapolis and Tokyo: University of Minnesota Press and University of Tokyo Press, 1975), pp. 220-230.

[a] Farm workers = economically active male population engaged in agriculture.

[b] Agricultural output in wheat units is the gross agricultural output net of intermediate products such as seed and feed. Individual products are aggregated by the price ratios to the price of wheat per one metric ton.

[c] Agricultural land area includes permanent pasture land.

productivity of Japanese agriculture. This chapter will review the current status and the historical evolution of agricultural research in Japan and will measure the productivity of investments in agricultural research.

Current System of Agricultural Research in Japan

In Japan, research is conducted mainly in public experiment stations under the auspices of national and prefectural governments. The mix of public and private agricultural research is shown in Table 2-3. Measuring both research expenditures and personnel, we find that about 59 percent of agricultural research is conducted at government institutions, nearly 38 percent at universities, and just over 3 percent in the private sector.

This structure contrasts markedly with industrial research in Japan (Table 2-3). It also differs from the United States, where roughly half of all agricultural research expenditure is made by private firms.[2]

Another distinctive aspect of the agricultural research system in Japan is the separation of agricultural experiment stations from education and exten-

Table 2-2. Distribution of Farms in Japan by Size of Cultivated Land Area

Year	Number of Farms, in thousands (% of total in parenthesis)						
	Less Than 0.5 Ha.	0.5-1 Ha.	1-2 Ha.	2-3 Ha.	3-5 Ha.	Larger Than 5 Ha.	Total
1908	2,016	1,764	1,055	348	163	62	5,408
	(37.3)	(32.6)	(19.5)	(6.4)	(3.0)	(1.1)	(100.0)
1910	2,032	1,789	1,048	322	156	71	5,417
	(37.5)	(33.0)	(19.3)	(5.9)	(2.9)	(1.3)	(100.0)
1920	1,935	1,829	1,133	341	154	92	5,485
	(35.3)	(33.3)	(20.7)	(6.2)	(2.8)	(1.7)	(100.0)
1930	1,891	1,892	1,217	314	128	70	5,511
	(34.3)	(34.3)	(22.1)	(5.7)	(2.3)	(1.3)	(100.0)
1940	1,796	1,768	1,322	309	119	76	5,390
	(33.3)	(32.8)	(24.5)	(5.7)	(2.2)	(1.4)	(100.0)
1950	2,531	1,973	1,339	208	77	48	6,176
	(41.0)	(32.0)	(21.7)	(3.4)	(1.2)	(0.8)	(100.0)
1960	2,320	1,923	1,430	233	91	60	6,057
	(38.3)	(31.7)	(23.6)	(3.8)	(1.5)	(1.0)	(100.0)
1970	2,025	1,614	1,286	256	90	71	5,342
	(38.0)	(30.2)	(24.1)	(4.8)	(1.7)	(1.3)	(100.0)

Source: Institute of Developing Economics, *One Hundred Years of Agricultural Statistics in Japan* (Tokyo, 1969), p. 116; Ministry of Agriculture and Forestry, Statistical Research Division, *1970 World Census of Agriculture Report on Farmhouseholds and Population* (Tokyo, 1971).

Table 2-3. Allocation of Expenditures and Staff to Agriculture and Nonagriculture in Public and Private Research in Japan, 1972

Type of Research Institution	Expenditures[a]		Staff	
	Agriculture[b]	Nonagriculture[c]	Agriculture[b]	Nonagriculture[c]
University[d]	35%	14%	40%	24%
Public				
National government	17	4	17	3
Local government	44	2	40	2
Private	4	80	3	71
Total	100	100	100	100

Source: Bureau of Statistics, Office of the Prime Minister, *Kagaku Gijutsu Kenkyu Chosa Hokoku* (Report on the Survey of Research and Development in Japan) (Tokyo, 1972), pp. 62, 150, and 166.

[a] Includes both current and capital expenditures.
[b] Includes forestry and fisheries research.
[c] Excludes medical research.
[d] Includes both public and private universities.

sion. This contrasts with the United States land grant college system, which is characterized by the trinity of education, research, and extension. In Japan, agricultural experiment stations are under the Ministry of Agriculture and Forestry. Agricultural colleges or university faculties of agriculture are under the Ministry of Education. No formal links between experiment stations and universities have been established.

Extension programs are also separate from the experiment stations. They are carried out by the prefectural extension services. However, because both the prefectural experiment stations and the prefectural extension services are under the agricultural departments of the prefectural governments, they operate in close cooperation. In many cases, senior extension specialists are stationed in the experiment stations.

There is also a division of labor between the national and the prefectural experiment stations. National experiment stations under the administration of the Agricultural, Forestry and Fishery Technology Commission within the Ministry of Agriculture and Forestry include the following: the Central Agricultural Experiment Station at Konosu and the seven regional stations for Hokkaido, Tohoku, Hokuriku, Tokai-Kinki, Chugoku, Shikoku, and Kyushu; six specialized experiment stations for horticulture, tea, sericulture, livestock, veterinary medicine, and agricultural engineering; one station for forestry; and nine stations for fisheries.

Under the same administration are the National Research Institute of Agri-

cultural Science, engaged in more basic research in the natural science aspects of agriculture; the National Research Institute of Agriculture, which is concerned primarily with social science aspects; the Food Research Institute for research on food nutrition, chemistry, and processing; the Plant Virus Research Institute; and the newly established Tropical Agriculture Research Center. In addition, there are the Farm Mechanization Research Institute and the Beet Research Institute, which have semipublic status, and more than 300 agricultural experiment stations and research institutes (including those for fishery and forestry research) operated by the forty-six prefectural governments.

The division of labor between the national and local experiment stations is rather broad, and there is considerable overlap. The national stations emphasize research projects for wide areas, while the prefectural stations tend to concentrate on research of local significance. Consequently, there is a tendency for the former to engage in more basic research and the latter in more applied research.

This division of labor is reflected in the differences in staff size between the national stations and local government research stations (Table 2-4). The universities and the national experiment stations, which conduct more basic research, have larger staffs than the prefectural stations, which stress applied research.

Evolution of the Agricultural Research System

This section outlines the historical evolution of agricultural research in Japan.[3] First, we will quickly review the quantitative growth of Japanese agriculture. The trends in agricultural output, inputs, and productivity are shown in Figure 2-1.

For the period 1878-1972, total output, input, and productivity in Japanese agriculture show secular growth trends except during World War II. Over the whole period total output more than tripled. Inputs of the two primary factors, labor and land, changed relatively slowly: labor measured by the number of farm workers declined about 30 percent, and land measured by cultivated land area increased by about 25 percent. To a large extent, the changes in labor and land canceled each other out in the growth in total inputs (aggregate of all conventional inputs by the shares of respective inputs in the total cost of agricultural production). Capital grew relatively slowly in the prewar years, only starting to rise at a rapid pace in the postwar period. The rates of growth in current nonfarm inputs, particularly fertilizers, have been much faster than in other inputs.

Overall, total inputs grew by about 80 percent over the whole period,

Table 2-4. Comparison of Staff Size and Amount of Expenditure for Agricultural Research among Universities and Government Institutions in Japan, 1972

Item	Institutions		
	Universities (N=63)	National Government (N=30)	Local Government (N=336)
Staff			
Total number	7,174	3,127	7,290
Average number per institution	114	104	22
Expenditures[a]			
Total			
Yen (million)	34,200	16,300	42,400
U.S. dollars (thousand)	129,000	62,000	160,000
Average per institution			
Yen (million)	543	543	126
U.S. dollars (thousand)	2,049	2,049	475
Average per staff member			
Yen (million)	4.8	5.2	5.8
U.S. dollars (thousand)	18.1	19.6	21.9

Source: Bureau of Statistics, Office of the Prime Minister, *Kagaku Gijutsu Kenkyu Chosa Hokoku*. (Report on the Survey of Research and Development in Japan) (Tokyo, 1972).
Note: Agricultural research here includes research in forestry and fisheries.
[a] Conversions from yen to dollars at rate of 265:1.

while the total output grew by as much as 280 percent. Consequently, total productivity, or output per unit of aggregate input, more than doubled. Three phases can be distinguished in the total output and productivity trends: relatively fast growth up to the late 1910s; relative stagnation in the interwar period; and a spurt forward in the post-World War II period.

In the following historical review we will describe the ways in which these growth patterns were related to the evolution of agricultural research.

National Government Initiatives

The national government first sought to develop agriculture by importing farm machinery, plants, and livestock. The Farm Machinery Exhibition Yard was established in 1871 in Tsukiji, Tokyo, to exhibit large-scale farm machinery imported from England and the United States. The machines were demonstrated at the Naito Shinjuku Agricultural Experimental Station, set up in 1872. The government also tried to transplant foreign plants and livestock. The Mita Botanical Experiment Yard (1874), the Shimofusa Sheep Farm (1875), the Kobe Olive Farm (1879), and the Harima Grape Farm (1880) were established for these trials.

The government also established institutions of advanced agricultural education: the Komaba Agricultural School in 1877 (now the University of

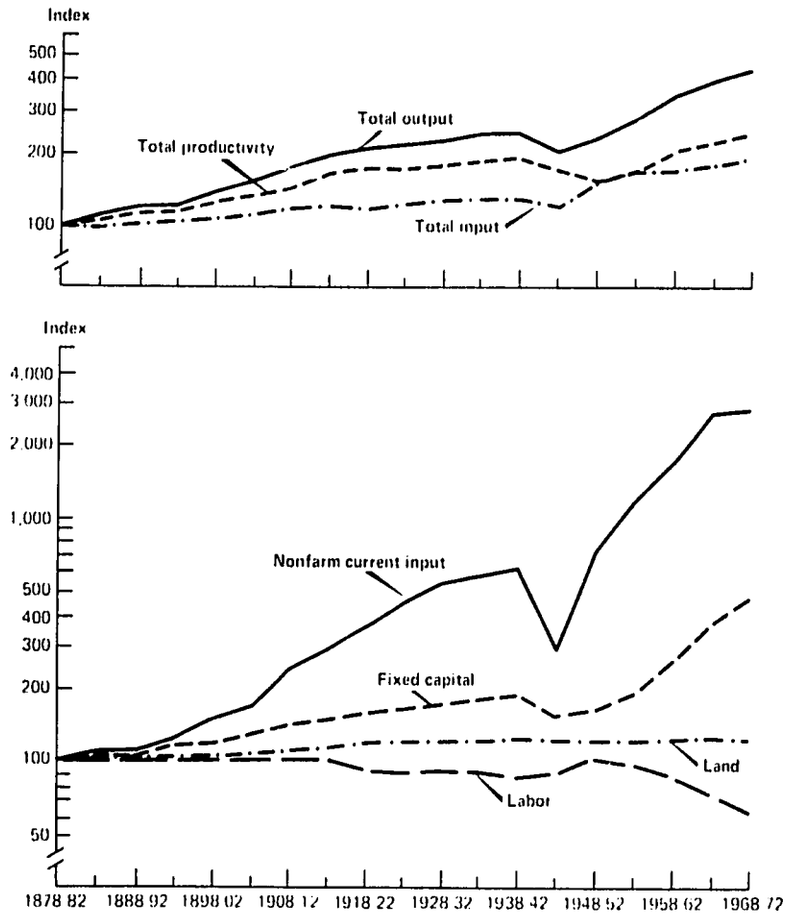

Figure 2-1. Trends in the indices of output, inputs, and productivity in Japanese agriculture (1878-82=100), five-year averages, semilog scale.
Source: Yujiro Hayami, et al., *A Century of Agricultural Growth in Japan: Its Relevance to Asian Development* (Minneapolis and Tokyo: University of Minnesota Press and University of Tokyo Press, 1975), pp. 32, 39.

Tokyo, College of Agriculture), and in 1875, the Sapporo Agricultural School which was designed to develop Hokkaido, the last frontier of Japan. British instructors were invited to staff the Komaba School and instructors from the United States were invited for the Sapporo School. The schools taught Anglo-American, large-scale mechanized farming.

This early "technology borrowing" is one example of the broad effort of

Meiji Japan to catch up with Western technology. But, in contrast to similar efforts in industry, this attempt was largely unsuccessful. Factor endowments and farm size in Japan were simply incompatible with large-scale machinery. In most cases the efforts to transplant foreign plants and livestock were not successful because of different ecological conditions.

The Meiji government quickly perceived this mistake and redirected its development strategy toward searching for modern technology that would be consistent with the factor endowments and ecological conditions of Japanese agriculture. In 1881, when their contracts were completed, the British agricultural instructors at the Komaba School were replaced by German scientists. Thereafter agricultural education in Japan placed primary emphasis on agricultural chemistry and soil science of the Liebig tradition. The facilities for demonstrating Western machinery, plants, and livestock were largely discontinued during the 1880s.

The newly founded Ministry of Agriculture and Commerce (1881) established the itinerant instructor system in 1885. Instructors traveled throughout the country holding agricultural extension meetings. In contrast to the earlier emphasis on importing Western technology, the itinerant instruction system was designed to diffuse the best seed varieties and cultural practices already used by many Japanese farmers. Not only the graduates of the Komaba School but also veteran farmers (*rōnō*) were employed as itinerant instructors in order to combine the best practical farming experience with the new scientific knowledge of the inexperienced college graduates.

To provide better information for the itinerant lecturers, the Experiment Farm for Staple Cereals and Vegetables was set up in 1885. By 1893, the farm, considerably expanded, had become the National Agricultural Experiment Station with six regional branch stations across the nation. The itinerant instuction program was subsequently absorbed by the National Agricultural Experiment Station. Meanwhile, the national government encouraged the prefectural governments to set up local experiment stations. However, only a few prefectures had established their experiment stations before the Law of State Subsidy for Prefectural Agricultural Experiment Stations was enacted in 1899.

The development of agricultural experiment stations in Japan was characterized from the beginning by the strong initiative of the national government. This experience in Japan contrasts with the experience in Western Europe. In England the famous Rothamsted Experimental Station was established in 1843, financed by Sir John Lawes. The Edinburgh Laboratory (founded in 1842) was supported by the Agricultural Chemistry Association of Scotland, a voluntary agricultural society. In France the first agricultural experiment station was established by Jean Boussingaullt in his estate at Bechelbrom in

1834. Even in Germany, where the first experiment station was publicly supported, Saxon farmers initiated the movement for the station and drafted its charter.

Why was the government of Meiji Japan (its leaders were primarily from the ex-*Samurai* class) clearly determined from the very beginning to take responsibility for conducting agricultural research? A part of the answer appears to lie in the organization of Japanese agriculture – a host of dwarf-sized, family farms. Individual farms were too small to take advantage of scale economies inherent in research. They were too small to exercise monopolistic power and gain enough benefit from research to cover the costs.

Because land was the factor limiting agricultural production, farmers demanded technology which would save land. Research emphasized the development of biological technology such as improved seed varieties. There was no incentive for private firms to conduct biological research since there were no institutions, such as patent laws, to allow them to profit from the research. Furthermore, because of the low price elasticity of demand for staple foods – the major products of Japanese agriculture – the gains from agricultural research were transferred primarily to consumers through declines in food prices. In this situation, the need for public support of agricultural research was obvious. Why did the national government rather than the local governments take the initiative? Why was it not left to cooperatives of farm producers, especially in the case of export crops?

The answer must be sought in the basic approach of Meiji Japan to economic development, which was to exploit agriculture for industrialization. When it opened its doors to foreign countries shortly before the Meiji Restoration, Japan was in danger of colonialization. The national slogan was *fukoku kyohei*, to "build a wealthy nation and strong army," and to attain this goal it was considered necessary to "develop industries and promote enterprises," or *shokusan kogyo*.

In predominantly rural Meiji Japan, industrialization was necessarily financed from agricultural surplus. Revenue for industrial development was raised by taxing agricultural land. Foreign exchange needed for imported goods was earned by exporting primary products. In a sense, the establishment of the National Agricultural Experiment Station in 1893 was a response to agitation for the reduction of the newly established land tax. The *Konoronsaku* (*A Treatise on the Strategy of Agricultural Development*), which was drafted in 1891 by the Agricultural Science Association and which had an immediate impact on the establishment of the experiment station, denied the argument for a land tax reduction on the basis that it would only contribute to the welfare of landlords and give no benefit to a large number of tenant farmers; it advocated "more positive measures to develop agriculture such as agricultural

schools, experiment stations, itinerant lecturing, and agricultural societies" to reduce the burden on farmers.[4]

More fundamentally, increasing the supply of food for the growing urban industrial population was critical for industrialization. If the food supply had not kept up with urban demand, the price of food would have risen. In the early stages of development characterized by a high Engel coefficient, a rise in food prices would have significantly increased the cost of living and wages. This would have reduced profits and depressed industrial accumulation of capital.

Given its aspirations for industrial development, it was natural for the government to undertake measures, including agricultural research, to develop agriculture and to increase the supply of food, a critical wage-good for industrial development. Furthermore, because foreign exchange was a constraint on the importation of capital goods and on economic development, it was rational for the government to use tax revenues to support research on export products such as tea and silk, even though this research might benefit the producers primarily.

Linkage with Extension and Education

The linkage between agricultural research and extension has traditionally been strong in Japan. As mentioned previously, the Experiment Farm for Staple Cereals and Vegetables was designed to provide relevant data for itinerant instructors. The itinerant extension program was later absorbed into the National Experiment Station. As prefectural experiment stations were established, extension programs were transferred to them. When the agricultural associations organized under the Agricultural Association Law (1899) began to develop extension programs with government subsidies, their extension workers were trained in agricultural training centers attached to the prefectural experiment stations.

In contrast, the connection between agricultural experiment stations and educational institutions has not been formally established. The pioneers of agricultural science in the Meiji period had expected otherwise. In the *Treatise on the Strategy of Agricultural Development* they proposed:

> It is advantageous that the agricultural experiment stations and the itinerant instruction system are combined . . . it is advantageous if the agricultural experiment stations belong to agricultural colleges . . . it is highly effective for students to see the projects in the experiment stations. The results of experiment are useful for experiment stations . . . Agricultural associations should encourage the study of students, and encourage farmers to use the established results of experiments.[5]

It appears they had in mind a trinity of research, extension, and education,

supported by agricultural associations – a system similar to that of the United States. However, the National Agricultural Experiment Station was established independently from the Komaba School. The system of national and prefectural experiment stations developed separately from institutions of advanced agricultural education.

This development may be explained by the strong (and hasty) demand of the government that experiment stations produce practical results for farmers immediately and by the fact that basic research at universities in the Meiji period was not producing practical techniques.

In the beginning stages, the staff at the agricultural colleges primarily studied principles and theories developed abroad. Although a few produced distinguished research, this was not immediately applicable on the farms. In the short run the more productive approach was to exploit the best indigenous farming practices by simple tests and demonstrations.

The initial research conducted at the Experiment Farm for Staple Crops and Vegetables and at the National Agricultural Experiment Station was primarily applied research. The major projects were field experiments comparing various seed varieties or husbandry techniques (for example, checkrow planting of rice seedlings versus irregular planting). Facilities, personnel, and, above all, the state of knowledge were not adequate for more than simple comparative experiments. Nevertheless, such experiments provided a basis for the rapid growth of agricultural productivity during the latter years of the Meiji period. This was a result of the substantial indigenous technological potential which could be further tested, developed, and refined at the new experiment stations as well as the strong propensity toward innovation among farmers, with whom the research workers effectively interacted.

For 300 years before the Meiji Restoration, farmers were constrained by feudalism. Personal behavior and economic activity were highly structured within a hierarchical system of social organization. Farmers were bound to their land and were, in general, not allowed to leave their villages except for such pilgrimages as the *Ise-Mairi* (Pilgrimage to the Ise Grand Shrine). They were not free to choose which crops to plant or which varieties of seeds to sow. The division of the nation into feudal estates discouraged communication. In many cases, feudal lords prohibited the export of improved seeds or cultural methods from their territories. Under such conditions the diffusion of superior seeds and husbandry techniques from one region to another was severely limited.

The Meiji Restoration removed feudal restraints. Farmers became free to choose which crops to plant, which seeds to sow, and which techniques to practice. The introduction of a modern postal service and of railroads reduced the cost of diffusing information about technology. The land tax re-

form, which granted a fee simple title to the farmers and transformed a feudal share tax on crops into a fixed land tax, increased the farmers' incentive to innovate. The farmers, especially of the *gōnō* class (landlords who personally farm part of their holdings), vigorously responded to such new opportunities. They voluntarily formed agricultural societies called *nodankai* (agricultural discussion society) and *hinshukokankai* (seed exchange society) and searched for better techniques. Rice production practices, such as the use of salt water in seed selection, improved preparation and management of nursery beds, and checkrow planting were discovered by farmers and propagated by the itinerant instructors. They were sometimes enforced by the sabers of the police. The major improved varieties of seeds, up to the end of the 1920s, also resulted from selections by veteran farmers.

Experiment station research was successful in testing and refining the results of farmer innovations. The *rōnō* techniques (veteran farmers' techniques) were based on experiences in the specific localities where they originated. They tended to require modification when transferred to other locations. Simple comparative tests effectively screened the *rōnō* techniques and varieties, thereby reducing greatly the cost of technical information for farmers. Slight adaptations of indigenous techniques based on experiments often gave them wide applicability.

Given the backlog of indigenous technological potential, the innovative attitude of farmers, and the infant state of university education and research, it might have been more effective at that time to organize the experiment stations and extension services separately from the universities. Also, the loose linkages between experiment stations and universities did not pose a serious problem during the Meiji period when the agricultural research-education-extension complex was small. Since the key personnel in experiment stations, extension services, and agricultural colleges were all graduates of either the Komaba School or the Sapporo School, the interaction among experiment stations and agricultural colleges worked sufficiently well on an ad hoc basis.

Centralization versus Decentralization

It appears that the evolution of the organization of agricultural research in Japan has been marked by a search for an optimum balance between centralization and decentralization. The pioneers of agricultural science in Japan seem to have recognized that agricultural technology is highly location-specific. To produce practical results for farmers, agricultural research must be conducted in various ecological regions. They also appear to have recognized the need for the coordination of central and local experiment stations. In the *Treatise on the Strategy of Agricultural Development* they proposed to estab-

lish one central experiment station in Tokyo, five regional stations, and one or more stations in each prefecture.[6] However when the National Agricultural Experiment Station (headquartered in Nishigahara, Tokyo) and the six regional branch stations were established, the director, Atsushi Sawano, considered the system inadequate. He remarked that "regional breakdowns are not sufficient for the variations in soil and climate. If additional budget is available, another forty-five stations must be established."[7]

Local political groups lobbied the National Diet for more branch stations, and the number of these was increased from six to nine in 1895. But the experiment stations were strapped for funds. The initial staff, including that in the branch stations, comprised only twenty research scientists and seven technicians. This increased to thirty scientists and fifteen technicians in 1899. Experiments were always handicapped by insufficient facilities and logistical support.[8] Under such conditions it was hardly possible to conduct more basic research in addition to the simple tests and demonstrations noted previously.

Meanwhile, the backlog of indigenous technological potential was gradually exhausted as it was exploited. Research institutions felt the need to recharge this declining potential by turning to more basic research. The prefectural experiment stations gradually accepted responsibility for more applied research. The rapid expansion of local research during this time is shown by the prefectural government's increasing expenditure for agricultural research (Table 2-5).

In response to the establishment of the prefectural experiment stations, the National Experiment Station reduced its branch stations from nine to three in 1903, with the intention of exploiting scale economies in more basic research by concentrating research resources in fewer stations. The following year, for the first time, the National Experiment Station launched an original crop breeding program at its Kinai Branch. The object of this project was to develop new rice varieties by artificial crossbreeding based on the Mendelian principles rediscovered in 1900. It took almost two decades before new varieties of major practical significance were developed, though the project contributed greatly to the accumulation of experience and knowledge. Another project was started in 1905 at the Rikuu Branch to improve rice varieties by pure line selection. This approach brought about quicker practical results. Thereafter the main efforts of crop breeding in the Taisho era (1912-25) were in pure line selection.

Rice breeding by pure line selection represented the final exploitation of the indigenous technological potential embodied in the *rōnō* varieties. As the purity of those varieties was raised, the potential was exhausted.[9] The exploitation and consequent exhaustion of indigenous potential became evident in the 1910s before more basic research represented by the crossbreeding

Table 2-5. Expenditures for Agricultural Research by National and Prefectural Governments in Japan, 1897-1970 (in thousand yen)[a]

Year	Total	National[b]	Prefectural
1897	616	367 (60)	249 (40)[c]
1902	2,044	930 (45)	1,114 (55)[c]
1907	2,032	718 (35)	1,314 (65)[c]
1912	3,044	822 (27)	2,222 (73)[c]
1918	2,521	849 (34)	1,672 (66)[c]
1923	5,385	1,286 (24)	4,099 (76)[c]
1927	6,561	1,251 (19)	5,310 (81)[c]
1932	8,196	1,686 (21)	6,510 (79)[c]
1955	9,478	4,190 (44)	5,288 (56)[d]
1960	12,300	4,661 (38)	7,639 (62)[d]
1965	38,814	12,257 (32)	26,557 (68)[b]
1970	60,093	17,257 (29)	42,836 (71)[b]

Source: Yujiro Hayami et al., *A Century of Agricultural Growth in Japan* (Minneapolis and Tokyo: University of Minnesota Press and University of Tokyo Press, 1975).

[a] Based on 1934-1936 prices. Parentheses enclose percentages of total expenditures.

[b] Five-year averages ending the years shown, except for the 1918 and 1923 figures which are the five-year averages ending in 1917 and 1922, respectively.

[c] Single-year figures of the years shown.

[d] Estimations: (1) Change in percentage between 1951-55 and 1956-60 was assumed to be the same between 1956-60 and 1961-65. (2) The percentage for 1958 was used for 1956-60.

project produced major breakthroughs. The rate of increase in rice yield began to decline. Japanese agriculture began to stagnate during the interwar period.

Meanwhile, not only the National Experiment Station but also the prefectural stations began crossbreeding projects. The projects were handicapped by a lack of coordination which tended to dissipate the limited research funds. In these circumstances, a nationwide coordinated crop breeding program called the Assigned Experiment System (the system of experiment assigned by the Ministry of Agriculture and Forestry) was established, first for wheat (1926), next for rice (1927), and subsequently for other crops and livestock.

Under the Assigned Experiment System, the national experiment stations were responsible for crossbreeding up to the selection of the first several filial generations. The regional stations, in each of eight regions, conducted further selections to adapt the seeds to regional ecologies. The varieties selected at the regional stations were then sent to the prefectural stations to be tested for their acceptability in specific locations. The varieties developed by this system

were called *Norin* (abbreviation of the words "Ministry of Agriculture and Forestry" in Japanese) varieties.

This system was outstandingly successful. The Mexican dwarf wheat, which is revolutionizing Mexican and Indo-Pakistan agriculture, was based on the *Norin* No. 10 wheat variety. The *Norin* numbered varieties successively replaced older varieties in the late 1930s. If the supply of fertilizer and other agricultural inputs had not been restricted during World War II, the second epoch of agricultural productivity growth in Japan – which occurred after the war – would probably have started in the late 1950s.

The Assigned Experiment System was an institutional innovation which economized on research resources – above all, knowledge and experience – while satisfying the requirement for location-specific agricultural research. The system has evolved so that now both the national and the prefectural experiment stations conduct crossbreeding from the first step of artificial crossing. This change reflects the increase in knowledge and experience of the prefectural stations. It has enabled the prefectural stations to conduct research more specifically designed to satisfy local demand.

Social Returns to Agricultural Research Investment

From the historical review in the previous section it seems reasonable to hypothesize that the evolution of agricultural research in Japan was spurred by the benefits which research contributed to society and to national development. To demonstrate the gains from public investment in agricultural research, we will attempt in this section to estimate the social rates of return to rice-breeding research.

Theoretical Framework for Estimating Social Returns

Using Marshallian concepts of social welfare and cost, social returns to rice-breeding research are measured by the changes in consumers' and producers' surpluses that result from the shift in the rice supply curve corresponding to a shift in the rice production function. (Producers' surplus is defined as the total value of output in agriculture minus the payment to the inputs applied to agricultural production that are supplied from nonagriculture; it includes not only the entrepreneurial profit of farmers but also land rent, wages to family labor, and returns to farm capital. For a more detailed discussion see chapter 6.) This relationship is shown in Figure 2-2, in which d and s_0 represent the actual demand and supply curves, whereas s_n represents the supply curve that would have existed if improved rice varieties had not been developed.

Assuming market equilibrium and no rice imports, the shift in the supply curve from s_n to s_0 would increase the consumers' surplus by (area ABC +

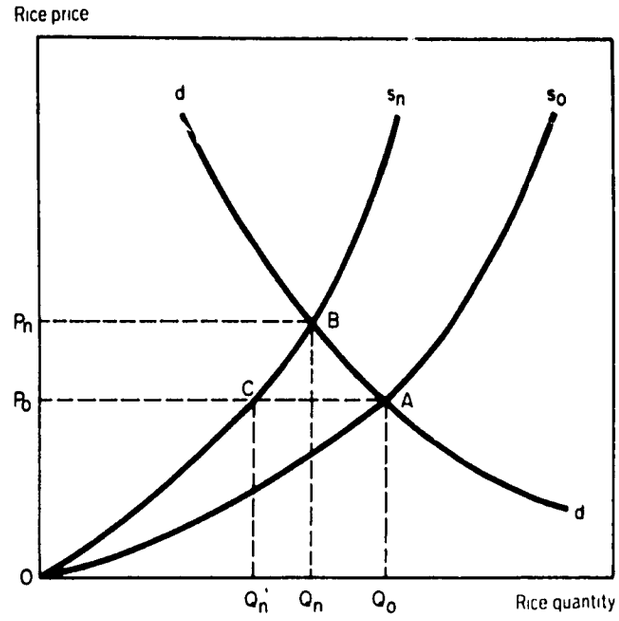

Figure 2-2. Model of estimating social returns to rice-breeding research.
Source: Masakatsu Akino and Yujiro Hayami, "Efficiency and Equity in Public Research: Rice Breeding in Japan's Economic Development," *American Journal of Agricultural Economics*, 57:1 (February 1975), 4.

area BP_nP_oC), the producers' surplus by (area ACO − area BP_nP_oC), and the social benefit by (area ABC + area ACO).

In reality, however, Japan remained a net importer of rice during this period. Rice imports were regulated by government tariffs and quotas.[10] As discussed previously, the government sought to prevent a rise in the cost of living of urban workers. In fact, the government maintained stable rice prices relative to the general price index until around 1960. Rice prices then began to rise sharply because government policy regarding rice shifted to protecting producers (Figure 2-3, lower section).

If basic policy was to secure sufficient rice to prevent a rise in the urban workers' cost of living, and, if increasing domestic rice production owing to varietal improvement and other means did not meet increasing demands, the gap would have to have been filled by imports. Let P_o in Figure 2-2 be the price of rice that the government determined to maintain. If the domestic supply schedule did not shift from s_n to s_o, the government would have in-

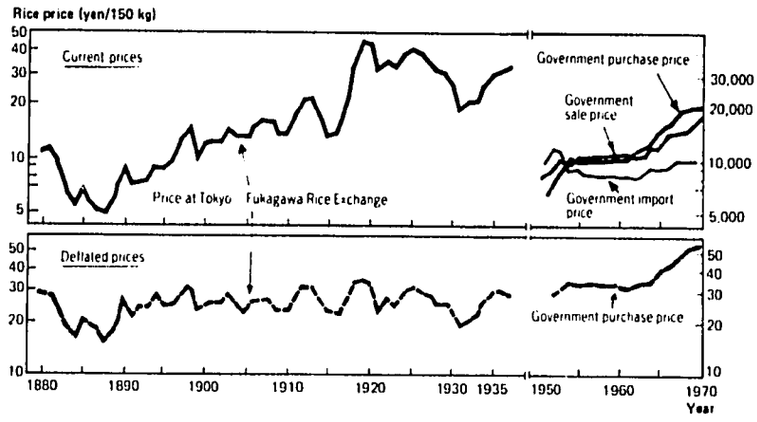

Figure 2-3. Changes in rice prices, both current and deflated by the General Price Index (1934-36 = 100), in Japan (log-scale in brown rice term), 1880-1937 and 1951-70.
Source: Yujiro Hayami, "Rice Policy in Japan's Economic Development," *American Journal of Agricultural Economics*, 54:1 (February 1972), 22.

creased rice imports by $Q'_n Q_o$. Then, the producers' surplus would have been reduced by area BP_nP_oC without being compensated for by area ACO. In this case, foreign exchange would have been reduced by area ACQ'_nQ_n.

If there had been no breeding program to shift the domestic supply from s_n to s_o, the producers' surplus would have been smaller by area ACO. This area may be defined as the producers' gain in economic welfare from the rice breeding research (assuming price stability through rice imports). Since the consumers' surplus would remain unchanged under this assumption, the producers' gain would equal the total social benefit produced from the rice breeding programs. Another contribution of the breeding research to the national economy in the open economy case would be the gain in foreign exchange by area ACQ'_nQ_o.

In reality, in spite of the efforts to shift the rice production function upward, domestic supplies did not keep up with demand. This resulted in rice imports of about 5 to 20 percent of domestic production. Therefore, s_o in Figure 2-2 would have been located somewhere to the left of A if we define A as the point of equilibrium of total market supply and demand. However, this does not require modification of our model. We will now estimate the social benefits of rice research in Japan using this model.[11]

Distribution of Social Benefits

Estimates of social benefits were conducted separately for the breeding programs before and after the introduction of the Assigned Experiment System

Table 2-6. Estimates of Social Benefits from Rice-Breeding Research Programs Begun before the Establishment of the Assigned Experiment System, Japan (million yen in 1934-36 prices)

	Autarky Case			Open Economy Case	
Year	Producers' Gain (1)	Consumers' Gain (2)	Total Social Benefits (3)=(1) + (2)	Producers' Gain (Total Benefits) (4)	Saving in Foreign Exchange (5)
1915 . . .	− 0.30	0.45	0.15	0.15	0.18
1916 . . .	− 0.32	0.48	0.16	0.16	0.19
1917 . . .	− 1.80	2.70	0.90	0.90	1.08
1918 . . .	− 4.20	6.30	2.11	2.10	2.52
1919 . . .	− 7.68	11.52	3.85	3.84	4.60
1920 . . .	− 12.47	18.75	6.28	6.25	7.50
1921 . . .	− 15.69	23.64	7.95	7.88	9.45
1922 . . .	− 26.21	39.51	13.30	13.17	15.80
1923 . . .	− 33.49	50.73	17.24	16.91	20.29
1924 . . .	− 45.90	69.75	23.85	23.25	27.90
1925 . . .	− 60.97	93.03	32.06	31.01	37.21
1926 . . .	− 57.37	87.54	30.17	29.18	35.01
1927 . . .	− 66.07	100.86	34.79	33.62	40.34
1928 . . .	− 67.65	103.38	35.73	34.46	41.35
1929 . . .	− 70.68	108.12	37.44	36.04	43.24
1930 . . .	− 86.68	132.87	46.19	44.29	53.14
1931 . . .	− 80.80	124.23	43.43	41.41	49.69
1932 . . .	− 102.25	157.86	55.61	52.62	63.14
1933 . . .	− 102.56	157.62	55.06	52.54	63.04
1934 . . .	− 77.01	118.41	41.40	39.47	47.36
1935 . . .	− 86.21	132.63	46.42	44.21	53.05
1936 . . .	− 103.53	159.35	55.82	53.12	63.74
1937 . . .	− 104.33	160.67	56.34	53.56	64.27
1938 . . .	− 103.65	159.62	55.97	53.21	63.85
1939 . . .	− 110.97	171.07	60.10	57.03	68.43
1940 . . .	− 95.79	147.52	51.73	49.18	59.01
1941 . . .	− 84.69	130.35	45.66	43.45	52.14
1942 . . .	− 100.18	154.12	53.94	51.38	61.65
1943 . . .	− 91.07	139.95	48.88	46.65	55.98
1944 . . .	− 81.11	124.52	43.41	41.51	49.81
1945 . . .	− 78.69	120.62	41.93	40.21	48.25
1946 . . .	− 73.44	112.35	38.91	37.45	44.94
1947 . . .	− 65.79	100.55	34.76	33.52	40.22
1948 . . .	− 69.27	105.70	36.43	35.24	42.28
1949 . . .	− 52.91	80.62	27.71	26.88	32.25
1950 . . .	− 57.49	87.50	30.01	29.17	35.00
1951 . . .	− 48.99	74.50	25.51	24.84	29.80
1952 . . .	− 48.84	74.15	25.31	24.72	29.66
1953 . . .	− 36.42	55.20	18.78	18.40	22.08

Table 2-7. Estimates of Social Benefits from Rice-Breeding Research Programs Established under the Assigned Experiment System, Japan (million yen in 1934-36 prices)

	Autarky Case			Open Economy Case	
Year	Producers' Gain (1)	Consumers' Gain (2)	Total Social Benefits (3)=(1)+(2)	Producers' Gain (Total Benefits) (4)	Saving in Foreign Exchange (5)
1932 . . .	− 0.66	0.99	0.33	0.33	0.39
1933 . . .	− 2.32	3.48	1.16	1.16	1.39
1934 . . .	− 3.12	4.68	1.56	1.56	1.87
1935 . . .	− 4.72	7.08	2.36	2.36	2.83
1936 . . .	− 7.40	11.10	3.71	3.70	4.44
1937 . . .	− 10.90	16.38	5.48	5.46	6.55
1938 . . .	− 15.15	22.80	7.65	7.60	9.12
1939 . . .	− 19.61	29.55	9.94	9.85	11.82
1940 . . .	− 19.96	30.09	10.13	10.03	12.03
1941 . . .	− 19.86	29.94	10.08	9.98	11.97
1942 . . .	− 26.97	40.71	13.74	13.57	16.28
1943 . . .	− 28.13	42.48	14.35	14.16	16.99
1944 . . .	− 29.69	44.88	15.19	14.96	17.95
1945 . . .	− 33.30	50.40	17.10	16.80	20.16
1946 . . .	− 37.74	57.18	19.44	19.06	22.87
1947 . . .	− 40.18	60.93	20.75	20.31	24.37
1948 . . .	− 50.49	76.68	26.19	25.56	30.67
1949 . . .	− 47.81	72.72	24.91	24.24	29.08
1950 . . .	− 59.86	91.20	31.34	30.40	36.48
1951 . . .	− 61.52	93.87	32.35	31.29	37.54
1952 . . .	− 62.64	95.43	32.79	31.81	38.17
1953 . . .	− 48.18	73.32	25.14	24.44	29.32
1954 . . .	− 51.04	77.64	26.60	25.88	31.05
1955 . . .	− 66.73	101.40	34.67	33.80	40.56
1956 . . .	− 47.42	71.88	24.46	23.96	28.75
1957 . . .	− 39.98	60.48	20.50	20.16	24.19
1958 . . .	− 37.64	56.88	19.24	18.96	22.75
1959 . . .	− 34.58	52.20	17.62	17.40	20.88
1960 . . .	− 32.79	49.47	16.68	16.49	19.78
1961 . . .	− 28.51	42.99	14.48	14.33	17.19

based on the data in Appendix 2-3. The results are summarized in Tables 2-6 and 2-7. The most remarkable aspect of the autarky case results is that the social benefits produced from the research were totally captured by the consumers; the producers were worse off. Such results were derived from the application of low price elasticities of demand and supply. In particular, the demand elasticity plays a decisive role in the distribution of benefits among consumers and producers.

In reality, however, Japan did not operate in the condition of rice autarky

during the period of this analysis. If it is assumed that rice was imported, the producers' situation would have been even worse (as shown in Figure 2-2 by area ACO and as measured in Tables 2-6 and 2-7) if there had been no program for rice-breeding research. Thus, rice research preserved a larger share of the Japanese rice market for domestic producers. Without the research the Japanese economy would have lost foreign exchange, by area ACQ'_nQ_o. In fact, as the estimates in Tables 2-6 and 2-7 indicate, the possible loss of foreign exchange owing to the shortage in the domestic rice supply during the 1930s would have amounted to about 5 percent of the total commodity import of Japan. Considering the chronic shortage of foreign exchange in the course of industrialization in Japan, the contribution of rice-breeding research to economic growth was quite significant. (However, it is difficult to estimate, in a term comparable to that of consumers' or producers' surplus, the gain in national economic welfare as a result of the saving of foreign exchange.)

In the open economy case, the producers were made better off by rice-breeding research, while the consumers continued to enjoy the same level of economic welfare without causing a drain on foreign exchange. In reality, however, it would appear that consumers' welfare could not have remained the same in the absence of the rice-breeding research. The constraints on foreign exchange would not have allowed additional rice imports on such a large scale. The autarky and the open economy cases in our analysis represent the polar cases between which reality lies.

The Social Rate of Returns

In order to assess the efficiency of rice-breeding research, both the external and the internal rates of returns are calculated by relating the research costs (data reported in Appendix 2-3) to the estimates of social benefits shown in Tables 2-6 and 2-7. (See accompanying box.)

The social rates of returns for the breeding programs before the Assigned Experiment System are calculated for two alternative cases: Case A assumes that net returns ($R_t - C_t$) in 1935 would have been maintained forever from that year; Case B assumes that net returns would become zero after 1953. Case A represents a polar case in which the knowledge and experience accumulated in a breeding program would continue to be utilized even after the varieties developed by the program were replaced by varieties developed by subsequent breeding programs, whereas Case B assumes that the life of the varieties ends when they are replaced by new ones.

In calculating the rates of returns in the programs under the Assigned Experiment System, two alternative assumptions about the stream of returns were made: Case A assumes that the net returns would have continued to be maintained forever at the 1951 level since that is the year when the area plant-

The external rate of returns (r_e) is defined as the rate calculated from the following formula:

$$r_e = \frac{100\,(iP + F)}{C}$$

where i is the external rate of interest, P is the accumulation of past returns, F is the annual future returns, and C is the accumulation of past research expenditures. The external rate of interest (i) is applied to the accumulation of both returns and expenditures. In this study 10 percent is assumed for the interest rate.

The internal rate of returns (r_i) is the rate that results in

$$\sum_{t=0}^{T} \frac{R_t - C_t}{(1 + r_i)t} = 0$$

where R_t is the social benefit in year t, C_t is the research cost in year t, and T is the year that the research ceases to produce returns.

ed in the *Norin* varieties reached a peak; Case B assumes that the net returns would have become zero after 1961.

The results of the estimates of the social rates of return for the autarky and the open economy cases are reported in Table 2-8. There are only small differences between the two. Both indicate that the crop-breeding research represents a lucrative public investment opportunity.

The estimates for the programs before the introduction of the Assigned Experiment System are comparable with Griliches's estimates for hybrid corn research in the United States (about 35 percent for the internal rate and 700 percent for the external rate of return); they also compare favorably with estimates for poultry research in the United States reported by Peterson (about 20 percent for the internal rate and 140 percent for the external rate).[12] The estimates of the rate of returns for rice research under the Assigned Experiment System are comparable with those for the cotton research in São Paulo, Brazil, by Ayer and Schuh (about 90 percent for the internal rate) and for wheat research in Mexico by Ardito Barletta (about 75 percent for the internal rate).[13] Judging from these estimates, there has been gross underinvestment in research to improve grain varieties in the world.

The results in Table 2-8 show that the social rate of return increased after the introduction of the Assigned Experiment System. This seems to suggest that efficiency was improved by this institutional innovation. We do not deny the possibility that the increase in the rate of return over time reflects scale

Table 2-8. Estimates of Social Rates of Returns to Rice-Breeding Research in Japan (million yen in 1934-36 constant prices)

Rates of Return	Autarky Case		Open Economy Case	
	Case A	Case B	Case A	Case B
Before Assigned Experiment System				
External Rate				
(1) Net cumulated past returns	985.88	7,660.95	952.52	7,392.64
(2) Past returns expressed as annual flow	98.58	766.09	95.25	739.26
(3) Net annual future returns	44.63	0	42.41	0
(4) Total net annual returns, (2) + (3)	143.21	766.09	137.66	739.26
(5) Cumulated past research expenditures	123.39	783.47	123.39	783.47
(6) Rate of return, 100 x (4)/(5)	116%	98%	112%	94%
Internal Rate	27%	25%	26%	25%
Under Assigned Experiment System				
External Rate				
(1) Net cumulated past returns	487.98	1,639.77	480.11	1,610.65
(2) Past returns expressed as annual flow	48.79	163.97	48.01	161.06
(3) Net annual future returns	31.73	0	30.67	0
(4) Total net annual returns, (2) + (3)	80.52	163.97	78.68	161.06
(5) Cumulated past research expenditures	14.51	46.78	14.51	46.78
(6) Rate of return, 100 x (4)/(5)	554%	350%	542%	344%
Internal Rate	75%	73%	75%	73%

economies inherent in the process of research in producing knowledge and information. However, if there were no organizational improvements to permit better coordination of the enlarged research complex, the increase in the efficiency of rice-breeding research would not have been as dramatic as measured in this study.

Conclusion and Implications

The Japanese agricultural research system evolved under the strong leadership of the government. The current system is dominated by public-supported institutions, including both national and prefectural experiment stations.

We hypothesized that the government's involvement in agricultural research activities was prompted by the high rate of social returns. The case study of rice-breeding research indicates that the investment in agricultural research was indeed lucrative for society. Moreover, we found that financing agricultural research out of tax revenue can be justified because the major gains from the research increased consumers' surplus or contributed to economic development by lowering the cost of living for urban workers and saving foreign exchange.

The government's recognition of the need for agricultural research is one of the keys to understanding how agriculture grew in Japan despite the very unfavorable endowment of land relative to labor. However, it appears that there was gross underinvestment in agricultural research even in Japan. For example, if many more resources had been allocated to agricultural research in the early days of modern economic growth, the interwar stagnation of Japanese agriculture might have been avoided or reduced considerably. Public planners and policy makers in the world should be constantly reminded that there is a tendency to underestimate the returns to research because of uncertainty and long gestation periods. Rarely are sufficient resources allocated to agricultural research. Hence, efficient allocation of research resources among different research enterprises is important.

The conflict between the needs for location-specificity and scale economies poses a critical problem in the allocation of scarce research resources. The Assigned Experiment System in Japan represents a successful attempt in solving this problem. Such organizational innovations should be promoted in developing countries whose research resources, particularly in research and technical staff, are very limited.

Interaction among research administrators, scientists, and farmers is of critical importance to produce information useful to farmers. At the same time, the interaction of agricultural scientists with those in neighboring disciplines is a source of research productivity. The close association of agricultur-

al experiment stations with extension programs and agricultural associations in Japan increased the responsiveness of agricultural research to the needs of farmers.

It must be noted, however, that this system was established without formally linking experiment stations with universities. Perhaps this represents a bad example which should not be repeated in developing countries. Today agricultural science in Japan is far more advanced than it was in the Meiji period. Specialized research with an interdisciplinary approach seems to be required for the transfer of technology developed in advanced countries to developing countries. For this requirement the close linkage between experiment stations and universities is necessary.

At the same time, the close linkage between experiment stations and universities should by no means be established at the sacrifice of the responsiveness of agricultural research to the needs of farmers. How to establish a close association between experiment stations and universities while promoting active interactions among farmers and research workers, either directly or through extension agents, remains a major unsolved issue in organizing agricultural research for agricultural economic development.

APPENDIXES

Appendix 2-1. Specification of Demand and Supply Schedules

The first step to estimate the changes in consumers' and producers' surpluses is the specification of the demand and supply schedules. In this study a constant elasticity demand function is assumed as

$$q = Hp^{-\eta}$$

where q and p are, respectively, the quantity and the price of rice, and η is the price elasticity of demand. Similarly, a constant elasticity supply function is assumed as

$$q = Gp^{\gamma}$$

where γ is the price elasticity of the rice supply. We assume a hypothetical supply curve that would have existed in the absence of improved varieties as

$$q = (1 - h)Gp^{\gamma}$$

where h represents the rate of shift in the supply function owing to varietal improvement. In competitive equilibrium the supply function is equivalent to

the marginal cost function derived from the production function. Since the relation between the rate of shift in the marginal cost function (h) and the rate of shift in the production function (k) can be approximated by

$$h \cong (1 + \gamma)k$$

the following approximation formulas hold in equilibrium:

$$\text{area } ABC \cong \frac{1}{2} p_o q_o \frac{[k(1 + \gamma)]^2}{\gamma + \eta}$$

$$\text{area } ACO \cong k p_o q_o$$

$$\text{area } BP_n P_o C \cong \frac{p_o q_o k(1 + \gamma)}{\gamma + \eta} \left[1 - \frac{1}{2} \frac{k(1 + \gamma)\eta}{\gamma + \eta} - \frac{1}{2} k(1 + \gamma)\right]$$

and

$$\text{area } ACQ'_n Q_o = (1 + \gamma) k p_o q_o.$$

For the derivation of the above formula, see Appendix 2-2.

Appendix 2-2. Derivation of the Model of Estimating Social Benefits from Rice-breeding Research

The relationship between h and k

The actual and the hypothetical supply functions that would have existed in the absence of improved varieties are assumed, respectively, as

$$q = Gp^{\gamma} \tag{1}$$

$$q = (1 - h)Gp^{\gamma}. \tag{2}$$

Assuming that the supply curves are equivalent to the marginal cost curves, the marginal costs $(\frac{dc}{dq})$ are

$$\frac{dc}{dq} = p = G^{-1/\gamma} q^{1/\gamma} \tag{3}$$

$$\frac{dc}{dq} = p = (1 - h)^{-1/\gamma} G^{-1/\gamma} q^{1/\gamma}. \tag{4}$$

Total cost curves derived by taking the integrals of the marginal cost curves which are assumed to pass through the origin are

$$C = \frac{\gamma}{(1 + \gamma)} G^{-1/\gamma} q^{(1 + \gamma)/\gamma} \tag{5}$$

$$C = \frac{\gamma}{(1+\gamma)} G^{-1/\gamma}(1-h)^{-1/\gamma} q^{(1+\gamma)/\gamma}. \tag{6}$$

Let q_o and q'_n represent respectively the output levels for a given cost in equations (5) and (6). Then, the relation between q_o and q'_n is represented approximately for a sufficiently small value of h as

$$(q'_n/q_o) \cong 1 - h/(1+\gamma). \tag{7}$$

Since k is denoted $(q_o - q'_n)/q_o$, the relationship between h and k can be shown approximately as $h \cong (1+\gamma)k$. This formula implies that h becomes infinite when $\gamma = \infty$. This is due to the approximate nature of the formula. Actually, h is equal to $k/(1-k)$ when $\gamma = \infty$.

The Formulas of Social Returns, Changes in Consumers' Surplus, and Producers' Surplus

Area ABC is derived as follows:

p_o and p_n in Figure 2-2 are represented respectively as

$$p_o = (H/G)^{1/(\gamma+\eta)} \tag{8}$$

$$p_n = (H/G)^{1/(\gamma+\eta)}(1-h)^{-1/(\gamma+\eta)}. \tag{9}$$

Hence, $(p_n - p_o) \cong p_o h/(\gamma+\eta)$ for a sufficiently small value of h. Thus, area $ABC \cong \frac{1}{2} p_o q_o h^2/(\gamma+\eta) = \frac{1}{2} p_o q_o [k(1+\gamma)]^2/(\gamma+\eta)$.

Area ACO is derived as follows:

$$\text{area ACO} = \int_0^{p_o} hGp^{\gamma}\,dp = p_o q_o h/(1+\gamma) \cong k p_o q_o.$$

Area BP_nP_oC is derived as follows:

$$\text{area } BP_nP_oC \cong (p_n - p_o)q_o - \frac{1}{2}(p_n - p_o)(q_o - q_n) - \text{area ABC}.$$

Since $(p_n - p_o)$ is approximately equal to $p_o h/(\gamma+\eta)$, and $(q_o - q_n)$ to $q_o h\eta/(\gamma+\eta)$, then

$$\text{area } BP_nP_oC \cong \frac{p_o q_o k(1+\gamma)}{\gamma+\eta}\left[1 - \frac{1}{2}\,\frac{k(1+\gamma)\eta}{\gamma+\eta} - \frac{1}{2}k(1+\gamma)\right].$$

Appendix 2-3. Parameters and Data of Estimating the Social Rates of Returns to Rice-Breeding Research

Demand and Supply Parameters

The estimate of the price elasticity of demand for rice (η) is available from Ohkawa, whose estimates are based on 1931-38 household survey data for the

urban population, and on 1920-38 market data for the rural population.[14] The estimates differ for different occupational, regional, and income groups, but they cluster around 0.2. We will adopt 0.2 for η.

The price elasticity of the rice supply (γ) was estimated by Hayami and Ruttan on the basis of 1890-1937 time-series data.[15] The supply elasticity was also estimated by Yuize on a 1952-62 time-series.[16] The results of the former study indicate that γ was in the vicinity of 0.2; those of the latter indicate that γ ranged from 0.2 to 0.3. Here we will adopt 0.2 for γ.

Shift in Rice Production Function

We estimated the rate of shift in the aggregate rice production function (k) by averaging the yield differences between the improved and the unimproved varieties for the same level of inputs, using the areas planted in the improved varieties as weights. The data for the differences in yield between the improved varieties and the varieties that were replaced by the improved varieties at the same level of inputs are based on the results of the comparative yield tests at various agricultural experiment stations.

A good collection of the results of comparative rice yield tests for the varieties developed before the Assigned Experiment System is available in the reports of a survey conducted by the Ministry of Agriculture and Forestry. These reports have gathered the results of the three years' tests for the 130 improved varieties in comparison with those of the varieties that they replaced. We used these data to calculate the rate of shift in the aggregate rice production function in the t-th year owing to varietal improvement (k_t) by the following formula:

$$k_t = \sum_i \sum_j k_{ij} \frac{A_{ijt}}{A_t}$$

where k_{ij} is the ratio of the increase in rice yield of the i-th variety in the j-th region over the variety that it replaced; and A_t and A_{ijt} are, respectively, the total rice area in the nation and the rice area planted in the i-th variety in the j-th region.

Because of data limitations a cruder method is applied for the estimation of the rate of the production function shift owing to the varieties developed by the Assigned Experiment System. Judging from a limited number of the results of comparative yield tests, we adopted 6 percent as the average rate of yield increases of the *Norin* varieties over the varieties that they replaced. This rate was multiplied by the ratio of the area planted in the *Norin* varieties in order to calculate the rates of shift in aggregate rice production owing to the breeding research under the Assigned Experiment System. The results of the estimation of the k_t's are shown in Table 2-9.

Table 2-9. Estimates in the Rate of Shift in the Rice Production Function owing to Varietal Improvement in Japan

Programs Initiated Before the Assigned Experiment System		Programs Established Under the Assigned Experiment System	
Year	k_t	Year	k_t
1915 . . .	0.01%	1932 . . .	0.02%
1916 . . .	0.01	1933 . . .	0.06
1917 . . .	0.06	1934 . . .	0.11
1918 . . .	0.14	1935 . . .	0.15
1919 . . .	0.23	1936 . . .	0.20
1920 . . .	0.36	1937 . . .	0.30
1921 . . .	0.52	1938 . . .	0.42
1922 . . .	0.79	1939 . . .	0.52
1923 . . .	1.11	1940 . . .	0.60
1924 . . .	1.48	1941 . . .	0.66
1925 . . .	1.89	1942 . . .	0.74
1926 . . .	1.91	1943 . . .	0.82
1927 . . .	1.97	1944 . . .	0.93
1928 . . .	2.08	1945 . . .	1.02
1929 . . .	2.20	1946 . . .	1.13
1930 . . .	2.41	1947 . . .	1.26
1931 . . .	2.73	1948 . . .	1.40
1932 . . .	3.17	1949 . . .	1.56
1933 . . .	2.70	1950 . . .	1.72
1934 . . .	2.77	1951 . . .	1.89
1935 . . .	2.80	1952 . . .	1.75
1936 . . .	2.87	1953 . . .	1.62
1937 . . .	2.94	1954 . . .	1.55
1938 . . .	2.94	1955 . . .	1.49
1939 . . .	3.01	1956 . . .	1.20
1940 . . .	2.94	1957 . . .	0.96
1941 . . .	2.87	1958 . . .	0.86
1942 . . .	2.80	1959 . . .	0.76
1943 . . .	2.72	1960 . . .	0.70
1944 . . .	2.58	1961 . . .	0.63
1945 . . .	2.44		
1946 . . .	2.22		
1947 . . .	2.08		
1948 . . .	1.93		
1949 . . .	1.79		
1950 . . .	1.65		
1951 . . .	1.50		
1952 . . .	1.36		
1953 . . .	1.22		

Value of Rice Output

Data for the value of rice output (p_0q_0) are obtained by valuing the physical outputs of rice by the 1934-36 average price in order to estimate the stream of social benefits in real terms. The years generally used as the basis of

Table 2-10. Expenditures on Rice-Breeding Programs by National and Prefectural Governments in Japan (thousand yen in 1934-36 constant prices)

Programs Initiated Before the Assigned Experiment System				Programs Established Under the Assigned Experiment System			
Year	National	Prefectural	Total	Year	National	Prefectural	Total
1904 . . .	135	330	465	1927 . . .	97		97
1905 . . .	136	327	463	1928 . . .	83		83
1906 . . .	137	362	499	1929 . . .	87		87
1907 . . .	130	365	495	1930 . . .	94		94
1908 . . .	162	445	607	1931 . . .	98		98
1909 . . .	158	439	597	1932 . . .	86	11	97
1910 . . .	160	489	649	1933 . . .	79	29	108
1911 . . .	185	502	687	1934 . . .	70	58	128
1912 . . .	142	465	607	1935 . . .	65	86	151
1913 . . .	113	402	515	1936 . . .	58	116	174
1914 . . .	121	468	589	1937 . . .	49	166	215
1915 . . .	134	520	654	1938 . . .	44	198	242
1916 . . .	142	541	683	1939 . . .	36	205	241
1917 . . .	106	483	589	1940 . . .	32	192	224
1918 . . .	94	499	593	1941 . . .	32	193	225
1919 . . .	100	538	638	1942 . . .	30	187	217
1920 . . .	98	657	755	1943 . . .	41	178	219
1921 . . .	130	923	1,053	1944 . . .	37	167	204
1922 . . .	119	834	953	1945 . . .	25	131	156
1923 . . .	150	877	1,027	1946 . . .		108	108
1924 . . .	182	785	967	1947 . . .		194	194
1925 . . .	112	818	930	1948 . . .		298	298
1926 . . .	135	1,035	1,170	1949 . . .		417	417
1927 . . .	126	1,180	1,306	1950 . . .		479	479
1928 . . .	139	1,265	1,404	1951 . . .		624	624
1929 . . .	147	1,140	1,287	1952 . . .		652	652
1930 . . .	163	1,297	1,460	1953 . . .		685	685
1931 . . .	175	1,350	1,525	1954 . . .		729	729
1932 . . .	320	1,450	1,770	1955 . . .		642	642
1933 . . .	243	1,456	1,699	1956 . . .		588	588
1934 . . .	252	1,454	1,706	1957 . . .		527	527
1935 . . .	261	1,536	1,797	1958 . . .		505	505
1936 . . .		1,323	1,323	1959 . . .		480	480
1937 . . .		1,257	1,257	1960 . . .		419	419
1938 . . .		1,150	1,150	1961 . . .		403	403
1939 . . .		1,075	1,075				
1940 . . .		791	791				
1941 . . .		690	690				
1942 . . .		593	593				
1943 . . .		500	500				
1944 . . .		401	401				
1945 . . .		265	265				
1946 . . .		186	186				
1947 . . .		268	268				
1948 . . .		337	337				
1949 . . .		394	394				
1950 . . .		382	382				
1951 . . .		409	409				
1952 . . .		424	424				
1953 . . .		427	427				

index construction are 1934-36 because it is considered that "normal" price relations prevailed during this period. The price of rice relative to the prices of other commodities was somewhat lower during this time because this period was characterized by a large inflow of rice from overseas territories – Korea and Taiwan – although the government tried to support the price of rice by increasing the government inventory. The valuation of output by the 1934-36 average price might result in an underestimation of the stream of social benefit.

Cost of Rice-Breeding Research

Data for the expenditure on rice-breeding research before the Assigned Experiment System are not readily available. There is an estimate that the ratio of expenditures on crop-breeding programs to the total expenditures of agricultural experiment stations in 1927 was 43 percent for the national experiment stations and 45 percent for the prefectural experiment stations.[17] We estimated the annual expenditures for rice-breeding research by multiplying these ratios by the total expenditures of the national and prefectural stations.

All expenditures for research under the Assigned Experiment System were paid for from the budget of the central government, and these data are readily available. In addition to the expenditures covered by the central government, prefectural governments paid for the costs of the tests of local adaptability of the *Norin* varieties and of the multiplication of improved seeds. Those expenditures by the local governments were estimated by multiplying the expenditures for crop-breeding programs in the prefectural experiment stations by the ratios of area planted in the *Norin* varieties to area planted in the total improved varieties.

The time-series of the expenditures on crop-breeding programs thus estimated were deflated by the Consumer Price Index, with 1934-36 = 100. The results are shown in Table 2-10. The estimates of the expenditures on crop-breeding programs include not only the cost of research and development but also the cost of extension, such as the multiplication of seeds. In addition, our cost data include not only the projects on rice but also those on *mugi* (wheat, barley, and naked barley), although rice research projects should outweigh all others in the programs.

NOTES

1. This chapter summarizes a part of the results of the research project entitled "Science and Agricultural Progress: The Japanese Experience," which was supported by a grant of the Rockefeller Foundation to the University of Minnesota Economic Development Center. It draws heavily on Masakatsu Akino and Yujiro Hayami, "Efficiency and Equity in Public Research: Rice Breeding in Japan's Economic Development," *American*

Journal of Agricultural Economics, 57 (February 1975), 1-10; Yujiro Hayami and Saburo Yamada, "Agricultural Research Organization in Economic Development: A Review of the Japanese Experience," *Agriculture in Development Theory*, ed. Lloyd G. Reynolds (New Haven: Yale University Press, 1975); and Yujiro Hayami, in association with Masakatsu Akino, Masahiko Shintani, and Saburo Yamada, *A Century of Agricultural Growth in Japan: Its Relevance to Asian Development* (Minneapolis and Tokyo: University of Minnesota Press and University of Tokyo Press, 1975).

2. Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore and London: Johns Hopkins University Press, 1971), p. 144.

3. The historical sketch in this section draws heavily on Hayami and Ruttan, *Agricultural Development*, pp. 153-163. Useful references are Toshio Furushima, ed., "Nogaku" ("Agricultural Science"), *Nihon Kagaku Gijutsushi Taikei* (*The Comprehensive History of Science and Technology in Japan*), vols. 22 and 23 (Tokyo: Daiichi Hoki Shuppan, 1967 and 1970); Nogyo Hattatsushi Chosakai (Agricultural Development History Research Committee), ed., *Nihon Nogyo Hattatsushi* (*History of Agricultural Development in Japan*), 10 vols. (Tokyo: Chuokoronsha, 1953-58); Takekazu Ogura, ed., *Agricultural Development in Modern Japan* (Tokyo: Fuji Publishing Co., 1963); Yukihiko Saito, *Nihon Nogakushi* (*The History of Agricultural Science in Japan*), 2 vols. (Tokyo: National Research Institute of Agriculture, 1968 and 1971).

4. Ministry of Agriculture and Forestry, *Meiji Zenki Kannojiseki Shuroku* (*The Compilation of Measures to Encourage Agriculture*), vol. 2, reprint (Tokyo: Dainihon Nokai, 1939), pp. 1765-1779, 1766-1767.

5. *Ibid.*, pp. 1778-1779.

6. *Ibid.*, p. 1774.

7. Saito, *Nihon Nogakushi*, p. 121.

8. *Ibid.*, pp. 126-134, 161-164.

9. Takamine Matsuo, "Suito Hinshu Kairyo Shijo no Shomondai" ("Problems in the History of Rice Variety Improvement"), Hattatsushi Chosakai Data no. 42, mimeographed (Tokyo, 1951).

10. For a historical review of rice policy in Japan, see Yujiro Hayami, "Rice Policy in Japan's Economic Development," *American Journal of Agricultural Economics*, 54 (February 1972), 19-31.

11. For the quantitative steps used to put the model into practice see Appendix 2-2.

12. Zvi Griliches, "Research Costs and Social Returns: Hybrid Corn and Related Innovations," *Journal of Political Economy*, 66 (October 1958), 419-431; W. L. Peterson, "Return to Poultry Research in the United States," *Journal of Farm Economics*, 49 (August 1967), 656-669.

13. H. W. Ayer and G. E. Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in São Paulo, Brazil," *American Journal of Agricultural Economics*, 54 (November 1972), 557-569; Nicolas Ardito Barletta, "Costs and Social Benefits of Agricultural Research in Mexico," Ph.D. dissertation (Chicago: University of Chicago, 1971).

14. Kazushi Ohkawa, *Shokuryo Keizaino Riron to Keisoku* (*Theory and Measurement of Food Economy*) (Tokyo: Nihon Hyoronsha, 1945), pp. 9-34, 77-96.

15. Hayami and Ruttan, *Agricultural Development*, pp. 236-237.

16. Yasuhiko Yuize, "Nogyo Seisan ni Okeru Kakaku Hanno" ("On the Price Responses in Agricultural Production"), *Nogyo Sogo Kenkyu*, 19 (January 1975), 107-142.

17. Takeichi Oda, "Honpo ni okeru Beibaku Hinshu Kairyo Jigyo no Taiko" ("Summary of the Rice and Mugi Varietal Improvement Programs in Japan"), *Dainihon Nokaiho* (November 1929), 14-28.

3

Organization and Productivity of the Federal-State Research System in the United States[1]

Willis L. Peterson and Joseph C. Fitzharris

The agricultural research system of the United States is discussed in this chapter under two broad headings. In part I, we examine the organization of the federal-state system. We investigate how political and physical geography as well as production and input trends in the agricultural sector influenced the search by more efficient farmers for new inputs, techniques, and organizational forms. The origins of the federal system and its structure are detailed. A view of the workings and structural complexities of the federal-state system is gained through an examination of the agricultural research system of Minnesota. The origins of the state system, the resulting organizational structure, and the types of work done at the state level are reviewed.

Part II deals primarily with the productivity of the federal-state research system. After briefly reviewing the relationship between agricultural research and farm productivity, we attempt to explain the absence of productivity growth in United States agriculture until about forty years after the establishment of the federal-state system. Viewing agricultural research and extension as an investment, we then provide rough estimates of the marginal internal rate of return to this investment for specified periods from the 1930s to the 1980s. Finally, some evidence is presented which bears upon the question of whether or not there is an efficient allocation of public agricultural research in the United States.

Organization of the Federal-State Research System

The federal-state agricultural research system of the United States is a decentralized, cooperative system composed of both federal and state agencies. Without central control, the system attempts to allocate resources, solve pressing problems, produce new varieties of crops and livestock, and conduct basic agricultural research.

The United States research system reflects the political dualism, geographic differentials, and historical accidents surrounding its origins. The vast bulk of work is done on the state level by the various autonomous state agricultural experiment stations. For this reason the following case study, in which we examine the development of the Minnesota Agricultural Experiment Station and the Institute of Agriculture in the University of Minnesota, will provide a good basis for understanding the overall system.

The Minnesota Case

The College of Agriculture of the University of Minnesota was founded in 1869, eleven years after the first efforts to develop a college of agriculture proved unsuccessful. The college lacked stability in the early years, having very few students and a rapid turnover in teaching staff. In addition, its experimental farm was inadequate and poorly funded. A new campus and a farm were acquired in 1882, and the Farmers' Lecture Courses, the forerunner of the Agricultural Extension Service in Minnesota, were initiated.[2]

As a part of the movement to gain federal support for agricultural research, the Minnesota legislature authorized a state agricultural experiment station at the university. Established by the university regents on the university farm in 1885, the Minnesota station remained a paper creation until the passage of the Federal Hatch Act in 1887. After Hatch Act funds became available, the station hired a staff and began operation.

Agricultural extension work was initiated in 1910, and the Agricultural Extension Service was established in 1914. In the years after 1893, branch stations were founded to serve diverse sections of the state. Expansion of the college faculty-station staff was followed by the beginning of graduate training. As this system developed, many of the geographic and economic forces that affected the national system also affected the state system.

The state setting. The Minnesota agricultural research, extension, and education system developed out of local, state, and national movements for government aid to agriculture. Farmers' organizations were instrumental in the origins and development of the Minnesota system. Soil differences, production trends, and other problems too great for farmers and farmers' organiza-

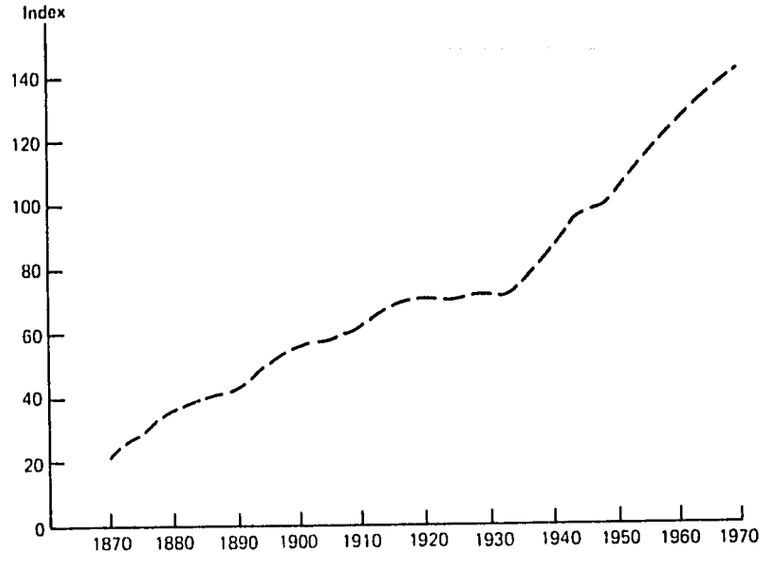

Figure 3-1. Index of United States farm production, 1870-1970.
Source: Bureau of the Census, *Historical Statistics of the United States*, 1960, p. 288 (Series K-190). USDA, *Agricultural Statistics, 1972*, p. 537 (adjusted from a 1967 base). Decennial observations, 1870-1910.

tions alone to solve helped shape the developing system of agricultural research in the state.

Geography. Because no single research unit could begin to deal with the problems posed by the great regional differences in soil and climate in the United States, the country's political structure demanded the creation of a federal-state agricultural research system.

The salient feature of Minnesota political geography is its urban-rural contrast, but this has not seriously affected the development of the Minnesota Agricultural Experiment Station and Institute of Agriculture. More important factors are soil and climatic differences throughout the state. There is considerable variation in growing season, temperature, and average moisture among the diverse regions of Minnesota. Type and quality of soil, which affect type of farming, vary across the state. Because of these physical and climatic factors, branch stations located in the major regions have been important components of the Minnesota agricultural research system.

Production and input trends. United States farm output tripled between 1870 and 1915. Then it remained roughly constant until 1935 when another period of rapid growth began which lasted until 1945. Since 1950, growth in farm output has been rapid (Figure 3-1).

The growth of farm output before 1915 paralleled the increase in improved acreage during the same period. After 1915, this very clear relationship between the expansion of farm land and the growth in farm output ceased to exist, as urbanization increased and farm land dwindled. Between 1915 and 1970, farm labor also declined drastically. Of the traditional factors of production only capital expanded.

The rise in farm output to 1900 can be explained by geographic expansion of agriculture, that is, by expansion in amount of land used for farming, although capital and the number of farmers were also increasing. After 1910, geographic expansion does not contribute appreciably to the expansion of output. Figure 3-2 illustrates the relationship among the expansion of land, labor, and capital. After 1900, capital becomes increasingly important, except during the agricultural depression of the 1920s and 1930s. Clearly, capital (the value of land and buildings) does not account for the amount spent on machinery, fertilizer, disease-resistant strains of crops, and better livestock. And perhaps even more important, capital does not include better farming practices.

Better farming practices alone tend, ceteris paribus, to increase output. Combining better farming methods with hardier and/or disease-resistant crop strains leads to a further increase in agricultural production. Improved health of livestock also increases farm income, or production. After 1880, all these developments resulted from the work of the agricultural experiment stations. These stations worked with existing crops, using a trial selection process. After 1900, some basic research led to cures for various livestock diseases (e.g., hog cholera serum). The objective of this work was to maintain yields and production levels.

Minnesota production trends. In Minnesota the value of agricultural production grew sevenfold between 1880 and 1920. During the 1920s and the early 1930s, output declined slightly. After 1935, production again rose, tripling by 1950. A brief decline in the late 1950s and early 1960s interrupted an otherwise continual increase in the value of agricultural production (Figure 3-3).

Between 1880 and 1930, farms doubled in number and improved acreage tripled. Land in farms continued to expand to 1950, after which it declined gradually (Figure 3-4). The decline in improved acreage after 1950, however, was twice as great as the decline in total acreage. Since 1940, the number of

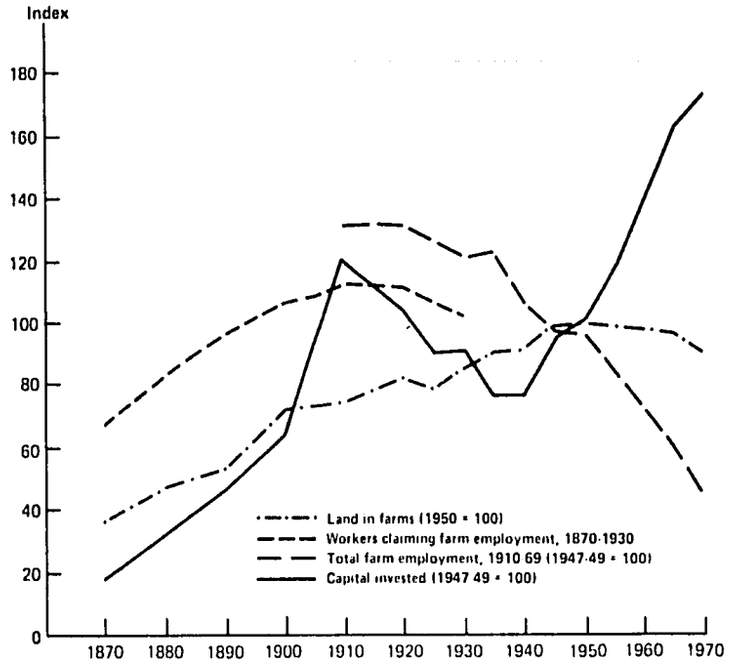

Figure 3-2. Indices of land, labor, and capital in United States agriculture, 1870-1970.
Source: Bureau of the Census, *Historical Statistics of the United States*, 1960, p. 72 (Series D-37), p. 280 (Series K 73-75). USDA, *Agricultural Statistics, 1962*, p. 512; *1972*, pp. 504, 523, 537; *1973*, p. 424.

farms has declined, and total labor employed (both paid and unpaid) in farming fell rapidly between 1940 and 1970. Aggregate capital input (in horsepower equivalents) is the only input that has risen over the entire period (Figure 3-5).[3]

Efforts by the Minnesota station to produce hardier crop varieties with shorter growing seasons resulted in increased land productivity between 1900 and 1920. In the 1930s, and again after 1950, land productivity rose as more fertilizers and pesticides and better disease-resistant crops were utilized. With the exception of the 1890s and the 1930s, labor productivity has risen. The expansion of land per worker has been uneven, varying with the adoption of new methods and machinery. The substitution for human power of animal power, steam power, and the internal combustion engine/diesel engine tractor explains much of the change in the ratio of land to worker (Figure 3-6).

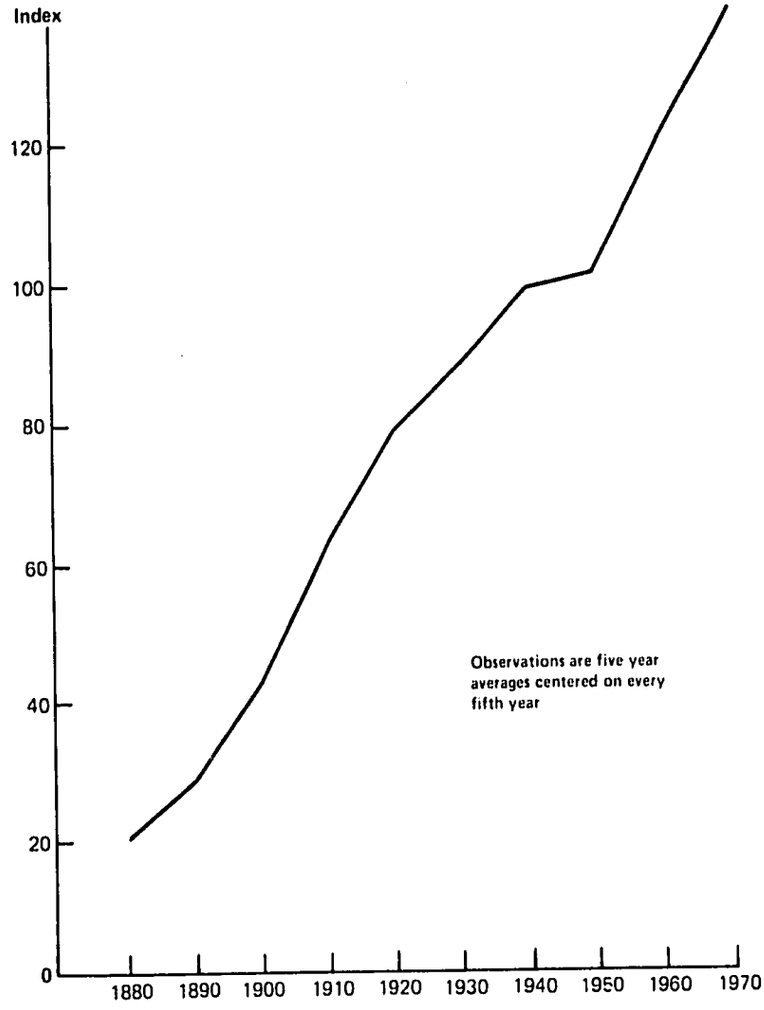

Figure 3-3. Index of the value of Minnesota agricultural production, 1880-1970 (constant dollar values, 1950 = 100).
Source: Joseph C. Fitzharris, *The Development of Minnesota Agriculture, 1880-1970: A Study of Productivity Change*, Department of Agricultural and Applied Economics Staff Paper P 74-20, St. Paul, University of Minnesota, September 1974, p. 5.

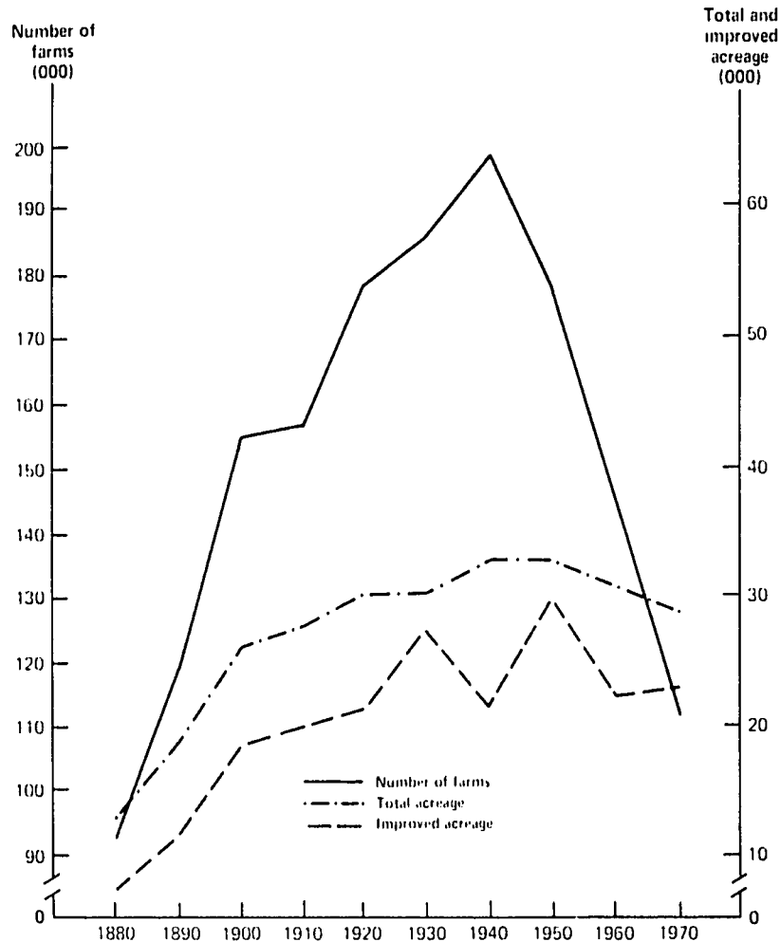

Figure 3-4. Minnesota agriculture, 1880-1970: Farms and farm acreage.
Source: Joseph C. Fitzharris, *The Development of Minnesota Agriculture, 1880-1970: A Study of Productivity Change*, Department of Agricultural and Applied Economics Staff Paper P 74-20, St. Paul, University of Minnesota, September 1974, p. 7.

Private efforts. Farmers' organizations in Minnesota from the 1850s to the 1890s attempted to solve many of the problems facing Minnesota farmers. Individual efforts had proved too costly, but group effort, because of the "free rider" problem, also failed. As a consequence, these organizations turned to the state government for assistance.

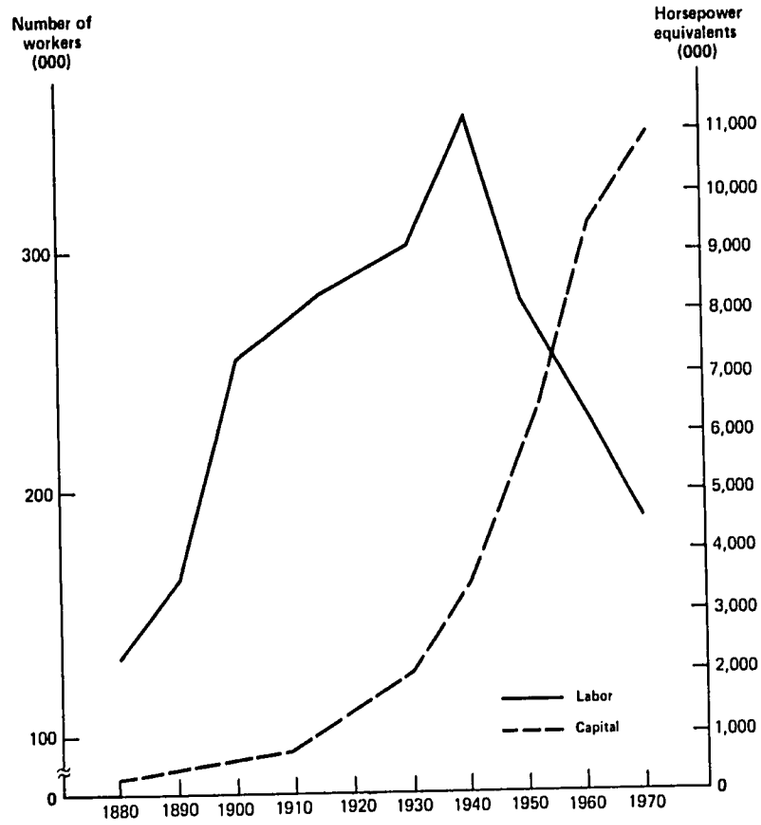

Figure 3-5. Minnesota agriculture, 1880-1970: Labor and capital (horsepower equivalent) inputs.
Source: Bureau of the Census, *Census of Agriculture*, 1880-1970. Joseph C. Fitzharris, *The Development of Minnesota Agriculture, 1880-1970: A Study of Productivity Change*, Department of Agricultural and Applied Economics Staff Paper P 74-20, St. Paul, University of Minnesota, September 1974, p. 9.

In 1885, two years before the Federal Hatch Act was passed, the Minnesota state government authorized an experiment station although it did not provide funding. Federal support was necessary for the development of the Minnesota station and agricultural experiment stations in other states. Yet in Minnesota, farmers' groups were instrumental in developing the agricultural experiment station. In the state elections of the 1880s and 1890s the objectives and accomplishments of the experiment station-college of agriculture

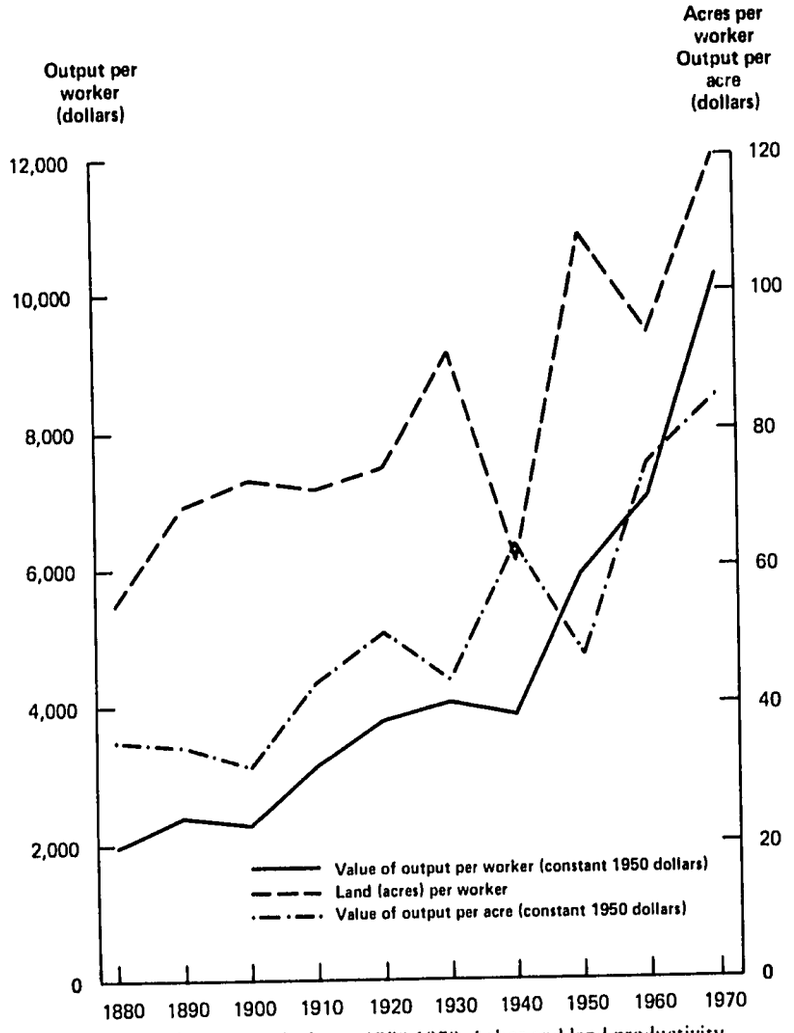

Figure 3-6. Minnesota agriculture, 1880-1970: Labor and land productivity. Source: Joseph C. Fitzharris, *The Development of Minnesota Agriculture, 1880-1970: A Study of Productivity Change*, Department of Agricultural and Applied Economics Staff Paper P 74-20, St. Paul, University of Minnesota, September 1974, p. 11.

were frequent topics of debate. These debates left the station and college administrators and the university regents firmly convinced that the first duty of the agricultural research, teaching, and extension system was to serve the farm sector's immediate needs. Basic research was thus given low priority in the early years.[4]

Origins of the Minnesota system. In 1881, Edwin D. Porter, the fourth professor of agriculture in the College of Agriculture, arrived in Minnesota and proceeded to meet with farmers' organizations, leading citizens, and legislators to determine their views on the role of the college and farm in the service of the state. Obtaining a new campus and farm for the college was Porter's first major accomplishment, and on the new farm he built the foundations for the Minnesota agricultural research and teaching system.[5]

From the early years of the college and station, the staff worked closely with the various farmers' organizations and commodity groups as they were founded. Frequently serving as officers of such groups, staff members gained close contact with the farmers and their problems.

In 1882, a lecture series called the Farmers' Lecture Courses was established, following the example of colleges in other states. Initially well received, the Lecture Courses, which were later expanded and renamed the Farmers' Institutes, went through a period of some uncertainty. In 1914 Congress passed the Smith-Level Act, which provided federal support for agricultural extension work. The Agricultural Extension Division of the experiment station was then separated from the station and became the Agricultural Extension Service. From 1910 to 1917 the Farmers' Institutes were absorbed by this service, which, by law, was supervised by a county farmers' organization called the Farm Bureau. This tie to a single farmers' organization, particularly in years of conflict among the various farmers' groups, had a deadening effect on the Minnesota Agricultural Extension Service (and on those of other states as well). Confidence in the service decreased, and many farmers believed that favoritism was shown to members of the Farm Bureau. In the 1950s, however, the service was formally separated from the farm bureaus and was funded by the state and federal governments, with the assistance of the counties in which state and federal agents were stationed.[6]

Structure. In 1888 the Minnesota Agricultural Experiment Station and Institute of Agriculture were organized in accordance with the requirements of the Hatch Act. The Institute (then the Department) of Agriculture was founded to provide supervision of teaching and research activities, and its dean was also the director of the Agricultural Experiment Station. Academic

subject-matter divisions were established in the station and college, and the same staff served both station and college.[7]

After the Agricultural Extension Service was initiated, the director was coequal with the station's vice-director and the associate dean of the college. When the Institute of Agriculture was created out of the Department of Agriculture in 1952, the directorship of the station was separated from the institute deanship. The college deans and the directors of the Experiment Station, the Agricultural Extension Service, and the Office of International Programs in Agriculture were coequal. The College of Veterinary Medicine became an autonomous unit, cooperating with the experiment station in animal research.

Over the years, the station and institute have made cooperative arrangements with agencies of the United States Department of Agriculture and with experiment stations in neighboring states, beginning with North and South Dakota in the 1890s. Several USDA personnel have been assigned to the station and given academic rank in the college. After Professor E. C. Stakman began working as a cooperating federal agent in barberry eradication and cereal rust investigation, numerous federal plant pathologists were assigned to the university, and in the 1950s the USDA Cereal Rust Laboratory was established at the university, cooperating with the Department of Plant Pathology.

Work done at the Minnesota station. In the first years of the Minnesota Agricultural Experiment Station's existence, the staff centered its efforts on disseminating information produced by other stations, adapting that information to Minnesota's soil and climatic conditions. It also began working to develop varieties of crops and shrubs suited specifically to Minnesota agricultural conditions. Later, the station began crop and livestock breeding experiments, conducted research in farm management and agricultural engineering, and worked on plant morbidities and mortalities, emphasizing the cereal rusts.

Much of the work done in the early years was maintenance work, or "applied-developmental" research, as illustrated by the work on cereal rusts. At first, barberry eradication programs were the major emphasis in the station's efforts to combat cereal rusts. Since the barberry plant harbored the wintering parasite, the fastest way to prevent cereal rust was to eradicate the wintering host. Later, as plant-breeding work became more sophisticated and as time permitted, disease-resistant plants were developed. Eradication of the barberry had "bought time" for the station to breed disease-resistant strains. The national effort was relaxed in the late 1940s, however, and in the early 1950s a serious outbreak of cereal rust destroyed much of Minnesota's wheat crop. From that time on, the Minnesota station, in close cooperation with

USDA laboratories and field units in Puerto Rico, on the mainland (particularly the Minnesota Cereal Rust Laboratory), and in Mexico (where new strains of cereal rust have been identified), has made an unremitting effort to breed disease-resistant plants. As a consequence, the problem of cereal rust, like that of blast, has been solved through the joint efforts of state and federal researchers.[8]

A leading and continuous line of work at the station has been crop adaptation. Efforts to move crops northward, adapting them to shorter growing seasons and colder climates, began in the 1890s. The initial work involved trial experiments and the selection of the best varieties. Considerable success was achieved in moving corn northward and in selecting wheat varieties better adapted to the shorter growing season of the northern two-thirds of the state. After the turn of the century, breeding and crossbreeding experiments were initiated. Breeding efforts were even more successful than trial experiments in producing varieties adapted to the rigorous climate and soil conditions in Minnesota. Much of this work has been cooperative, involving the neighboring state experiment stations, the Minnesota branch stations, and various bureaus in the USDA.[9]

Analysis of station publications reveals that applied-developmental work in the first forty years of the station was closely associated with basic research on crops and livestock (feeding trials, breeding, and varietal adaptation) and engineering work. There was a particular emphasis on human and animal nutrition studies in the years before World War I. In the 1920s and 1930s a pronounced trend toward basic-applied work began to develop.[10]

Maintenance research conducted into the 1920s proved to be very useful for the station. Although the station's work did not result in an increase in agricultural productivity, it probably prevented any appreciable decline in productivity owing to crop and animal diseases. Moreover, by conducting adaptation work for both plants and animals, the station produced strains and varieties which could be grown in Minnesota's colder climate and shorter growing season. Shelterbelt and drainage work improved both the soil and the soil retention of the farm. On balance, although the station did not make many new discoveries, it did preserve the status quo.

In the 1920s, the stations began moving more heavily into basic-applied research. The long time-lag between the initial investment in basic work and the beginnings of positive returns helps to account for the relatively constant productivity of the agricultural sector.

The Federal-State System

The federal-state agricultural research system developed in response to forces and factors operative in the American economy in the nineteenth cen-

tury. Originating in legislative response to the demands of farmers and their organizations, the system is still closely linked to farm groups. Its structure, powerfully influenced by its origins, is not well understood. Americans think of their state stations as autonomous bodies cooperating with other stations and with the USDA. Foreign observers often see the American system as quite centralized, despite some provincial tendencies.[11] Such observers also tend to view the stations' combination of teaching, research, and extension as inefficient.[12]

Origins and early development. In the 1790s, agricultural societies were established in several states. These societies, formed by the more successful, wealthier farmers, encouraged their members to experiment, to collect new varieties of seeds and animals, and to spread this knowledge widely. To this end, the societies published the proceedings of their meetings, sponsored farm journals, and sponsored and were instrumental in the establishment of state agricultural fairs.

As private effort and initiative in agricultural research became increasingly costly, the problem of adequately supporting this research grew. By the 1840s the agricultural societies had turned for assistance to their state governments, several of which responded by founding state departments of agriculture. These departments did not conduct research but served instead as collectors and disseminators of information.

In 1862 Congress authorized the establishment of the United States Department of Agriculture. Although this federal department was not explicitly charged with conducting research, the implication that it should do so was clear. Also in 1862, Congress passed the Morrill Land Grant College Act. This act allocated public lands to the various states to be used to support one or more state colleges of agricultural and mechanical arts. Such colleges were encouraged to maintain experimental farms and to conduct adaptive trials of crops, shrubs, and livestock. These farms, intended to support the teaching function of the colleges, became useful as well in the colleges' efforts to serve farmers' needs for information.

Because in the early 1800s the existing body of agricultural knowledge was inadequate to provide a solid academic curriculum in agricultural education, the colleges worked to extend the scientific underpinnings of agriculture. By the 1870s, the inability of the colleges of agriculture to broaden the frontiers of knowledge and to solve agricultural problems had become apparent. The first agricultural experiment station was established in Connecticut in 1876. Subsequently other states established stations, many of which were separate from the state colleges of agriculture.[13]

The Morrill Land Grant College Act of 1862 and the Hatch Agricultural

Experiment Station Act of 1887 reflect the emergence of a dual federal-state approach to agricultural research. Under these acts, each state received funds for a college of agricultural and mechanical arts and for an agricultural experiment station. This division of effort along state lines had a practical benefit not fully realized by the legislators when the acts were first passed.

In response to the Hatch Act's provision of federal funds, the states authorized the establishment of experiment stations attached to their colleges of agriculture. It may be noted that the American agricultural experiment stations, unlike their German model at Moeckern, Saxony, were and are attached to colleges of agriculture. And in similar fashion, the agricultural extension services of the various states are connected to the agricultural colleges.[14]

Farmers and farmers' organizations have played a central role throughout the developments detailed above: the establishment of state departments of agriculture; the pressure for authorization of a federal department of agriculture; the allocation of federal lands to the states for the support of agricultural colleges; and the movement – at both state and federal levels – for the establishment of state agricultural experiment stations. As we have seen, the more successful, wealthier farmers were instrumental in obtaining government assistance for the agricultural sector. These farmers and their organizations, after helping to initiate the institutional arrangements necessary to utilize government aid,[15] continued to press for such assistance and served as "watch dogs" over the system they had helped to create by criticizing, demanding, and protecting.

Within the federal-state structure, the states have set up research systems in which the college of agriculture forms the base, while research activities are carried out by the staff of the state agricultural experiment station attached to the college. Extension work is the responsibility of the state agricultural extension service, which operates in the counties but is also attached to the state agricultural college.

On the federal level, the USDA maintains a large staff of research workers in the national capital and in laboratories, stations, and other federal installations across the country. Additional federal workers and facilities are located on the campuses of colleges of agriculture in the various states. The states and the federal government cooperate closely on problems that cross state borders or that are national in scope or origin. An example is the problem of cereal rust disease, mentioned earlier, which involved not only federal and state cooperation within the United States but cooperation between the United States and Mexican governments, with some work conducted at research units in northern Mexico.[16]

Productivity of the Federal-State Research System

Agricultural Productivity, 1870-1972

It is helpful to think of research as a production activity in which the inputs consist of scientific man-years, laboratory facilities, and the like, and output is composed of new knowledge. To determine the productivity of research, we need to measure both input and output. Although research inputs can be measured fairly easily, at least in monetary terms, the same is not true for output. Fortunately research output can be evaluated indirectly by measuring the productivity of the industry toward which the research is directed.

In the case of agricultural research, part of the output is transmitted directly to farmers and part is utilized by experiment stations and farm suppliers as an intermediate input. In both situations the new knowledge makes possible the production of new or improved inputs for agriculture. To the extent that improvements in the quality of agricultural inputs are not fully and accurately measured, we *may* obtain an increase in total factor productivity in agriculture. Hence we may use the observed growth in agricultural productivity as a proxy or indirect measure of the output of agricultural research.

As shown in Figure 3-7, the major share of the growth of agricultural productivity in the United States over the past century has taken place since the mid 1930s. Given the establishment of agricultural experiment stations in the late 1880s, it is puzzling why it took over forty years for productivity growth to begin. One possible explanation for the "long dry spell" is that agricultural research simply did not produce any significant results during its early years. But this is too easy an explanation. It does not appear that there was any abrupt change either in the organization of the agricultural research establishment or in the quality of its personnel just before agricultural productivity growth started. If research was not productive in 1900, why should it suddenly have become so in 1930?

Maintenance research. We may shed some light on this puzzle by considering the nature and the absolute amount of research conducted during the early 1900s. As we observed in a previous section, experiment station personnel appear to have devoted the majority of their time to solving immediate and pressing problems faced by farmers. If crop or livestock production was declining or was threatened by disease or some other problem, it was the job of the researcher to come up with a solution to ensure, at least, that agricultural productivity did not decline. In other words, the research effort during the early years of the experiment station system appears to have been aimed largely at maintaining agricultural productivity in the face of a constant surfacing of new problems. It is reasonable to suppose that without this research

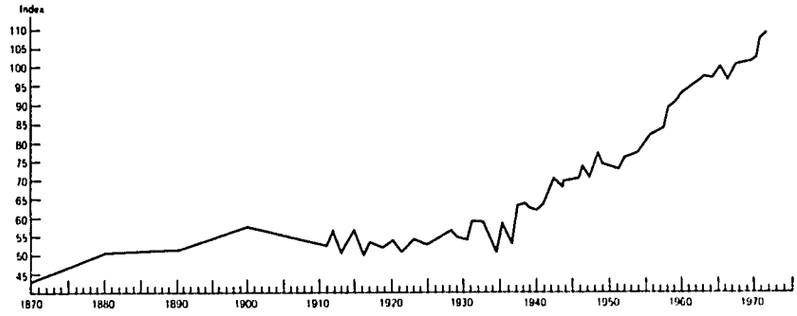

Figure 3-7. Index of output per unit of input, United States agriculture, 1870-1972, 1967 = 100.
Source: USDA, *Agricultural Statistics, 1962*, p. 54; *1972*, p. 31. Decennial observations, 1870-1910.

agricultural productivity would have declined between 1900 and 1935 instead of remaining fairly constant.

Although there can be little doubt that a certain amount of research is required just to maintain productivity in agriculture, two unanswered questions persist: how much research was required for maintenance purposes in the early 1900s and how much is required today? As technology has improved over the years, has the amount of research necessary to maintain productivity increased, remained about the same, or declined? One might argue that as varieties of crops and breeds of livestock are bred up to produce greater yields they lose some of their inherent resistance to disease and pests and thus require an increasing amount of maintenance research. On the other hand, it is probably true that because of both the increase in the stock of knowledge and the creation of new chemical inputs many diseases and pests which represented major problems for farmers fifty years ago are now either nonexistent or routinely controlled. This would imply a decrease in the research required to maintain productivity. In sum, there does not appear to be a strong argument for either a greater or a smaller amount of maintenance research today than was needed in the early 1900s.

The annual expenditures on total agricultural research have, of course, increased greatly over the years. Unless the required maintenance research has increased proportionately with the total, which does not appear likely, the absolute amount of research devoted to technology-producing activities, as opposed to maintenance work, also has increased substantially.

Research deflators. To gauge accurately the growth in real research inputs

Table 3-1. Alternative Research Deflators

Year	Consumer Price Index	Index of Associate Professor Salaries
1915	24	12
1920	48	16
1930	40	23
1940	34	22
1950	58	40
1960	71	57
1972	100	100

Source: For 1915-42, George Stigler, "Employment and Compensation in Education," National Bureau of Economic Research, Occasional Paper no. 33, 1950; for 1948-72, *American Association of University Professors Bulletin*, respective years.

over time it is necessary, because of the increase in the general price level, to deflate the expenditure figures. However, the use for this purpose of a common price deflator such as the Consumer Price Index (CPI) probably will result in a gross underestimate of past research when compared with current figures because professional salaries, which weigh heavily in total research costs, have risen faster than the general price level over the past fifty to sixty years.

To estimate the increase in research costs more accurately, a price index reflecting the average salaries of associate professors in public universities was constructed. As shown in Table 3-1, these salaries multiplied about eight times between 1915 and 1972, whereas the general price level has increased about four times.

Even when we adjust past research expenditures to reflect the change in research costs by using the index of associate professor salaries, the average annual research input (state experiment stations plus USDA) during the 1915-25 period comes to only about 8 percent of the total public research in 1970. As shown in Figure 3-8, annual real research expenditures begin to climb sharply after 1925, increasing by 57 percent between 1925 and 1930. It seems reasonable to assume that at least 5 to 10 percent of total current research is required for maintenance purposes. Unless the amount of research required for maintaining productivity has increased greatly since 1930 (in real terms), it appears safe to say that the bulk of the research input before 1925 was necessary simply to maintain productivity. If this is so, we should expect productivity to show an increase only after 1930, when research inputs began to surpass the maintenance level by a noticeable margin.

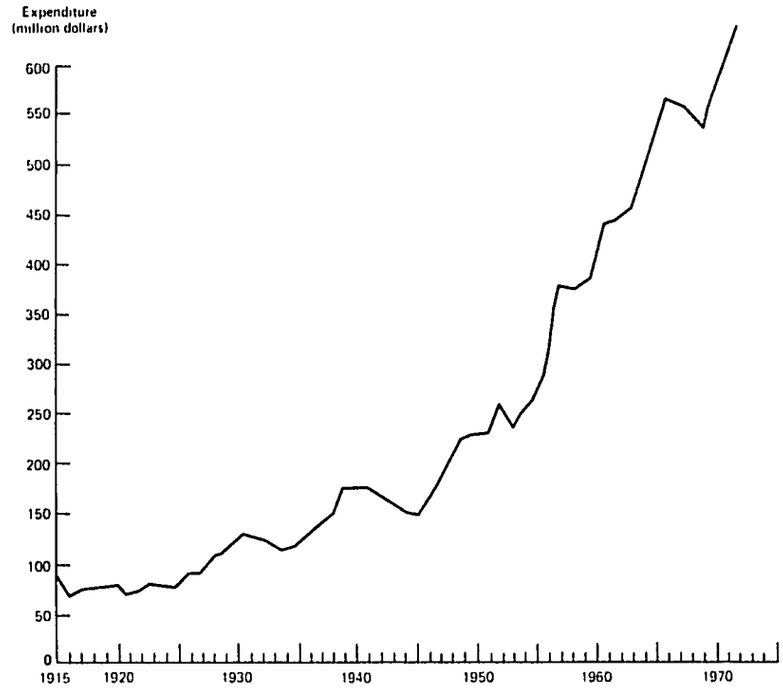

Figure 3-8. United States SAES plus USDA research expenditures, 1915-72, constant 1972 dollars (millions).
Source: See Appendix 3-1. Deflated by Index of Associate Professor Salaries, 1972 = 100.

Marginal Rates of Return to Research and Extension

Methodology. The methodology that has been used to measure the rate of return to investment in agricultural research is reviewed elsewhere in this volume (see chapter 6). In general, two approaches have been utilized. The first, which might be called the index number approach, uses productivity gains to measure the value of inputs saved or consumer surplus stemming from research.[17] The second technique, which might be called the production function approach, involves the use of research as a separate variable in a production function to measure its marginal product and marginal rate of return.[18]

We will use the index number technique in an attempt to measure the value of inputs saved as a consequence of an *increase* in agricultural productivity. To obtain a rough first approximation of the marginal rate of return

(as opposed to an overall average), we measure value of *additional* inputs saved over specific periods as a result of the *growth* in productivity and in value of output. We will assume that the growth in productivity (output per unit of input) during a given six-year period is the result of research conducted over the preceding six-year period. This implies a six-year lag between research and its output.

Estimates by decades. Because United States agricultural productivity began its recent long-term growth in 1937, we take 1937–42 as the first of four six-year periods. The average annual value of additional inputs saved during each of these periods, along with the corresponding research and extension inputs, are presented in Table 3-2. For the purpose of computing rates of return, both research and inputs saved are deflated by the Consumer Price Index, 1972 = 100. The fact that research was relatively cheap (compared to inputs saved) in the early years should be reflected in its rate of return. Also, to take account of private research and extension, figures relating to public research and extension are multiplied by two. This implies that private research and extension were equal to public expenditures over the period. We shall argue in the next section that this procedure results in an underestimation of the true rate of return.

Matching the research and extension expenditures with the corresponding additional inputs saved, we compute marginal internal rates of return for each of the four six-year periods (see accompanying tabulation). The internal rate

Period	*Rate of Return*
1937–42	50%
1947-52	51
1957-62	49
1967-72	34

of return is that rate of interest which makes the accumulated research and extension expenditures at the end of the investment period just equal to the discounted present value of the additional inputs saved at the beginning of the payoff period. In calculating the internal rate of return, we assume that the average value of marginal inputs saved over the six-year period will continue into perpetuity. However, because of the high discount rate, these future returns have a small influence on the computed rate of return.

Biases. Although the computed rates of return to agricultural research and extension in the United States turn out to be very attractive, we have reason to believe that these estimates of the true rate of return are biased downward for a number of reasons. First, no return is credited to maintenance research. To capture a return to this activity we would have to know what the productivity

Table 3-2. Average Annual Expenditures for Public Research and Extension with Corresponding Additional Inputs Saved (1972 dollars, in millions)

Research and Extension Expenditures[a]		Additional Inputs Saved[b]	
Period	Annual Average	Period	Annual Average
1931-36	148	1937-42	5,868
1941-46	192	1947-52	6,587
1951-56	322	1957-62	11,747
1961-66	671	1967-72	10,010

[a] Derived from data in Appendix 3-1.

[b] Total inputs saved in year t are obtained by multiplying value of farm marketings plus home consumption by the proportionate change in total factor productivity, 1910-36 = 100. Marginal inputs saved in year t are obtained by subtracting average annual total inputs saved during the preceding six-year period from total inputs saved in year t.

would have been if no such research were performed. Because this information does not exist, we do the next best thing by measuring the gain in productivity from a base period. If productivity declines in the absence of maintenance research, we understate the true productivity gains attributable to research. Our procedure implies a zero return for the years 1921-26 when in fact it is difficult to believe that research during that period was any less productive than it was from 1931 to 1936.

The practice of doubling public research and extension in order to include an estimate of private expenditures should also bias the rate of return downward. We can expect that input prices already include a return to private research and extension. This in turn should increase the input measure and result, therefore, in less productivity gain than would occur if all research and extension were public expenditures. The fact that not all research and extension is aimed at increasing productivity provides a third source of downward bias. For example, most of the extension work in home economics is concerned with improving the quality of life, not only in rural America but also in towns and cities.

On the other side of the coin, one might argue that the rate of return is biased upward because no charge has been made for the increased education of farm people. However, most of the evidence to date suggests that the primary role of education in agriculture is to speed up the adoption of new inputs in order to move more quickly toward an optimum allocation of resources as opposed to a pure "worker effect."[19] In fact the same argument applies to extension, which also yields a return by speeding up the adjustment to new inputs or information.

Future Returns

As we have seen, although the marginal internal rates of return to agricultural research and extension appear to have been relatively high, the figures suggest that this return is beginning to decline. Of course, if research and extension are subject to the law of diminishing returns, it is reasonable to expect a decline in the rate of return to this investment in the absence of additional complementary inputs Moreover, the fact that researchers' and extension agents' salaries probably have increased more rapidly than their marginal productivities in recent years would also imply a decrease in the rate of return to investment in these activities. We might ask, therefore, whether there is a danger that the marginal rate of return to agricultural research and extension will fall below a minimum acceptable level, say 15 percent, in the foreseeable future.

Over the past two decades (1952-72) public agricultural research and extension expenditures (deflated by the CPI) have nearly doubled each decade, for a compound real rate of growth of almost 7.5 percent annually. In 1952 these expenditures totaled $305 million, rising to $509 million by 1962 and $997 million in 1972. If the past twenty-year expenditure growth rate continues over the next decade – which is quite possible in view of the increased concern over world food supplies – public research and extension expenditures would reach $1.336 billion in 1976 and $2 billion in 1982 (1972 dollars).

Predicting future productivity growth is subject to even more uncertainty. If the 1967-72 growth rate continues, the United States total factor productivity index would increase from 109 in 1972 to 124 in 1982 (1967 = 100). Such an increase does not appear unrealistic, particularly if research and extension expenditures continue to grow as much as we have assumed. If we further assume a value of agricultural output of $60 billion per year over the next decade (it was $61 billion in 1972), we can make a rough guess at the expected marginal internal rate of return to 1971-76 research and extension expenditures as they are reflected in 1977-82 productivity growth and resources saved. Utilizing the same procedure by which we computed the marginal internal rates of return presented earlier (see section on "Estimates by Decades") – doubling public research and extension, etc. – we obtain an expected marginal internal rate of return of about 29 percent for 1971-76 research and extension expenditures. Hence there does not appear to be any immediate danger of driving the marginal rate of return to investment in agricultural research and extension in the United States below an acceptable level, at least over the next several years. In fact the rate of return could increase if productivity growth continues at about the same pace and if the value of agricultural output increases because of increased exports and higher farm prices.

Research Allocation

The overall rate of return to all research and extension is a composite of the rates of return to investment in thousands of projects and activities. We know that the overall return will be maximized, for a given expenditure, only if the rates of return on all individual projects are equalized. However, the output of research is very stochastic in nature. Thus it probably is not very fruitful to try to predict expected rates of return on individual projects. At this level, the return is determined largely by the skill (and luck) of the researcher.

On the other hand, as we look at more aggregative groupings of the total research effort, it would seem to be possible to measure ex post marginal rates of return to make predictions about the short-run future. Viewing research as a separate variable in a Cobb-Douglas type production function, we see that its marginal product is equal to $e(O/R)$ where e is the production elasticity of research and O/R is dollars of related output per dollar of research (average product). We know there is great variation among commodities and among states in the average product of research. For example, the average product of corn research in the United States is over four times that of cotton research (Table 3-3). Of course, differences in production elasticities of research between corn and cotton may to a certain extent offset differences in average products, although it is improbable that the ratio of the research elasticities would reach the magnitude of four. Similarly, there is a rather wide divergence between the average products of research in the largest and smallest agricultural states.

Whether marginal products of research exhibit the same variation as the average products is an open question. Preliminary evidence reported by Bredahl suggests that for the most part production elasticities of research are not significantly different among commodities or among large and small states.[20] Therefore it appears fairly certain that the larger the average products of research, the higher the marginal products and hence the marginal rates of return to research. This in turn suggests that, if the objective is to maximize output, growth in agricultural research budgets should take place where the greatest number of dollars of related output can be expected per dollar of research.

This is not to say that marginal rates of return will be equalized if average products or even marginal products are equalized. For one thing, differences in the research lags associated with different commodities will be reflected in different rates of return for the same marginal products. For example, we might expect the lag between research and its output to be longer for livestock than for crops and poultry. If so, an optimum allocation of research would be characterized by higher marginal products for livestock than for crops and poultry.

Table 3-3. Average Products of Research in the United States in 1969

Item	Output per Dollar of Research
Corn	712
Soybeans	672
Wheat	430
Cotton	173
Swine	485
Beef	442
Dairy	323
Poultry	262
Sheep and Wool	76
Ten largest agricultural states	351
Ten smallest agricultural states	97

Source: Howard Engstrom, "Productivity Differences in Agricultural Research Between States," Department of Agricultural and Applied Economics, St. Paul, University of Minnesota, May 1972, pp. 6 and 12.

Differences in lags may also be important among experiment stations. If the large stations engage in more basic research than the small stations, where research may be largely adaptive in nature, we may expect the lag to be longer in the large stations. If so, the large stations would have to exhibit higher marginal products than the small stations in order to have the same marginal rate of return. On the other hand, it is questionable whether differences in lags could justify differences in marginal products or even average products of the order of magnitude of four to five times. Needless to say, we need more information on differences in marginal products and lags of research among commodities and among experiment stations.

APPENDIX

Appendix 3-1. Appropriations for Public Research and Extension (current dollars, in millions)

Year	State Agricultural Experiment Stations[a]	USDA	Extension
1915	4.6	6.0	3.5
1916	3.8	5.2	4.9
1917	3.8	5.8	6.2
1918	4.2	6.3	11.3
1919	4.2	6.9	14.7
1920	5.0	7.7	14.7
1921	5.2	7.8	16.8
1922	6.3	8.2	17.2
1923	7.0	8.5	18.5
1924	7.6	8.4	19.1
1925	7.3	9.3	19.3
1926	8.9	10.2	19.5
1927	9.3	10.5	20.1
1928	11.4	11.7	20.7
1929	12.0	13.8	22.9
1930	13.1	15.5	24.3
1931	12.5	16.7	25.4
1932	12.1	16.1	24.3
1933	11.4	13.1	22.0
1934	11.1	11.1	19.8
1935	11.1	11.4	20.4
1936	12.1	14.4	28.3
1937	12.9	16.4	30.0
1938	14.8	18.0	31.6
1939	15.6	23.3	32.4
1940	16.8	22.1	33.1
1941	16.7	21.4	33.5
1942	17.7	22.0	34.5
1943	17.5	21.8	35.0
1944	18.8	22.0	36.3
1945	19.8	22.9	38.2
1946	23.6	27.6	44.6
1947	28.1	33.2	53.7
1948	35.3	38.2	60.2
1949	39.9	46.0	67.2
1950	48.2	46.8	74.6
1951	50.5	45.1	77.6
1952	56.4	45.0	81.8
1953	60.0	45.3	86.8
1954	68.0	46.0	91.6
1955	73.8	53.4	100.7
1956	85.4	59.6	110.1
1957	92.2	86.6	118.2
1958	105.9	83.7	128.7
1959	110.3	99.0	136.0
1960	120.3	105.2	141.7

Appendix 3-1 – continued

Year	State Agricultural Experiment Stations[a]	USDA	Extension
1961	127.3	128.9	149.4
1962	142.1	126.4	159.2
1963	151.3	136.1	168.6
1964	169.3	149.8	177.9
1965	181.8	192.5	188.9
1966	223.4	212.7	201.2
1967	239.7	218.5	213.7
1968	261.5	219.5	225.5
1969	274.0	213.2	242.0
1970	296.1	238.7	290.7
1971	319.3	263.1	331.9
1972	348.8	294.0	354.4
1973	382.9	303.9	385.1

Source: State Agricultural Experiment Stations: For 1915-60," Report on the Agricultural Experiment Stations," published by Office of Experiment Stations through 1953 and by Agricultural Research Service from 1954 through 1960, Washington, D.C. For 1961-73, "Funds for Research at State Agricultural Stations," Cooperative State Experiment Station Service, Washington, D.C.

USDA: For 1915-53, "Report of the Director of Finance," USDA, Washington, D.C. For 1954-73, "Appropriations for Research and Education," prepared by Office of Budget and Finance, USDA, Washington, D.C.

Extension: For 1915-55, "Annual Report of Cooperative Extension Work in Agriculture and Home Economics," Federal Extension Service, USDA, Washington, D.C. For 1956-73, unpublished data from the extension service.

[a] Federal plus nonfederal funds available. Excludes fees and sales.

NOTES

1. The research reported in this chapter was undertaken by the authors as part of their larger project on "Technology, Institutions and Development: Minnesota Agriculture, 1880-1970," funded by a grant from the Rockefeller Foundation to the University of Minnesota Economic Development Center.

2. Andrew Boss, *Minnesota Agricultural Experiment Station, 1885-1935*, Minnesota Agricultural Experiment Station Bulletin no. 319 (St. Paul: University of Minnesota, 1935); Joseph C. Fitzharris, "Science for the Farmer: The Development of the Minnesota Agricultural Experiment Station, 1868-1910," *Agricultural History*, 48 (January 1974), 202-214.

3. Joseph C. Fitzharris, *The Development of Minnesota Agriculture, 1880-1970: A Study of Productivity Change*, Department of Agricultural and Applied Economics Staff Paper P 74-[illegible] (St. Paul: University of Minnesota, September 1974).

4. Boss, *Minnesota Agricultural Experiment Station*; Fitzharris, "Science for the Farmer"; interview with E. C. Stakman, October 2, 1974.

5. Boss, *Minnesota Agricultural Experiment Station*; Fitzharris, "Science for the Farmer."

6. "Annual Report of the Director of the Minnesota Agricultural Extension Service, 1936, 1953," typescripts (St. Paul: University of Minnesota Libraries Collection, 1889-1965).

7. Interviews with Dean William F. Hueg, Jr., July 23, 1973, and Dean Hubert Sloan, 1973; Boss, *Minnesota Agricultural Experiment Station*; "Annual (Biennial) Report of the Director of the Minnesota Agricultural Experiment Station, 1888/89-1964" (St. Paul: University of Minnesota Libraries Collection).

8. E. C. Stakman, Richard Bradfield, and Paul C. Mangelsdorf, *Campaigns against Hunger* (Cambridge, Mass.: Harvard University Press, 1967); interviews with E. C. Stakman, June 6, 1973, and October 2, 1974; interview with John R. Rowell, August 7, 1973; Sterling Wortman, "International Agricultural Research Institutes: Their Unique Capacities," paper presented at the Tenth Anniversary Celebration of the International Rice Research Institute, Los Baños, Philippines, April 20-21, 1972.

9. Boss, *Minnesota Agricultural Experiment Station*; Herbert Kendall Hayes, *A Professor's Story of Hybrid Corn* (Minneapolis: Burgess, 1963).

10. Fitzharris, "Science for the Farmer."

11. H. C. Knoblauch, et al., *State Agricultural Experiment Stations: History of Research Policy and Procedure*, USDA Miscellaneous Publication no. 904 (Washington, D.C.: United States Government Printing Office, 1962); also, this view is frequently approached by I. Arnon, *Organization and Administration of Agricultural Research* (London: Elsevier, 1968), pp. 5-18.

12. Arnon, *Agricultural Research*, pp. 58-65.

13. Knoblauch, *State Agricultural Experiment Stations*; Albert C. True, *A History of Agricultural Experimentation and Research in the United States, 1607-1925, Including a History of the United States Department of Agriculture*, USDA Miscellaneous Publication no. 251 (Washington, D.C.: United States Government Printing Office, 1937).

14. Knoblauch, *State Agricultural Experiment Stations*; Albert C. True, *A History of Agricultural Extension Work in the United States 1783-1923*, USDA Miscellaneous Publication no. 15 (Washington, D.C.: United States Government Printing Office, 1928).

15. Fitzharris, "Science for the Farmer,"; Douglass C. North and Robert Paul Thomas, *Institutional Change and American Economic Growth* (Cambridge: At the University Press, 1971).

16. Stakman, Bradfield, and Mangelsdorf, *Campaigns against Hunger*; interviews with Stakman, 1973 and 1974; and with Rowell, 1973.

17. See T. W. Schultz, *The Economic Organization of Agriculture* (New York: McGraw Hill, 1953); Zvi Griliches, "Research Costs and Social Returns. Hybrid Corn and Related Innovations," *Journal of Political Economy*, 66 (October 1958), 419-431; Willis L. Peterson, "Return to Poultry Research in the United States," *Journal of Farm Economy*, 49 (August 1967), 656-669.

18. Zvi Griliches, "Research Expenditures, Education, and the Aggregate Agricultural Production Function," *American Economic Review*, 54 (December 1964), 961-974; Peterson, "Return to Poultry Research"; Robert E. Evenson, "The Contribution of Agricultural Research and Extension to Production," Ph.D. dissertation (Chicago: University of Chicago, 1968).

19. See F. Welch, "Education in Production," *Journal of Political Economy*, 78 (January-February 1970), 35-39; Y. Kislev and N. Shchori Bachrack, "The Process of an Innovation Cycle," *American Journal of Agricultural Economy*, 55 (February 1973), 28-37; and Wallace E. Huffman, "Decision Making: The Role of Education," *American Journal of Agricultural Economics*, 56 (February 1974), 85-97.

20. Maury Bredahl, 1975, personal communication.

4

Productivity of Agricultural Research in Colombia[1]

Reed Hertford, Jorge Ardila, Andrés Rocha, and Carlos Trujillo

This chapter will compare four recent studies of the economic returns to varietal research on rice, cotton, wheat, and soybeans in Colombia. The four studies are part of a larger program of agricultural research, extension, and education administered since about 1950 by the Colombian Agricultural Institute (ICA) and its predecessor agencies, the Department of Agricultural Research (DIA) and the Office of Special Studies (OSS). Our main hypothesis was based on calculations of returns made previously for Colombia, the United States, and several other countries. For Colombia, Harberger had estimated that the average rate of return on all capital ranged from 8 to 10.5 percent between 1960 and 1968 and that the opportunity cost of public funds was about 10 percent during the late 1960s.[2] Studies by Griliches[3] and Peterson[4] for the United States, by Ardito Barletta for Mexico,[5] by Ayer and Schuh for Brazil,[6] and by Duncan for Australia[7] found rates of return to varietal improvement in excess of 10 percent. These investigations also suggested, however, that returns obtained in the United States were exceeded by those obtained in the other countries studied. Accordingly, we hypothesized that the estimated rates of returns for the four Colombian varietal improvement programs would exceed both the opportunity cost of capital within the country and the rates of return previously reported for similar United States programs.[8]

This hypothesis derived additional support from the commonsense notion that, because Colombia began agricultural research after the United States

and other developed countries, it should have been able to draw on a large stock of knowledge about plant-breeding techniques and on extensive international collections of plant materials to reduce the gestation periods and development costs of its programs. If we assume that research enterprises in Colombia and the United States are comparable in organization and competence, the cost effectiveness of and returns to research in Colombia should be greater. At the same time, important socioeconomic and structural constraints in Colombia could prevent higher returns to investments in varietal improvement, even if technical breakthroughs had been more easily made.

The foregoing considerations, together with the nature of the data available for analysis, led us to adopt a methodology which could assist us in distinguishing the contributions of biological, socioeconomic, and structural factors to the calculated returns to research. The "social benefits" of varietal research were estimated in the usual way - as changes in consumers' and producers' surpluses resulting from shifts in product supplies generated by the use of improved seeds. (See chapter 6 of this volume.) But the shift in supply itself was taken as the product of two separately estimated variables: the difference in yields between two (average) farm plots of one hectare each, one plot being planted entirely to the improved seeds and the other to the unimproved varieties, multiplied by the percentage of crop land actually planted in the improved variety. We then associated the first of these variables, the "yield advantage" of the improved variety, with the biological determinants of returns and the second variable, "the rate of adoption," with the socioeconomic, structural, and biological determinants, recognizing that a large yield advantage can be a primary cause of rapid and high levels of adoption.

Because it was our impression at the outset that the technical and biological work of the four Colombian varietal improvement programs had been well done, we felt that our main hypothesis would be rejected only if the rates of adoption were low, which would mean that there were major socioeconomic and structural constraints. The only crop of the four studied which evidenced such constraints was wheat. It had been grown under near subsistence conditions by small, traditional farmers in some of Colombia's poorest agricultural areas. Also, for a number of years massive wheat imports, made under PL 480, had depressed the relative price of wheat.

The final step of our analysis concerned the way the yield advantage was to be calculated. We felt that estimates based only on comparisons of yields obtained on plots seeded to new varieties and others seeded to unimproved varieties would be biased upward because of the strong, positive interactions of the new varieties with such inputs as fertilizers and water. Therefore, in comparing yields and calculating the yield advantages of new varieties, we attempted to determine the effects of other inputs by estimating the produc-

tion relation between yields, seed varieties, and other variables which may have interacted with the seed varieties.

The next four sections of this chapter discuss the returns to research in rice, cotton, wheat, and soybeans, respectively. The final section compares our main results and summarizes our principal conclusions.

Rice[9]

Colombia's rice research program was initiated in 1957 by a predecessor agency of ICA. Its establishment coincided with a sharp rise in rice imports occasioned by an outbreak of the *hoja blanca* disease. (According to *FAO Rice Reports* for relevant years, Colombia usually imported about 2,000 metric tons of rice annually but imported 10,200 tons in 1957; in 1958 and 1959 imports returned to earlier levels.) This is a virus prevalent in Latin America – with symptoms like the stripe disease of Japan – which first caused substantial losses in Venezuela in 1956 and in Colombia in 1956 and 1957.[10] Accordingly, the initial objectives of the research program included varietal selection and breeding for higher yields and resistance to the *hoja blanca* virus.[11]

Rice varieties resistant to the disease were collected throughout Colombia as a first step; in addition, 2,200 varieties were imported from the United States Department of Agriculture's World Collection of Rice in Beltsville, Maryland. By 1959, about 400 of these varieties had shown promising resistance to the virus. Because they were mainly *japonica* varieties, which are not consumed in Colombia, the research program sought to breed the virus resistance of *japonica* into the local long-grain varieties.[12] It was estimated that this might take four to five years. In the interim, the one superior United States variety which had shown some virus resistance, Gulfrose, was multiplied and released in 1961.

Napal, the first improved variety produced by the Colombian research program, was released in 1963. Napal had the long-grain characteristics of Bluebonnet 50, the most popular nontraditional variety, and was resistant to *hoja blanca*.[13] Unfortunately, it was attacked by *bruzone* (rice blast disease) in 1965 and disappeared from commercial use thereafter. In the same year, Tapuripa, earlier imported from Surinam, was distributed to farmers as an alternative to Bluebonnet 50 and Gulfrose. It was long grained and flinty, with some resistance to blast and *hoja blanca*.

In 1966, the Colombian rice research program added an objective derived from the International Rice Research Institute (IRRI): to develop dwarf varieties with a high grain-to-straw ratio and resistance to lodging. About 3,000 additional varieties were imported from IRRI, and an order went out to re-

tain only those varieties already in the Colombian collection which outyielded the most prevalent local variety by 100 percent.

In 1969, ICA joined forces with the rice program of the International Center for Tropical Agriculture (CIAT). Personnel, facilities, budgetary resources, and objectives were shared under informal agreements between the two institutions. This reinforced Colombian ties with IRRI, since the head of CIAT's rice research team had served on IRRI's staff.

In 1968, ICA and CIAT introduced IR-8, which spread quickly even though the medium-type chalky grain sold generally at a 30 percent discount and was susceptible to blast disease. However, it was resistant to *hoja blanca*. Following strong commercial interest, CIAT and ICA also introduced IR-22 in 1970 and recommended it to farmers in irrigated tropical areas.

Between 1966 and 1970, ICA released independently one additional rice variety, ICA-10, which never assumed any commerical importance. Its yields were inferior to the IRRI varieties, although it was superior to and/or less variable than either Gulfrose or Napal. Its grain quality was also less desirable than Tapuripa's.

In 1971, ICA released the CICA-4 variety. Compared with earlier varieties it had improved disease-resistance, was more adaptable to changes in water and air temperature, and it had good grain appearance and cooking qualities. It also produced slightly superior yields. Simultaneously, CICA-4 appeared in Ecuador as INIAP-6, in the Dominican Republic as Advance 72, and in Peru as Nylamp.

Yields recorded in commercial field trials of the seven major rice varieties released by the Colombian and joint CIAT-ICA programs after 1957 are shown in Table 4-1, together with data obtained from the same source on yields of the check variety Bluebonnet 50. The 665 individual trials which are the basis for these yield statistics include all that are available for the fifteen-year period 1957-71. It should be mentioned that ICA's commercial trials, or *pruebas regionales*, are conducted on commercial farms that agree to collaborate with the institute's programs. Farmers run the trials, but materials and instructions are provided by ICA.

The three rice varieties released before 1966 show average yields of 4.1 metric tons per hectare, representing a yield advantage over Bluebonnet 50 of about 33 percent. Varieties introduced after 1966, including ICA-10, double that yield advantage, bringing it to 65 percent above Bluebonnet 50.

In view of these yields, it is interesting to note that the area planted to improved rice varieties did not become a significant proportion of all rice land until the second, or post-1966, stage of the research program (see Table 4-2). Data in the table on the percentage of acreage sown to a given variety were estimated in the following way. First, available information on sales of certi-

Table 4-1. Average Rice Yields from Commercial Trials by Variety, Colombia, 1959-71[a]

Year	Variety (in kilos per hectare)							
	Bluebonnet 50	Gulfrose	Napal	Tapuripa	ICA-10	IR-8	IR-22	CICA-4
1959	1,927							
1960								
1961	2,893	3,071						
1962	2,967	4,065						
1963	3,875	5,391	4,420					
1964	4,336	4,138	5,166					
1965	3,462	2,739	4,343					
1966	1,590		2,436	3,645				
1967	2,893			2,690	4,707	6,098		
1968	3,208		5,356	4,600	4,789	5,890		
1969	3,544		5,110	4,625	5,450			
1970	3,339			4,500	3,852	5,180	5,420	6,125
1971	3,164			3,610	4,234	4,748	5,080	4,600
Average	3,099	3,880	4,344	4,025	4,441	5,473	5,250	5,362

Source: Jorge Ardila, "Rentabilidad social de las inversiones en investigación de arroz en Colombia," M.S. thesis, Bogota, ICA/National University Graduate School, 1973, Table 5.

[a] Blanks indicate no regional trials were undertaken.

fied seeds by variety were converted to hectare equivalents by dividing by the estimates of seeding rates provided by the ICA National Rice Program director. Second, lacking data on farm-produced seeds of the improved varieties, we assumed that the proportion of all acreage planted to certified seeds of any variety was equal to the proportion planted to later generation seeds produced outside the seed multiplication and certification program. This estimating procedure was followed here, as well as for wheat and soybeans, to estimate total area planted to improved seeds because it produced the simplest and "best fit" between available data on certified seed sales and "expert opinion."

To estimate the shift parameter of each new variety -- its yield advantage over Bluebonnet 50 -- production functions were fit to the *pruebas regionales* data, using standard least-squares procedures. In the final round of estimation, reported yields (kilos per hectare) were taken as a function of twenty variables: size of the trial plot, seeding rate, seven seed variety variables, two variables to distinguish different time periods, four variables relating to irrigation and its interactions with seed variety, and five variables to differentiate locations and their interactions with variety. Only the first two of these variables entered as continuous arguments. Other continuous variables (relating

Table 4-2. Land Area Planted to Six Improved Varieties of Rice as a Percentage of the Total Area Planted in Rice, Colombia, 1964-73[a]

Year	Variety (in %)						All Improved Varieties (%)
	Napal	Tapuripa	ICA-10	IR-8	IR-22	CICA-4	
1964	2.5						2.5
1965	2.1						2.1
1966		0.1					0.1
1967		3.2	0.1				3.3
1968		21.2	0.6	0.3			22.1
1969 . . .		18.0	0.5	3.7			22.2
1970		12.4	0.2	18.2			30.8
1971		6.9		26.1	3.1	5.0	41.1
1972				18.9	10.1	18.3	47.3
1973				20.1	24.3	12.6	57.0

Source: For 1964-71, Jorge Ardila, "Rentabilidad social de las inversiones en investigación de arroz en Colombia," M.S. thesis, Bogota, ICA/National University Graduate School, 1973, Table 11; for data after 1971, ICA, director of the National Rice Program.

[a] Blanks indicate less than 0.1 percent.

particularly to "cultural practices") were either discarded or respecified in noncontinuous form in the final results presented in Table 4-3.

Because CICA-4 was taken as the check variety, the estimated coefficients on the variety variables are to be interpreted as their "yield disadvantage" in kilos per hectare compared with CICA-4. When results are interpreted in this way, it is evident that the Colombian rice research program has produced through time continuous and substantial improvements in yields. Again, the superiority of the varieties released after 1966 is evidenced.

Results suggest, however, that yields of CICA-4 as well as those of IR-8 and IR-22 are positively influenced by irrigation. The coefficient on the irrigation variable indicates that yields of all varieties are increased by about 1.2 tons with average irrigation practices. Roughly another ton is added when irrigation is applied to IR-8, IR-22, or CICA-4, as indicated by the coefficients on the variables of interaction of those varieties with irrigation. This evidence from the production functions, coupled with data which show that dry land rice yields increased 7 percent during the 1961-72 period while those of irrigated rice increased 133 percent, leads to an inference that the newer varieties have benefited mainly the irrigated rice areas.[14] The other side of the coin, of course, is that the adoption of improved varieties was assisted by the existence of irrigated crop land.[15]

Most of ICA's research has been focused on the irrigated rice areas. Its largest programs have been located at the Palmira and Espinal experiment stations. Although about 75 percent of all Colombian rice land is now irrigated,

Table 4-3. Production Function Estimates for Rice Based on Commercial Trial Data, Colombia, 1957-72

Independent Variable	Estimated Coefficient	Estimated t Statistics
1. Size of trial plot	− 0.15	− 2.30
2. Seeding rate	2.46	1.58
3. Bluebonnet 50	− 1,609.66	− 3.45
4. Gulfrose	− 1,486.56	− 1.31
5. Napal	− 1,742.79	− 1.83
6. Tapuripa	− 884.31	− 1.80
7. ICA-10	− 536.93	− 1.13
8. IR-8	− 798.97	− 1.54
9. IR-22	− 589.97	− 0.72
10. Irrigation	1,220.20	5.84
11. Irrigation * IR-8 interaction	1,278.09	3.21
12. Irrigation * IR-22 interaction	700.44	0.89
13. Irrigation * CICA-4 interaction	1,061.87	2.11
14. Location	1,185.26	7.12
15. Location * Gulfrose interaction	991.98	0.94
16. Location * Napal interaction	940.33	1.06
17. Location * IR-8 interaction	428.22	1.24
18. Location * CICA-4 interaction	− 1,340.16	− 3.14
19. Time I	1,228.03	6.74
20. Time II	− 509.78	− 2.20
Intercept	2,028.30	3.64
	$R^2 = 0.67$	n = 665

Source: Jorge Ardila, "Rentabilidad social de las inversiones en investigación de arroz en Colombia," M.S. thesis, Bogota, ICA/National University Graduate School, 1973, Table 13.

almost 100 percent has been irrigated traditionally within the areas served by Palmira and Espinal.[16]

This emphasis on the irrigated areas may have been induced by expectations of the sort of variety-irrigation interactions found in the regression results. More plausible is the commonsense explanation that the ICA's creditability would have been seriously threatened had it not produced varieties which yielded well in the irrigated areas of Colombia, since the controlling interests of the rice growers and commercial trade are found there. It has been reported that half of the value of all dues collected by the National Federation of Rice Growers comes from Tolima.

Regression results were used to estimate the overall percentage change in rice supply attributable to the yield advantage of all improved varieties over Bluebonnet 50. It was estimated as a weighted sum – divided by average commerical yields – of the regression coefficient of each improved variety minus the coefficient corresponding to Bluebonnet 50, with weights equaling the percentage of all rice land planted which was sown in each variety.[17] This

Table 4-4. Alternative Values of the Supply Shift Parameter for Rice Attributable to Improved Varieties, Colombia, 1964-71

Year	Estimate (%) Simple (1)	Varietal Effects (2)
1964	1.05	− 0.16
1965	1.01	− 0.15
1966	0.13	0.03
1967	− 0.17	1.07
1968	10.99	5.73
1969	12.81	5.98
1970	14.89	7.42
1971	15.96	10.38

Source: Jorge Ardila, "Rentabilidad social de las inversiones en investigación de arroz en Colombia," M.S. thesis, Bogota, ICA/National University Graduate School, 1973, Tables 5, 11, 12, 13, 17, and 20.

estimate is shown in column 2 of Table 4-4. The "simple" estimate of the yield advantage of the improved varieties is shown in column 1 of the table and is based only on the data for the average annual yield of each variety obtained in the *pruebas regionales* and already presented in Table 4-1.[18]

The fact that the simple estimates of the shift parameter exceed the estimates that are made up only of varietal effects from the regression is consistent with the finding that only the improved varieties of rice interacted with other variables of the production function. Since those interactions were on balance positive and are included in the simple estimate but not in the varietal-effects estimate, the former overstates the shift parameter by as much as seven percentage points.

The simple and varietal-effects estimates were combined with assumed values of the price elasticities of supply and demand to provide upper- and lower-bound estimates of gross social benefits of the new seed varieties for the period 1964-71.[19] Values considered for the price elasticities of supply were zero, 0.2347, and infinity, the intermediate value being derived from the only supply study available for Colombian rice;[20] values considered for the price elasticity of demand were − 0.5, − 1.372, and − 2.0, the intermediate value again having been estimated in another study.[21] Maximum gross benefits resulted from using the simple estimates of the shift parameter and price elasticities of demand and supply, respectively, of − 0.5 and zero; minimum benefits corresponded to price elasticities of demand and supply of − 2.0 and infinity and the varietal-effects estimate of the supply shift parameter. Both estimates of benefits are shown in Table 4-5 for the 1964-71 period.

Table 4-5. Estimated Benefits and Costs of the Rice Research Program in Colombia, 1957-80 (in thousands of 1958 pesos)[a]

Year	Estimated Benefits		Estimated Costs
	Maximum	Minimum	
1957 . . .			15
1958 . . .			193
1959 . . .			235
1960 . . .			286
1961 . . .			429
1962 . . .			441
1963 . . .			252
1964 . . .	3,733	− 563	445
1965 . . .	4,750	− 699	538
1966 . . .	553	127	519
1967 . . .	− 827	5,157	867
1968 . . .	61,659	27,291	937
1969 . . .	60,872	23,675	2,074
1970 . . .	69,444	27,883	2,779
1971 . . .	107,470	52,255	4,165
1972-80	107,543	52,255	4,202[b]

Source: For estimated benefits, preceding tables; for estimated costs, Jorge Ardila, "Rentabilidad social de las inversiones en investigación de arroz en Colombia," M.S. thesis, Bogota, ICA/National University Graduate School, 1973, Tables 44 and 46.

[a] Blanks indicate no benefits.

[b] Figures for subsequent years were estimated by assuming 4,202 grew by 10 percent annually.

Costs of the research program for the same period, also shown in Table 4-5, include direct costs, indirect costs, and complementary costs; these terms were defined earlier by Ardito Barletta.[22] Direct costs of the rice program were available only after 1964. For this reason available cost data were regressed on the number of employees assigned to the rice program and ICA's total expenses for all research programs; the resulting regression coefficients and available data on the two independent variables of the regression were then used to estimate the direct cost data for the missing years, 1957-65. Complementary costs associated with the new program – those it incurred with other collaborating programs – were estimated for this study by the director of the National Rice Program. Included were costs associated with the entomology, plant physiology, plant pathology, soils, and extension programs. Indirect costs included staff training costs, opportunity costs of the services of fixed capital and land, management costs, and the costs of "inter-

national cooperation."[23] The latter category comprised the major program cost, the total costs of the CIAT rice program from 1969 to 1972, as estimated by the head of that program, and a prorated share of the cost of Rockefeller Foundation personnel stationed in Colombia from 1958 through 1968. The simple sum of total costs for the 1957-71 period equaled 14.2 million 1958 pesos. The costs of international cooperation were calculated at 5.0 million or 35 percent of the total but are probably understated since benefits derived from the "capital stock" of IRRI and other institutions have not been charged to the Colombian program. (This is discussed further elsewhere in this chapter.) All costs for the rice program in 1971 represented about 12 percent of ICA's total expenses for research.

Recognizing that the current stock of new varieties will continue to produce into the future, we projected the costs and benefits of the Colombian rice program to 1980 using assumptions, when necessary, which would bias downward the estimate of internal rates of return. It was assumed on the cost side, for example, that the real value of the cooperative CIAT-ICA rice program would increase at a rate of about 10 percent a year, primarily on the grounds that programs which are relatively new and reputedly successful tend to grow. Since this assumption was made, ICA's budget has been severely cut, and CIAT's rice program has been phased down. Nonetheless, we hold to the initial assumption to avoid overstating the final estimate of the internal rate of return. On the side of the projection of gross benefits, it was assumed that the value of production during the 1972-80 period will average 581 million pesos, a sum which equals the value of the rather good 1971 crop (in 1958 pesos); that the rate of adoption of the new rice varieties after 1973 will stabilize at the estimated 1973 level of 57.0 percent;[24] that the percentage of rice land planted to IR-8 will trend downward linearly to zero by 1980; that the percentages of all rice land sown to IR-22 and CICA-4 will be equal after 1973; and that the increase in the shift parameter implied by these assumptions will approximately equal increases in commercial yields over the period 1972-80. The increases in yields would be 14 and 11 percent, respectively, for the maximum and minimum values of the shift parameters.

The resulting internal rate of return corresponding to the stream of maximum gross benefits was found to be 82.3 percent; the rate estimated on the basis of the stream of minimum gross benefits was 60.1 percent.[25]

Cotton[26]

Cotton has turned in a striking performance in Colombia. Since the mid 1930s, yields have about quadrupled – in fact, their pattern of change has been broadly similar to that of cotton yields in the United States. Currently,

Colombian cotton yields are comparable to United States yields and roughly twice as high as average yields for all of South America (Table 4-6). In an earlier comparative analysis of changes in cotton yields, it was concluded that Colombia ranked fourth in yield increases in the 1950-60 period among the twenty-four countries that produced 97 percent of all cotton in 1960.[27] Production after the mid 1930s increased at least fifteen times, or from about 30,000 bales in 1937-38 to over 500,000 bales in the early 1970s.[28]

Yields and production advanced most rapidly in two different but not widely separated periods of time: 1951-54 and 1957-59. Yields about doubled in the first period. Although they also increased in the second period, production evidenced a much larger increase of 167 percent. Developments in both periods appear to have been the result of changes in government policies.

The first period of rapid development followed the reopening of the Colombian Ministry of Agriculture in 1948 and the introduction of new policies emphasizing the need to replace imports of food and fibers with local products. For cotton, this meant that the textile industry had to consume stated allotments of national cotton. This produced an 82 percent increase in the farm price between 1948 and 1951.[29] When the local textile industry was faced with the prospect of consuming larger quantities of national cotton, it promoted the establishment in 1948 of the Cotton Development Institute (IFA) for purposes of improving the quality and uniformity of local cotton through both research and the control of ginning.[30] Eventually a government institute with its own budget, IFA also assumed responsibilities for cotton extension, seed distribution, and credit.

The second surge in production, occurring at the end of the 1950s, paralleled changes in exchange policies. The official exchange rate in Colombia was 2.5 pesos per United States dollar from 1951 through May 1957. The free rate was 3.0 to 3.5 pesos through 1954 and then edged up to 6.9 pesos by mid 1957. On June 18, 1957, the official rate was increased to 7.6 pesos. Through the 1951-57 period, the Colombian textile industry was permitted to import raw cotton and capital items at the official exchange rate. As a result, imports steadily built up to a level of 77,000 bales in 1957; production stood at 95,000 bales in that same year. In 1958, following reforms, production jumped to 220,000 bales and in 1959 reached 256,000 bales. Imports fell to 36,000 bales in 1958 and to slightly less than 2,000 bales in 1959, at which time Colombia also showed its first exportable surplus of cotton in several decades. During the early 1960s exports averaged about 100,000 bales and by 1968 had reached a level of almost 300,000 bales.

As producers of cotton attained national prominence and power by satisfying domestic consumption and exporting a growing surplus, the National

Table 4-6. Comparative Statistics for Cotton Yields, 1934-35/1938-39 to 1973-74[a]

Year	All Crops, Index for Colombia	Cotton (pounds per acre)		
		Colombia	United States	South America
1934-35 to 1938-39 . . .		133	212	181
1947-48	100	152	267	163
1950-51	115	167	269	175
1951-52	102	150	269	203
1952-53	109	227	280	197
1953-54	119	317	324	212
1956-57	143	319	409	178
1959-60	152	377	462	207
1962-63	176	398	457	231
1965-66	158	352	526	244
1966-67	164	470	480	232
1967-68	176	516	447	267
1970-71		463	437	222
1973-74[b]		470	519	249

Source: For all crops, index for Colombia, *Changes in Agricultural Production and Technology in Colombia*, Foreign Agricultural Economic Report no. 52 (Washington, D.C.: Economic Research Service, USDA, 1969), Table 30; for cotton, Secretariat, International Cotton Advisory Committee, *Cotton-World Statistics*, Washington, D.C., various issues.

[a] Blanks indicate no data available.

[b] Preliminary.

Federation of Cotton Growers (FNA) began to absorb IFA's functions. In 1968, IFA was dissolved completely, and its research and extension activities were passed on to the ICA. Some of its other activities were absorbed by the Ministry of Agriculture.

The inheritance of the IFA was meager when it assumed responsibilities for organized cotton research in 1948. On the advice of an English mission, some cotton research was begun in the Cauca Valley in 1928 but was later suspended when attention there was turned, by a visiting mission from Puerto Rico, to the prospects for sugarcane research. In 1934, some research was established in Armero, State of Tolima, to introduce and test United States Uplands and some Peruvian varieties. Until 1948, however, the most progress had been made in improving the perennial tree cotton. A station on the outskirts of Barranquilla on the north coast is reported to have obtained yields of 350-400 kilos per hectare or at least twice the then prevailing average yield.[31] Nonetheless, one of the first things IFA did was to close that station, since the quality of the tree cotton was considered inferior to imported cotton and tree cotton had become infested with diseases which threatened the introduction of annual varieties.

From the beginning, the institute's sole research objective was the intro-

duction, testing, and multiplication of improved United States cotton varieties. No attempt was made to produce a national variety until 1961, and that effort appears to have languished until IFA's research was absorbed by ICA in 1968.

ICA adopted the same primary objective for its cotton research program as IFA. But, it added a second objective – the development of a national cotton variety through selection and hybridization. It also improved the design of research, expanded experimentation beyond the three locations used by IFA (at Buga, Espinal, and Codazzi), and undertook more trials on a commercial scale as *pruebas regionales*.

Actually, the first United States cotton variety was introduced into Colombia well before the establishment of IFA. Deltapine 12 was imported by cotton producers in 1941 and came into general use in Tolima State during the 1940s. The year before, the Brazilian variety *Expresso do Brazil* had been introduced and it likewise gained acceptance in Tolima during the 1940s. In the late 1940s and the 1950s, Deltapine 15, Earlystaple, Coker 124 B, and Deltapine Smoothleaf were introduced. These so-called "T" type cottons accounted for about 93 percent of all cotton production by 1959; Deltapine was by all odds the most important among them. By 1971, Deltapine 15 was no longer in use but Deltapine 16 accounted for 42 percent of all cotton acreage, Deltapine Smoothleaf for 38 percent, Acala 1517 BR-2 for 8 percent, and Stoneville 213 for 8 percent, with the remaining 4 percent being accounted for by Deltapine 45 and Coker 201.[32]

As noted, the cotton research program emphasized the selection and multiplication of promising United States varieties rather than the development of improved national varieties. The United States varieties sharply increased Colombian cotton yields. To estimate the contribution of the Colombian selection and testing program, two questions need examination.

First, would single farmers or groups of farmers acting without government help have been as efficient or more efficient in selecting and importing United States varieties than IFA and ICA?

Colombian cotton production is concentrated among a small group of farmers. As of 1958, 422 farmers accounted for 61 percent of total production;[33] in 1967, 343 producers were reported to have accounted for 40 percent of all output. At prevailing average yields, this would imply that each large cotton producer was harvesting about 550 acres, given total production for Colombia of 465,000 bales in 1967. The data for 1958 imply that each of the 422 farmers was harvesting in that year only about 200 acres of cotton, suggesting that large cotton producers were major contributors to the increase in production that occurred between 1958 and 1967.[34]

The demand curve facing producers has been highly elastic because of the

Table 4-7. Average Yields of Seed Cotton by Variety Obtained from Commercial Trials Conducted in Colombia, 1953-72

Variety	Number of Observations	Yield (kilos per hectare)
Deltapine 15	193	2,312
Deltapine Smoothleaf	71	2,369
Stardel	18	2,296
Stoneville 213	39	2,375
Coker 124 B	12	2,634
Acala BR-2	48	2,287
Deltapine 45	9	2,693
Deltapine 45 A	40	2,575
Deltapine 16	42	2,457
Coker 201	27	2,568
Total[a]/average	499	2,366

Source: Andrés Rocha, "Evaluación económica de la investigación sobre variedades mejoradas de algodón en Colombia," M.S. thesis, Bogota, ICA/National University Graduate School, 1972, Table 10.
[a] Excludes twenty-four trials on other varieties.

existence of an export market. The elastic demand curve would have served as insurance to individual innovators that prices and profits would not be eroded by the increased production brought about by the diffusion of their innovations. The fact that the industry was composed of a few large farmers makes it more probable that a single individual or small group could have anticipated large enough rewards from search and research efforts to justify undertaking them.

However, it seems unlikely that a farmer-based research effort would have outperformed IFA and ICA. There seems to be no basis for believing that a private research effort would have uncovered other, more effective varieties than IFA or ICA did. Because of their official status, the two institutes probably were able to import new varieties into Colombia more easily and rapidly. Similarly, they were able to control the distribution of improved seeds. For example, IFA controlled all cotton gins. However, it was probably the special privileges and franchises that IFA and ICA possessed as offical government agencies – not "pure differences" in organization of research – which facilitated their success.

The second question needing examination is whether there were, in fact, significant differences in yields among the imported United States varieties when grown under Colombian conditions.

The programs of both IFA and ICA were founded on the premise that such yield differences did exist. The claim was made that it would be worthwhile to identify the size of these differences and to key programs of seed

Table 4-8. Production Function Estimates for Cotton Based on Commercial Trial Data in Colombia, 1953-72

Independent Variable	Estimated Coefficient	Estimated Standard Error of Coefficient
1. Nitrogen	2.58	0.53
2. Irrigation	606.56	48.71
3. Parcel type	− 471.41	61.41
4. Rain deficiency	− 1,150.22	47.60
5. Stardel	− 241.43	89.09
6. Coker 124 B	− 214.75	109.08
7. Acala BR-2	− 331.64	59.23
8. Location 1	381.53	88.86
9. Location 2	189.13	80.78
10. Location 3	600.73	94.34
11. Location 4	1,094.14	149.39
12. Location 5	349.18	91.05
13. Location 6	− 649.88	116.68
14. Location 7	− 408.99	181.04
15. Location 8	991.48	71.77
16. Location 9	408.49	62.74
17. Location 10	1,167.86	77.85
18. 1953	− 218.53	106.79
19. 1954	− 268.37	81.12
20. 1967	− 428.55	156.78
21. 1970	363.15	61.72
22. 1971	366.96	70.66
23. 1972	452.88	75.20
Intercept	2,081.20	n.a.[a]
	$R^2 = 0.82$	n = 523

Source: Andrés Rocha, "Evaluación económica de la investigación sobre variedades mejoradas de algodón en Colombia," M.S. thesis, Bogota, ICA/National University Graduate School, 1972. Table 3.

[a] Not available.

multiplication and distribution to them. If, however, yields of all United States varieties harvested in Colombia were equal, then there would be no payoff to a program of varietal selection and distribution. Any individual farmer could import a variety of United States cotton selected at random and expect to obtain as good results as he would have obtained through an organized program of research like IFA's and ICA's. Similarly, such a program would not be useful if the distribution of yields by variety were the same in both the United States and Colombia.

To explore the question of yield differences more carefully, all available data were obtained on the IFA and ICA commercial trials, which were comparable in design to those reported earlier for rice. The trials covered the period 1953-72 and included 523 individual experiments. They are summarized in Table 4-7 as mean values of yields obtained for each of ten cotton varieties.

Additional trial data were destroyed when IFA's research was absorbed by ICA. Presumably, they included information on the two check varieties, Deltapine 12 and *Expresso do Brazil*.

It is evident from the data in Table 4-7 that gross differences in yields are not appreciable and that it would be difficult to reject the hypothesis that they were all, in fact, equal. For this reason, a more refined test was made by estimating production functions from the trial data. In the final round of estimates, twenty-three variables entered the regression; their estimated coefficients and related statistics are shown in Table 4-8. The first variable measures the quantity of nitrogen applied per hectare, the second simply indicates whether or not irrigation was applied, the third adjusts for the fact that some of the trials were undertaken on plots which were "small" by *pruebas regionales* standards, the fourth is an index used by attending agronomists for the lack of rainfall, and Variables 8 through 17 adjust for the location of the experiments, and 18 through 23 adjust results for abnormal years.

Regression results indicated that the only varieties out of the ten tested with yields significantly different from Deltapine 15 were Stardel, Coker 124 B, and Acala BR-2; in each case their adjusted yields were lower than those for Deltapine 15 and lower by rather similar and "small" amounts. On the basis of these results, it is concluded that no significant, positive benefits were derived from the Colombian cotton research programs.[35]

Wheat[36]

In an earlier study of the production trends of Colombia's major crops, it was claimed that "the wheat situation in Colombia contains a number of paradoxes. Despite good experimental development and government programs to expand production, both acreage and output have declined sharply in recent years."[37] Other more refined data now available continue to show that both acreage and production have declined over the past twenty years. The area cultivated in wheat fell steadily from a level of 175,000 hectares in 1953 to about 70,000 hectares in 1973; over the same period production was halved. Yields increased by about 25 percent in the 1953-58 period but stabilized at just above 1,000 kilos per hectare until 1972. In the most recent two years for which information is available (1972 and 1973), yields have increased again, and by about 20 percent.[38] Still, the average yield increase over the entire twenty-year period has been rather unimpressive.

The best explanation currently available for the decrease in acreage planted is that increasing PL 480 sales have dampened incentives for Colombian farmers to devote land to wheat production.[39] According to FAO *Trade Yearbooks*, the quantity of wheat imported has increased over the 1953-73

period from a third to almost three times the quantity of total wheat produced. The modest rise in yields may be attributable to the same forces and to a shift in the regional distribution of wheat production from the State of Boyaca where yields are higher than average to the State of Nariño in southern Colombia where farms are small and poor and yields have traditionally been below the national average.

The wheat improvement program is one of Colombia's oldest programs. It dates from 1926 when the *La Picota* experiment station was established in the central region of the country (State of Cundinamarca) for the purpose of improving yields and certain characteristics of wheat, barley, oats, and rye. Through 1951, at least half the total costs of the activities of *La Picota* were absorbed by wheat research. In 1947, "cold climate" wheat research expanded out from *La Picota* to two additional locations: one at Bonza in Boyaca and another at Isla in Cundinamarca. A few years later, additional locations for research were acquired at Tibaitata (Cundinamarca) and Obonuco (Nariño). After the addition of the Surbatá Station in Boyaca in 1959 for cold climate wheat research, activities were consolidated there, in Tibaitata, and in Obonuco.

Colombia's wheat research has received important assistance from a number of different foreign and national organizations In 1948, personnel of the program were sent to Mexico to study methods of wheat breeding with the staff of the OSS in Mexico City, then supported by the Rockefeller Foundation. Later, in 1950, Rockefeller personnel were assigned to collaborate with the Colombian research program; the foundation's assistance continued until the mid 1960s. In 1953, wheat seed distribution and multiplication programs received a lift from the Colombian Agricultural Credit Bank which ultimately assumed responsibility for them. Two years later the National Federation of Rice Growers provided some support for research on the potential for wheat production in the warmer tropical areas that traditionally produced rice; similar support was received in the same year from INA, the National Marketing Institute. The federation of barley producers, PROCEBADA, contributed to the wheat program's budget in the 1959-61 period to support expansion of the *pruebas regionales* effort; aid was received for the same purpose from FENALCE, a federation of Colombian cereal producers. In the 1967-71 period, the wheat program was assisted by the University of Nebraska Mission, financed by a consortium of international assistance agencies, including USAID and major United States foundations.

Data compiled on the costs of the wheat improvement program reflect this support from the outside and provide a profile of the development of the program. Table 4-9 presents data on the direct, complementary, and indirect costs of the program – comparable in all respects with the cost data shown

Table 4-9. Cost of the Colombian Wheat Research Program by Major Category, 1927-73 (in thousands of 1972 pesos)

Year	Direct Costs[a]	Complementary Costs[b]	Indirect Costs[c]	Added Costs of New Seeds[d]	Total Costs
1927	184		9		193
1928	236		9		245
1929	287		11		298
1930	338		12		350
1931	389		15		404
1932	441		17		458
1933	492		48		540
1934	543		52		595
1935	598		58		656
1936	653		63		716
1937	708		69		777
1938	709		78		787
1939	709		108		817
1940	710		120		830
1941	711		135		846
1942	670		143		813
1943	630		156		786
1944	589		170		759
1945	548		189		737
1946	508		207		715
1947	467		239		706
1948	416		255		671
1949	365		279		644
1950	315		351		666
1951	403		394		797
1952	492	88	440		1,020
1953	580	117	315	655	1,667
1954	669	74	349	2,638	3,730
1955	758	93	385	242	1,478
1956	1,169	238	511	1,680	3,598
1957	1,117	232	562	282	2,193
1958	996	271	584	1,058	2,909
1959	841	365	483	1,170	2,759
1960	1,202	319	500	2,182	4,203
1961	914	388	510	3,002	4,814
1962	828	277	396	2,599	4,100
1963	615	280	280	2,717	3,892
1964	1,229	487	1,146	2,628	5,490
1965	1,889	658	585	5,548	8,680
1966	2,427	592	957	4,129	8,105
1967	2,150	993	2,307	8,731	14,181
1968	2,919	915	1,261	7,050	12,145
1969	3,045	1,314	2,768	5,623	12,750

Table 4-9 – continued

Year	Direct Costs[a]	Complementary Costs[b]	Indirect Costs[c]	Added Costs of New Seeds[d]	Total Costs
1970	2,352	1,446	3,106	3,343	10,247
1971	2,020	1,603	3,260	2,901	9,784
1972	1,501	1,467	2,407	1,507	6,882
1973	1,570	1,385	2,354	1,626	6,935

Source: Carlos Trujillo, "Rendimiento económico de la investigación en trigo," M.S. thesis, Bogota, ICA/National University Graduate School, 1974, Tables 4.1, 4.2, 4.3, 4.4, and 4.5.

[a] Salaries, supplies, and office materials directly related to the wheat varietal improvement program.

[b] Represents costs of the plant pathology, soils, entomology, biometrics, extension, and plant physiology programs incurred on behalf of the wheat improvement program; for the period 1927-51 these costs were included in direct costs.

[c] Includes costs associated with the use of experiment station facilities, agricultural machinery, and land as well as costs of administration and training of program staff.

[d] Equals the difference between the average price of certified wheat seeds and the price received by farmers times the quantity sold of certified seeds; for the period 1927-49, improved varieties relevant to this study were not planted.

earlier for the rice improvement program – plus data on the additional costs to farmers of the improved wheat seeds which were adopted after 1952. It can be seen that, beginning in 1927, total costs built up slowly and by 1935 had reached a level which was subsequently maintained for about fifteen years. Following the establishment of the joint Colombian-Rockefeller Foundation program, direct, complementary, and indirect costs again built up to a level which was maintained until 1964 with the exception of three years – 1959, 1963, and 1964, the latter two being years during which the research agency was reorganized. Investments began to drift upward after 1964 and then increased sharply during the period of the University of Nebraska Mission's presence, falling off after the mission began to leave Colombia in 1971. From 1968 through 1971, total costs of the program represented only 5 percent of ICA's research budget but fully 3 percent of the value of wheat production. Wheat research had become an expensive program.

Activities of the research program revolved around four kinds of wheat: cold climate, warm climate, *Triticales*, and Durums. The first has been the most important in terms of both the time and the resources devoted to it.

When the research program began in 1927, some promising cold climate wheats were introduced from the United States and tested over a six-year period. Fifteen varieties were released to farmers from the *La Picota* experiment station in 1933. By the early 1940s, the number had increased to twenty-four. Of these the best eight were Klein, General San Martin, Klein 40,

Marzuolo, Pentad, Florence, Barcino Barbado, and Bola Picota. Because the latter two were the most widely used varieties by the mid 1940s, they are considered as check varieties in this analysis. The first reference to the yields indicated that between 850 kilos and 1.5 tons per hectare were expected. The other six of the eight varieties could reasonably be expected to yield 1.8 to 2.8 tons per hectare under experimental conditions.[40]

The vast majority of promising wheats were obtained by crossing local *criolla* varieties. By the early 1940s it was thought that available foreign varieties were inferior to local Colombian wheats and thus the program turned inward until the arrival of foreign personnel in the early 1950s. When the OSS was established in Colombia with Rockefeller Foundation support, 11,000 varieties were immediately imported from the Rockefeller Mexican program. Selections were made from these imports primarily on the basis of their resistance to the yellow, black stem, and leaf rusts. These rusts had become the major preoccupation of the Colombian wheat improvement team because data produced in 1949 showed that wheat yields were being cut 6 percent by leaf and stem rusts and 14 to 41 percent as a result of yellow rust.[41]

The first new commercial variety released after the establishment of the joint Colombian-Rockefeller Foundation program was Menkemen 52. Distributed in 1953, it was the product of a cross of varieties from the Mexican collection, including Mentana and Kenya. It reduced time to maturity by thirty-five days, was somewhat resistant to the major rusts, had strong stems, and outyielded Bola Picota by 30 percent. Two years later a second variety, Bonza 55, was released. It was the product of two Rocamex varieties, Yaqui and Kentana. Because it was especially resistant to the yellow rust of Nariño State, it was most widely distributed there. A third variety, Nariño 59, was released in 1959; it also was particularly well adapted to the State of Nariño, being resistant to its variety of yellow rust. Three years later, a large batch of new varieties produced by the joint Colombian-Rockefeller program was released, including Miramar 63, Bonza 63, Crespo 63, Napo 63, Tiba 63, and Tota 63. At the time this release was made, the industry was advised that the research program would in the future attempt to make "batch releases" (i.e., releases of more than one variety) to reduce susceptibility to new wheat rusts. Millers are reported to have reacted adversely to this announcement on the grounds that a single mill could not handle more than two varieties of wheat; an appeal was made to the research team to revise its strategy. As it turned out, the wheat program for cold climates made only one additional release – in 1968 Sugamuxi 68, Zipa 68, and Samacá 68 were distributed simultaneously.

The Colombian wheat plant began to change as the result of the introduction of dwarf varieties from Mexico in 1958. The effort to incorporate char-

Table 4-10. Comparative Wheat Yields for Thirteen Varieties Obtained Under Experimental Conditions, Colombia, 1970

Variety	Area Planted (hectares)	Reported Yields (kilos per hectare)	Reported Yields Compared with Bola Picota Yield (%)
Menkemen 52	0.095	2,820	427
Bonza 55.	0.123	2,360	358
Nariño 59	0.106	1,700	258
Bonza 63.	0.153	2,220	336
Miramar 64	0.101	2,535	384
Crespo 63	0.163	1,570	238
Napo 63	0.274	2,770	420
Tiba 63.	3.740	3,017	457
Tota 63.	0.200	2,680	406
Zipa 68.	0.134	3,000	455
Samacá 68	0.050	3,700	561
Sugamuxi 68.	0.223	2,300	348
Bola Picota.	0.132	660	100

Source: Colombian Agricultural Institute (ICA), *Informe del Programa Nacional de Trigo* (Bogota: ICA, 1970), Appendix 4.

acteristics of the smaller plant did not, however, gain force and importance until about 1964. By 1970, 60 percent of all materials in the Colombian wheat research program included dwarf wheats. Of the thirteen improved varieties released to farmers after the establishment of the joint Colombian-Rockefeller program, small-plant characteristics were incorporated in nine of them: Bonza 63, Miramar 63 and 64, Napo 63, Tiba 63, Tota 63, and the three varieties released in 1968. In this regard it is important to mention that practically none of Colombia's wheat is irrigated and that the use of fertilizer is negligible.

In 1971, ICA published the data in Table 4-10 comparing yields obtained under experimental conditions on small plots of land for twelve improved varieties and Bola Picota. Reported yield advantages over the Bola Picota variety were in excess of 500 percent for the highest yielding wheats and not less than 250 percent for any improved variety. By international standards, these yields of the Colombian varieties also appeared to be quite good. As Table 4-11 indicates, in the International Wheat Trials of 1968 three of Colombia's most recently released wheats outyielded the best of the Mexican wheats, Azteca 67. The average level of these yields, however, is extremely high even by experiment station standards in Colombia (e.g., those reflected in Table 4-10).

With reference to the second category of wheat research – namely, that undertaken on "warm climate" varieties – it is worth mentioning that large

Table 4-11. Comparative Wheat Yields Obtained for Colombian and Mexican Varieties in the International Nursery Trials, 1968

Variety	Country of Origin	Reported Yields (kilos per hectare)
Sugamuxi 68	Colombia	6,232
Crespo 63	Colombia	6,215
Samacá 68	Colombia	6,217
Azteca 67	Mexico	6,110
Tota 63	Colombia	6,054
Napo 63	Colombia	6,044
Tiba 63	Colombia	5,894
Penjamo 62	Mexico	5,833
Centrifén	Chile	5,755
Norteño	Mexico	5,538
Lerma Rojo 64 x Sonora 64	Mexico	5,349
Sonora 64 x TZ.PP	Mexico	5,249
Nai 60(B)	Mexico	5,249
Bonza 63	Colombia	5,233
Jaral	Mexico	5,166
Zipa 68	Colombia	5,116

Source: Colombian Agricultural Institute (ICA), *Informe del Programa Nacional de Trigo* (Bogota: ICA, 1968), p. 13.

areas of wheat had existed in the warmer regions since the colonial period. However, these wheat areas were practically eliminated in the mid 1930s as a result of attacks by stem rust. Thus in 1955 when the first rust-resistant varieties were available, the Federation of Rice Growers persuaded the research agency to experiment with Bonza and Menkemen in the Cauca Valley and Tolima State. Although the rust resistance of the new wheats was confirmed in these early studies, the experiments were not continued because of the unpromising levels of yields obtained. It was thought at the time that, for wheat to compete with rice, 2,500 to 3,000 kilos of wheat per hectare would be required. Commercial yields averaged 1,500 kilos, and maximum experimental yields did not exceed 2,750 kilos per hectare.[42]

The wheat program first experimented with rye as a rust-resistant, high-protein, water-saving alternative to wheat in 1937, and experiments with *triticales* were initiated in *La Picota* in 1946. However, interest in *triticales* appears to have languished until recently. The wheat program has also evidenced interest in Durum wheats. Work began on Durum in 1952 and was stepped up somewhat in the mid 1960s. However, it was not successful primarily because of the high humidity in Colombia's wheat areas, the short days, and the occasional heavy rainfalls which occur when the grains are maturing.

As with rice and cotton, available data on the *pruebas regionales* were col-

lected in an attempt to quantify the shift parameter and gross social benefits attributable to the Colombian wheat research program. However, the collection of these data was much more difficult for wheat than for rice and cotton because the information had been scattered when the research program changed its affiliation with outside agencies. In the final analysis, data for only 1,016 individual trials were obtained for the 1953-73 period; many more trials had been undertaken on the major improved varieties.

Most of the trials for which data were obtained (about 80 percent) related to six varieties: Bonza 63, Crespo 63, Menkemen 52, Napo 63, Nariño 59, and Tota 63. By region, the bulk of the data related to two states, Cundinamarca and Nariño. Only about 5 percent of the data are from the State of Boyaca. The director of the National Wheat Program stated that this does not reflect any slighting of the Boyaca wheat regions because there are many regions in Cundinamarca and Nariño that are fully representative of the areas in Boyaca. Given that wheat production in Boyaca has declined more sharply than in any other state, the facts here are important, although difficult to establish and qualify. Finally, it should be noted that most of the *pruebas regionales* data obtained (70 percent) were for the years 1963, 1964, 1968, 1971, and 1972.

Table 4-12 summarizes the data collected for thirteen improved wheat varieties and two check varieties, Bola Picota and "150." Mean yields in kilos per hectare are reported by variety, together with the estimated standard error of yields, the range of trial yields corresponding to a 5 percent level of probability, and the coefficient of variation of yields. When compared with the data in Table 4-10, it is apparent that these data assign rather different relative yield ranks to specific varieties. For example, in Table 4-12 the yield of Menkemen 52 puts it in twelfth place among the improved varieties, but its yield in Table 4-10 ranks it in third place. Also, the average level of yields reported in Table 4-12 is lower than the averages of Tables 4-10 and 4-11, and the yield advantage of the improved varieties is noticeably less than indicated by Table 4-11.

The range in yields of all improved varieties in Table 4-12 includes the upper-bound yield reported for Bola Picota; the range in yields for six out of the thirteen improved varieties includes the upper-bound yield for "150." The yield advantages of Samacá 68 and Bonza 63, as a percentage of the average yields of "150" and Bola Picota, are 83 and 75 percent, respectively; the corresponding value for all improved varieties shown in Table 4-12 is 50 percent.

To adjust these estimates of the gross yield advantage of the improved wheat varieties for the effects of other determinants of yields, production functions were estimated from the data on commercial trials. The final ver-

Table 4-12. Comparative Wheat Yields for Fifteen Varieties Obtained in Commercial Trials, Colombia, 1953-73

Variety	Number of Observations	Output per hectare (kilos) Mean	Standard Error	Range at 5% Probability Lower Bound	Upper Bound	Coefficient of Variation of Yields (%)
"150"	8	1,624	1,022	771	2,476	62.9
Bola Picota	8	1,194	895	448	1,941	74.9
Samacá 68	47	2,584	1,592	2,117	3,051	61.6
Bonza 63	106	2,460	1,197	2,230	2,690	48.7
Miramar 63	29	2,348	1,218	1,885	2,812	51.9
Zipa 68	31	2,190	1,382	1,684	2,697	63.1
Bonza 55	77	2,172	1,504	1,831	2,513	69.2
Crespo 63	129	2,115	1,369	1,876	2,353	64.7
Tiba 63	51	2,110	1,265	1,754	2,466	59.9
Nariño 59	119	2,106	1,351	1,861	2,352	64.1
Napo 63	136	2,097	1,340	1,869	2,324	63.9
Sugamuxi 68	12	1,973	1,157	1,238	2,708	58.7
Tota 63	104	1,893	1,283	1,643	2,142	67.8
Menkemen 52	138	1,836	1,237	1,627	2,044	67.4
Miramar 64	21	1,643	1,496	960	2,326	91.1
All varieties	1,016	2,099	1,340	2,027	2,175	66.1

Source: Carlos Trujillo, "Rendimiento económico de la investigación en trigo," M.S. thesis, Bogota, ICA/National University Graduate School, 1974, Table 5.7.

sion of the production function is shown in Table 4-13. Thirty-nine variables entered: twelve of these represented zero-one adjustment variables for the location of the trials; fourteen adjusted for the effects of variety; four, measured as indices above a certain threshold level and zero otherwise, accounted for major diseases reported (*vaneamiento*,[43] foot and root rot, stem rust, and dwarfing virus); one adjusted for seeding rates of 80 kilos per hectare (only two rates were actually reported – 80 and 111 kilos per hectare); two each were used to adjust for soil type and reported weather; and one variable each adjusted for how well the soil had been worked before planting, for weed growth, and for the application of lime. Coefficients on the noncontinuous variables shown in Table 4-13 need to be read with some care. Since the regression package reparameterized all variables by imposing the restriction that the sum of the regression coefficients equal zero, an estimate of the corrected mean yield associated with a given noncontinuous variable should be calculated by adding its estimated coefficient to the overall mean value of yields, which was 2,099 kilos per hectare.

The statistical significance of the variety variables entering the regression was surprisingly low. Only the estimated coefficients on the Bonza 63 and

Table 4-13. Production Function Estimates for Wheat Based on Commercial Trials in Colombia, 1953-73

Independent Variable	Estimated Coefficient	Estimated t Statistic
1. *Vaneamiento*	− 13.8	− 6.98
2. Foot and root rot	− 11.1	− 5.75
3. Stem rust	− 8.6	− 3.18
4. Dwarfing virus	− 15.8	− 3.73
5. Plot size	− 48.5	− 5.88
6. Seeding rate	− 225.0	− 3.69
7. Good soils	482.7	8.10
8. Poor soils	− 340.2	− 4.31
9. Poor prior soil preparation	− 157.1	− 2.68
10. Heavy weed growth	− 300.6	− 6.79
11. Unfavorable weather	− 1,333.9	− 10.20
12. Favorable weather	895.4	8.43
13. Lime applied	154.1	2.35
14. Location 1	− 732.0	− 3.21
15. Location 2	3,672.8	16.40
16. Location 3	692.4	7.37
17. Location 4	1,604.9	9.24
18. Location 5	− 466.9	− 2.29
19. Location 6	− 1,084.6	− 4.44
20. Location 8	− 349.1	− 3.12
21. Location 9	− 644.9	− 5.38
22. Location 10	− 831.1	− 6.60
23. Location 11	−812.2	− 1.94
24. Location 12	− 856.6	− 3.05
25. Location 13	49.1	0.56
26. Menkemen 62	− 113.2	− 1.20
27. Bonza 55	98.8	0.89
28. Nariño 59	163.8	1.70
29. Miramar 63	− 375.5	− 2.17
30. Bonza 63	340.5	3.27
31. Miramar 64	− 300.3	− 1.46
32. Crespo 63	210.9	2.12
33. Napo 63	131.7	1.44
34. Tiba 63	− 169.2	− 1.28
35. Tota 63	− 80.7	− 0.77
36. Zipa 68	− 152.8	− 0.92
37. Samacá 68	196.9	1.22
38. Sugamuxi 68	210.3	0.80
39. Bola Picota	− 303.5	− 0.91
Intercept	2,460.8	15.73
	$R^2 = 0.53$	n = 1,016

Source: Carlos Trujillo, "Rendimiento económico de la investigación en trigo," M.S. thesis, Bogota, ICA/National University Graduate School, 1974, Table 5.14.

Crespo 63 varieties were positive and significant. In an independent estimate of the partial contribution of the variety variables as a group to yield variance, the significance of the variety variables was found to be less than that of any other single variable or group of variables (e.g., the variables adjusting for location).

Also, the values of the estimated yield advantages of most of the improved varieties are lower on the basis of the regression of Table 4-13 than on the basis of the unadjusted estimates of mean yields presented in Table 4-12. The largest and most significant yield advantage of any improved variety in the regression – that of Bonza 63 – is only 36 percent more than the adjusted yield of Bola Picota, or roughly half the value implied by the unadjusted yield estimates of Table 4-12.

Table 4-14 presents statistics summarizing the use of the improved varieties of wheat. Underlying these summaries are data for each improved variety used in weighting shift parameters taken from the estimated production function to arrive at an average annual estimate of the percentage yield increase of improved wheats over average commercial yields. Two estimates of these weights were considered, and their implications for overall rates of adoption are reflected in Table 4-14 in the "upper-bound value" and in the "most probable value" of the percentage of wheat land planted to improved varieties. The first estimate simply assumes that the total use of an improved variety equaled in any year two times its reported sales in certified form and that the average seeding rate was 120 kilos per hectare for all varieties. As can be seen in the table, this assumption results in levels of adoption in the late 1960s which were high by known standards for unirrigated wheat. The second estimate – the one used in this study – maintained that the total seed use of any variety would equal two times its certified sales and that seeding rates averaged 120 kilos per hectare but set the germination rate of certified seeds at 86 percent and the corresponding rate for seeds retained and planted by farmers from prior harvests at 39 percent. These low rates of germination, based on several ICA studies,[44] were not encountered for rice, cotton, or soybeans. Since the sum of the two germination rates is 125 percent, the effect of this procedure was to assume that the real, postgermination rate of employment of an improved variety was 1.25 times its quantity sold in certified form.

Estimates of the yield advantage of each improved variety taken from the regression, divided by average commercial yields in each year and weighted by the appropriate adoption rate, produced two streams of gross benefits for the 1953-73 period of the Colombian wheat improvement program. In each case it was assumed that the c.i.f. import price of wheat was the relevant "price" at which to value the crop. Because of the overvaluation of the Co-

Table 4-14. Selected Data on Employment of Improved Wheat Varieties in Colombia, 1953-73

Year	Total Certified Seed Sales (tons)	Wheat Land in Improved Varieties(%)	
		Upper-Bound Value	Most Probable Value
1953	147	1.4	0.9
1954	1,039	8.9	5.6
1955	113	0.9	0.5
1956	639	5.2	3.3
1957	599	5.5	3.4
1958	1,610	22.0	13.7
1959	3,050	43.4	27.1
1960	2,149	28.7	17.9
1961	2,830	33.7	21.1
1962	2,470	31.7	19.8
1963	2,100	31.8	19.9
1964	1,864	27.0	16.9
1965	2,782	38.6	24.1
1966	3,113	45.0	28.1
1967	3,795	66.6	41.6
1968	4,494	83.2	52.0
1969	2,809	72.0	44.6
1970	1,694	56.5	35.1
1971	1,641	56.9	35.3
1972	1,528	40.4	25.3
1973	1,429	33.0	20.5

Source: Carlos Trujillo, "Rendimiento económico de la investigación en trigo," M.S. thesis, Bogota, ICA/National University Graduate School, 1974, Tables B.3, 5.17, and 2.10.

lombian peso, this assumption underestimates the gross benefits of research. It was found, however, that the estimated internal rate of return to the wheat improvement program would increase by only 4 percent if the (higher) price received for wheat by farmers was used instead.

In one of the yield advantage estimates it was assumed that the price elasticity of the supply of wheat equaled 0.55 and that the price elasticity of demand was −0.04. These values of the price elasticity parameters were derived from estimates of two independent studies.[45] For the second estimate of gross benefits, it was recognized that wheat was imported throughout the 1953-73 period and that the value of gross benefits should therefore not include a surplus to consumers.

The two estimates of gross benefits, as well as the total costs shown in Table 4-9, were then projected through 1976 on assumptions similar to those used for rice. The internal rate of return estimated for the "closed economy"

case corresponding to the stream of net program benefits (gross benefits minus costs) for the 1927-76 period was 11.9 percent. When allowance was made for the fact that wheat was imported, the estimated internal rate of return was reduced to 11.1 percent.

Soybeans [46]

Soybean production in Colombia has grown very rapidly in recent years. The total area cultivated was only 16,000 hectares in 1962; production stood at 25,000 tons, and yields were 1,500 kilos per hectare in the same year. By 1972, just ten years later, the area harvested had increased to 58,000 hectares, production was 116,000 tons, and yields had risen by a third to 2,000 kilos.[47] This rapid development is attributed to the fact that soybeans are excellent in rotation with several major crops (cotton, in particular) and that the demand for soybeans has been strengthened by a fast-growing poultry industry. The crop is cultivated in Colombia only in the Cauca Valley; this is probably because the feed industry is near there. An equally important explanation, however, is that available high-yielding, disease-resistant soybean varieties produced by the ICA experiment station at Palmira have been adapted to conditions found in the Cauca Valley.

ICA did not begin soybean research until 1960, and then work was restricted to the Palmira Station. In about seven years, however, the research effort produced three new varieties with superior yield potential and resistance to major diseases, principally *cercóspora*, a fungus which attacks and destroys almost all parts of the soybean plant. Table 4-15 summarizes experimental data relating to yields of four soybean varieties obtained for this study. Unfortunately, data generated from commercial fields or *pruebas regionales* were unavailable; thus, the information used in Table 4-15 and elsewhere in this section relates to small experimental plots of the Palmira Station. However, the use of experimental data is somewhat less troublesome for soybeans than for other crops because of the high level of technology and improved practices used by farmers in the Cauca Valley.

The ICA Pelican, Lila, and Taroa varieties were released successively by the experiment station. The Mandarin variety was imported earlier from the United States and by 1967 had come to occupy about four-fifths of all soybean acreage. Compared with the data previously shown for cotton, rice, and wheat, the yield superiority of the improved varieties in Table 4-15 is not particularly outstanding.

Nonetheless, adoption of the new varieties has been nothing short of spectacular. Table 4-16 presents the percentages of soybean acreage planted to each of the four main varieties grown in the 1967-71 period. These data were

Table 4-15. Average Soybean Yields from Experimental Trials by Variety, Colombia, 1967-71 (in kilos)

Year	Unimproved Variety, Mandarin	Improved Varieties		
		ICA-Pelican	ICA-Lili[a]	ICA-Taroa
1967	2,068	2,406		2,490
1968	2,329	2,373	2,700	2,650
1969	1,756	2,138	2,525	2,400
1970	1,751	2,373	2,300	2,500
1971	1,828	2,578	2,410	3,034
Average	1,946	2,455	2,483	2,622

Source: Gabriel Montes, "Evaluación de un programa de investigación agrícola: El caso de la soya," M.S. thesis, Bogota, University of the Andes, 1973, Table 3.

[a] No experiment reported for 1967.

estimated using a procedure analogous to the one followed for the other crops discussed in this chapter, i.e., total acreage planted to a variety in a given year was taken to be equal to two times certified seed sales of that variety divided by an estimate of the seeding rate. The important point to note about the data in Table 4-16 is that roughly three-quarters of the area planted in soybeans used the Mandarin variety in 1968 and 1969, while by 1971 Mandarin had practically disappeared, and ICA Pelican and Lili varieties had come to be used on 84 percent of all acreage.

There were two major reasons for the rapid and high levels of adoption of the improved varieties. First, there was a severe outbreak of the *cercóspora* fungus on the Mandarin variety in 1969. In 1970 ICA found itself in the en-

Table 4-16. Land Area Planted to Improved Varieties of Soybeans as a Percentage of the Total Area Planted in Soybeans, Colombia, 1967-71[a]

Year	Variety					Total
	Mandarin	ICA-Pelican	ICA-Lili	ICA-Taroa	Other	
1967[b]	89	1			10	100
1968	77	13			10	100
1969	71	18	5		6	100
1970	35	29	24		12	100
1971	2	43	41	2	12	100

Source: Gabriel Montes, "Evaluación de un programa de investigación agrícola: El caso de la soya," M.S. thesis, Bogota, University of the Andes, 1973, Table 6.

[a] Estimates derived from data on certified seed sales, assuming that the total use of a variety of seed equaled two times its sales in certified form. Blanks indicate less than 0.5 percent.

[b] Only data on ICA-Pelican use were available. The Mandarin estimate was derived on the assumption that "other" varieties occupied 10 percent of all acreage planted in 1967 as they did in 1968.

Table 4-17. Production Function Estimates for Soybeans Based on Experimental Data, Colombia, 1967-71

Independent Variable	Estimated Coefficient	Estimated t Statistic
1. ICA-Pelican	268.44	3.06
2. ICA-Lili	418.31	3.93
3. ICA-Taroa	436.95	4.37
4. Number of weedings	86.93	2.43
5. Herbicide and insecticide use	78.45	2.35
6. Rainfall	113.11	1.75
7. *Cercóspora*	− 107.30	− 3.68
8. Plant density/seeding rate	200.80	4.58
Intercept[a]	692.08	
	$R^2 = 0.70$	n = 68

Source: Gabriel Montes, "Evaluación de un programa de investigación agrícola: El caso de la soya." M.S. thesis, Bogota, University of the Andes, 1973, Table 8.

[a] No estimated t statistic was available.

viable position of having two high-yielding, fungus-resistant varieties available for distribution and plenty of seed. Second, it was easy for this news to get around; the only Colombian farmers interested in soybean production are in a relatively small geographic area, where some of the best communication and infrastructure facilities in the country are located. The farmers themselves are among the most modern in Colombia.

As with cotton, rice, and wheat, an attempt was made to generate more refined estimates of the yield superiority of the new soybean varieties by identifying a relation between yields and their major determinants, including seed variety. Final results of this effort are shown in Table 4-17, which reports on a regression of experimental yields on three independent variables for the major improved seed varieties (observations on the check variety, Mandarin, were included in the regression, of course), the number of times the experiment was weeded, kilos per hectare of active herbicide and insecticide ingredients applied, millimeters of rainfall, the presence of the *cercóspora* fungus measured as an index with a range of 0 to 5, and an index (likewise with a range of 0 to 5) which reflected essentially the ratio between the observed plant density and the seeding rate. Signs of all estimated coefficients are those which were hypothesized at the outset, and the significance of most coefficients is seen to be high. One exception, the estimated coefficient for rainfall, reflects the fact that the rainfall variability was limited because most experiments were undertaken in a small geographic area. The statistical strength of the plant density/seeding rate variable is attributable to the fact that it is capturing the effects of several unspecified cultural practices used in the ex-

Table 4-18. Estimated Benefits and Costs of the Soybean Research Program in Colombia, 1960-80 (in 1,000 pesos, 1958)[a]

Year	Gross Benefits: Based on "Varietal Effect" Shift Parameters	Gross Benefits: Based on "Simple" Shift Parameters	Total Costs
1960			40
1961			41
1962			37
1963			39
1964			33
1965			37
1966			40
1967	49	62	57
1968	1,288	2,230	98
1969	3,102	6,187	179
1970	7,847	16,300	463
1971	10,217	28,643	267
1972-80 . . .	10,217	28,643	267

Source: Gabriel Montes, "Evaluación de un programa de investigación agrícola: El caso de la soya," M.S. thesis, Bogota, University of the Andes, 1973, Table 14 and 21

[a] Blanks indicate no benefits during this period.

periments. This variable may thereby have adjusted the estimated coefficients of the improved varieties for the experimental nature of the data – the high levels of technology and intensive use of improved cultural practices. The fact that the coefficients on the improved varieties increase in value from Pelican (the first released) through Lili to Taroa (most recently released) indicates substantial progression in ICA's research program. A test of the null hypothesis that the estimated coefficient on the Pelican variety equaled that of the Lili variety was rejected at the 99 percent level of significance. Similarly, the hypothesis that the coefficients estimated for the Lili and Taroa varieties are equal was rejected at the 95 percent level.

The yield advantage of the improved varieties taken from the production function, divided by commercial yields and weighted by the percentages of the land area planted in each variety, led to a "varietal effect" estimate of the shift parameter. The yield advantage of the improved varieties estimated directly from the data in Table 4-15, also divided by commercial yields and weighted by the percentages of the land area planted in each variety, led to a "simple" estimate of the shift parameter associated with the soybean research program. These two estimates of the shift parameter were combined with plausible values for the price elasticities of demand and supply – respectively, – 0.77[48] and infinity – to give a range of gross benefits in each year for the 1967-71 period. These two streams of gross benefits are shown in Table 4-18

along with estimates of the costs of the soybean research program, which include the same categories of expenses as do the other three commodities considered in this chapter. Costs and benefits were projected nine years beyond 1971 on the assumption that in real terms both would remain about constant. The resulting internal rate of return for the smaller benefit stream was 79 percent, while the rate for the larger one was 96 percent. These rates did not change appreciably when program costs were assumed to increase 10 percent annually after 1971.

Comparisons and Conclusions

At the outset we hypothesized that net internal rates of return to varietal improvement of rice, cotton, wheat, and soybeans in Colombia had been higher than the opportunity cost of public funds (10 percent) and, in fact, even higher than rates of return on the order of 50 percent calculated for similar programs in the United States. Among the four programs, somewhat lower estimated returns were expected for wheat because its domestic price had been under pressure from PL 480 imports, and production had moved to less productive areas.

To examine this latter possibility more carefully – as well as the roles of socioeconomic and structural constraints generally in the estimated returns to research – the total shift in product supplies caused by the use of improved varieties generated through research was divided into two parts: an estimate of the "yield advantage" of the new over the old varieties and an estimate of the rate of adoption of the new varieties. Low returns attributable to socioeconomic and structural constraints were then associated mainly with low rates of adoption; the role of the biological determinants of the return to research was associated principally with the calculated yield advantage of the improved varieties. The yield advantage was estimated with regression techniques which were designed to factor out assumed positive interactions between the improved varieties and such inputs as fertilizers and water.

Our main results are summarized in Table 4-19. Estimated net internal rates of return were found to exceed 50 percent in the cases of soybeans and rice. Returns calculated for the wheat improvement program turned out to be much lower – in fact, well below the 50 percent level; and gross returns to cotton research were found to have been negligible. In all cases, the estimated yield advantage was smallest when interactions of the improved varieties with other variables were factored out.

The very high rates of return estimated for soybean research were explained by a large shift in product supply caused principally by the rapid uptake of the new varieties and their virtual displacement of the unimproved Mandarin

Table 4-19. Selected Comparative Data on the Rice, Cotton, Wheat, and Soybean Varietal Improvement Programs in Colombia[a]

Concept	Unit	Rice	Cotton	Wheat	Soybean
1. Estimated net internal rates of return	Percentage	60-82	0[b]	11-12	79-96
2. Estimated value of the supply shift parameter, 1971	Percentage	10-16		16	17-35
3. Estimated yield advantage, 1971	Percentage	25-39		46	17-36
4. Land area planted to improved varieties, 1971	Percentage	41	100	35	98
5. Average yields, 1971, Colombia/United States	Ratio	0.68	1.03[c]	0.53[c]	1.01[c]
6. Total research costs/value production, 1968-71	Percentage	0.5	0.1	3.0	0.1

Source: Concepts 1-4 are based on a summary of previous tables in this study. Concept 5, Colombia, is from: Jorge Ardila, "Rentabilidad social de las inversiones en investigación de arroz en Colombia," M.S. thesis. Bogota, ICA/National University Graduate School, 1973; Gabriel Montes, "Evaluación de un programa de investigación agrícola: El caso de la soya," M.S. thesis. Bogota, University of the Andes, 1973; Andrés Rocha, "Evaluación económica de la investigación sobre variedades mejoradas de algodón en Colombia," M.S. thesis. Bogota, ICA/National University Graduate School, 1972; and Carlos Trujillo, "Rendimiento económico de la investigación en trigo," M.S. thesis. Bogota, ICA/National University Graduate School, 1974. Concept 5, United States, is from USDA, *Agricultural Statistics, 1973*, p. 441. For concept 6, see Ardila (1973); Montes (1973); Rocha (1972); and Trujillo (1974).

[a] Blanks indicate no data available.

[b] Since gross benefits were negligible, this net rate should be negative.

[c] 1970-72 average.

seed. The calculated yield advantage of the new varieties was not spectacular. The striking adoption pattern of the improved soybeans was attributed to the strength of product demand, derived in the main from a fast-growing poultry industry, the geographic concentration of production in a small area (the Cauca Valley), which facilitated the rapid diffusion of information concerning the improved varieties, the expected severity of attacks by the *cercóspora* virus, to which the improved varieties were resistant, and the fact that soybean producers figure among Colombia's most modern farmers. That soybean yields have been practically equal in Colombia and the United States in recent years (Table 4-19) reinforces our characterization of the industry as a modern one.

The Colombian cotton industry has evidenced similar characteristics. Yields of cotton in Colombia have not only equaled United States yields but even surpassed them in some recent years. Adoption of the improved United States varieties of cotton was practically instantaneous as a result of the govern-

ment's ownership of gins and control over seed distribution. Yield increases since the early 1950s, when improved varieties came into widespread use, have been spectacular. Still, in spite of these similarities with the case of soybeans, it was concluded that returns to the cotton research program have been negligible.

This apparent contradiction was explained in terms of the organization of the research effort. The Colombian textile industry, long accustomed to importing United States cotton, partly as a result of a preferential rate of exchange, was compelled "to buy Colombian" by a change in government policy. Textile firms then sponsored the establishment of research which would lead ultimately to the local production of United States varieties of cotton. The final organization of the research program involved merely the importation, local testing, and distribution to farmers of the highest yielding United States varieties. This organization was justified on the premise that yields obtained locally from the United States cotton would vary according to variety; thus, there would be a payoff for identifying those kinds of cotton which yielded best under local conditions.

Our data did not sustain this premise, however. Information compiled on about 500 commercial field trials undertaken in Colombia for over ten varieties of improved United States cotton indicated that differences in yields by variety were minimal. Thus, the main research activity – local testing of imported varieties – appears to have been unnecessary. United States varieties could just as well have been selected at random for distribution in Colombia. Therefore, even though the widespread use of United States cotton increased yields, resulting surpluses were not attributed to the cotton research program.

As mentioned earlier in this section, net internal rates of return found for the rice research program were high by any standard of comparison. Yet, in view of the comparative data of Table 4-19, they are a puzzle. Although the ranges of estimated rates of return for the rice and soybean programs overlap, we see that the range of the calculated supply shift parameter for rice is significantly lower than the corresponding range for soybeans, principally because of differences in the levels of adoption of the improved rice and soybean varieties. Also, it can be observed that estimated rates of return to rice were much higher than those for wheat, even though the calculated values of their supply shift parameters were roughly comparable. Why then were estimated net rates of return to the rice research program so high?

An important answer lies with the cost side of the net rates of return calculations and with the organization of the rice improvement program. We believe that the direct costs of rice research to Colombia were effectively reduced by the program's having tapped into the accumulated stock of plant-breeding capital – general knowledge, improved breeding techniques, and

plant materials – available in the two international centers, CIAT and IRRI, and in the World Collection of Rice. Without that accumulated capital, the costs of achieving comparable shifts in the supply of rice would have been higher and the corresponding net rates of return would have been lower.

This characteristic of the rice program was also found in the wheat research program. In fact, wheat had a longer history of using the accumulated foreign stock of plant-breeding capital than did rice. Linkages with the Rockefeller-Mexican program dated from about 1948, and additional collaborative support was provided the program during the late 1960s and early 1970s by the University of Nebraska Mission to Colombia. Judged from a purely technical and biological point of view, these foreign inputs were associated with success as they were in the case of rice. The estimated yield advantages of the improved wheat varieties were found to be large, even after the effects of variables which interacted with the new wheat varieties had been factored out. If they were included, the improved wheats could be shown to outyield the unimproved varieties by considerably more than 250 percent. Also, in international nursery trials the Colombian wheats easily outyielded the Mexican wheats from which they were largely derived.

Thus, the low estimated returns to the wheat research program were not the result of technical failures in plant breeding. Part of the explanation for the low returns lies in patterns of on-farm adoption of the improved seeds. The uptake of the new wheat varieties was notoriously slow. Fully twelve years elapsed from the time the first improved varieties of wheat were sold commercially in 1953 until they were in use on roughly one-quarter of all wheat land. Rates of adoption peaked at 50 percent in 1968 and then began a downward trend. Levels of use of the improved varieties in 1974 were estimated to include barely a fifth of all crop land planted to wheat. The slow uptake of the new seeds and the low levels and distressing trends in their use were attributed primarily to socioeconomic and structural constraints on production, especially the depressed domestic market resulting from continued PL 480 imports at levels which represented a large multiple of national production.

Two additional explanations for the low estimated rates of return to wheat research should also be stressed. One is that it became a very expensive program in the middle and late 1960s. Annual investments averaged fully 3 percent of the total value of wheat production, a figure which was not even remotely approximated by investments made in the other three varietal improvement programs (Table 4-19). A second explanation relates to the program's long gestation period. The Colombian wheat program dates from 1927. Yet our review of that history indicated that a well-organized research effort probably did not get underway until 1948, and the first improved varieties were not released on a major scale until 1953. As a consequence, investments

(albeit at reduced levels) were being made for almost a quarter of a century before offsetting benefits were realized, and this had an adverse effect on the calculated net rates of return for wheat research.

NOTES

1. An earlier version of this chapter was presented in a workshop on Methods Used to Allocate Resources in Applied Agricultural Research in Latin America which was held at the International Center for Tropical Agriculture (CIAT), November 26-29, 1974. The current version of the chapter benefited from comments of participants in that workshop and from suggestions subsequently made by Norman R. Collins and Alain de Janvry.

2. A. C. Harberger, "La tasa de rendimiento del capital en Colombia," *Revista de Planeación y Desarrollo*, 1:3 (October 1969).

3. Zvi Griliches, "Research Costs and Social Returns: Hybrid Corn and Related Innovations," *Journal of Political Economy*, 66:5 (October 1958), 419-432.

4. Willis Peterson, "Returns to Poultry Research in the United States," *Journal of Farm Economics*, 49:3 (August 1967), 656-669.

5. Nicolas Ardito Barletta, "Costs and Social Benefits of Agricultural Research in Mexico," Ph.D. dissertation (Chicago: University of Chicago, 1971).

6. Harry W. Ayer and G. Edward Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in São Paulo, Brazil," *American Journal of Agricultural Economics*, 54:4 (November 1972), 557-569.

7. R. C. Duncan, "Evaluating Returns to Research in Pasture Improvement," *Australian Journal of Agricultural Economics*, 16:3 (December 1972), 153-168.

8. See, for example, Willis Peterson, "The Returns to Investment in Agricultural Research in the United States," *Resource Allocation in Agricultural Research*, ed. Walter Fishel (Minneapolis: University of Minnesota Press, 1971), p. 160..

9. This section draws heavily on the work by Jorge Ardila, "Rentabilidad social de las inversiones en investigación de arroz en Colombia," M.S. thesis (Bogota: ICA/National University Graduate School, 1973).

10. S. H. Ou, *Rice Diseases* (England: Commonwealth Mycological Institute, 1972), pp. 28-33. Apparently, the attack was least severe where the Colombian red rice was grown; see Philippe Leurquin, "Rice in Colombia: A Case Study in Agricultural Development," *Food Research Institute Studies*, 6:2 (1967), 231.

11. The means by which the disease was transmitted were not identified with the insect, *Sogotodes*, until 1958.

12. Chemical control of the virus, though expensive, proved somewhat effective among partially resistant varieties; see G. E. Galvez, "*Hoja Blanca* Disease of Rice," *The Virus Diseases of the Rice Plant* (Baltimore: Johns Hopkins Press, 1968), pp. 35-49.

13. Bluebonnet 50 was first imported to Colombia in 1954. The history of its introduction and rapid adoption is discussed by Leurquin, "Rice in Colombia," pp. 250 and 251.

14. *Informe de Gerencia al XIII Congreso Nacional* (Bogota: FEDEARROZ, 1971), p. 32.

15. In 1948 Raul Varela Martinez, *Industria y comercio de arroz en Colombia* (Bogota: Ministerio de Agricultura y Canaderai, 1949), p. 15, estimated that 18 percent of all

rice land was irrigated and 16 percent was partly irrigated. By 1974, it is estimated that the percentage of rice land irrigated had increased to about 75 percent.

16. See, for example, Leurquin, "Rice in Colombia," Tables 5 and 11.

17. The exception to this procedure was taken in estimated CICA-4's yield advantage since, given the specification of the regression, the yield advantage of CICA-4 simply equals the negative value of the coefficient on Bluebonnet 50.

18. The varietal-effects estimate shown here evidences lower values for the shift parameters than the source (Ardila, "Arroz en Colombia," Tables 17 and 20) by reason principally of the omission of adjustments for "time." Ardila originally added appropriate values of the coefficients on the time variables in each year to the yield differentials estimated from the production functions. Since those coefficients are on net strongly positive for the 1964-71 period, the effect was to increase estimated values of the shift parameters.

19. Calculations based on the varietal effects plus interaction effects shift parameters are not included here but can be inspected in Ardila, "Arroz en Colombia," Table 27.

20. Nestor Gutierrez and Reed Hertford, *Una evaluación de la intervención del gobierno en el mercado de arroz en Colombia*, Technical Pamphlet no. 4 (Palmira: Centro Internacional de Agricultura Tropical, 1974), Table 3.

21. *Ibid.*, Table 4

22. Ardito Barletta, "Agricultural Research in Mexico."

23. One staff member of the rice program held a doctorate and four others held masters degrees. Costs of training personnel of the National Federation of Rice Growers at the ICA/National University Graduate School were also included.

24. This is a more moderate assumption than that used by Ardila, "Arroz en Colombia," Table 35, who assumed that the percentage of area sown in improved rice would fall between 72 percent and 84 percent by 1980. The data of Dana G. Dalrymple's *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less-Developed Nations*, Foreign Agricultural Economic Report no. 95 (Washington, D.C.: Economic Research Service, USDA, 1974), Table 38, indicating that adoption rates in the Philippines, Malaysia, and India are topping out at rates well under 60 percent, plus the analysis by Robert Evenson, "The 'Green Revolution' in Recent Development Experience," *American Journal of Agricultural Economics*, 56:2 (May 1974), 387-394, suggest that the use of improved varieties may never reach 70 percent in Colombia and that an assumption of 57 percent is more conservative and probable.

25. Ardila, "Arroz en Colombia," placed a range on the internal rate of return of 53.0 to 53.4 percent. The minimum (and the maximum) reported here would have been lower, and lower than Ardila's estimates, had the additional costs of the new varieties to farmers been netted out of "gross benefits." Data on those costs were simply judged to be too weak to include.

26. This section is based largely on the work by Andrés Rocha, "Evaluación económica de la investigación sobre variedades mejoradas de algodón en Colombia," M.S. thesis (Bogota: ICA/National University Graduate School, 1972).

27. Philippe Leurquin, "Cotton Growing in Colombia: Achievements and Uncertainties," *Food Research Institute Studies*, 6:2 (1966), 145.

28. These and other production and trade data cited in this section were obtained from the relevant number of *Cotton-World Statistics* published by the Secretariat of the International Cotton Advisory Committee, Washington, D.C.

29. *Changes in Agricultural Production and Technology in Colombia*, Foreign Agri-

cultural Economic Report no. 52 (Washington, D.C.: Economic Research Service, USDA, 1969), p. 76.

30. Leurquin, "Cotton Growing," pp. 158-159.

31. *Ibid.*, p. 154.

32. *Cotton in Colombia*, FAS-M (Washington, D.C.: Foreign Agricultural Service, USDA, 1971), p. 11.

33. *The Cotton Industry of Colombia*, FAS-M-113 (Washington, D.C.: Foreign Agricultural Service, USDA, 1961), p. 9.

34. *Agriculture Production and Trade of Colombia*, ERS-Foreign 343 (Washington, D.C.: Economic Research Service, USDA, 1973), p. 31.

35. This is not to deny the role of improved United States varieties in increasing Colombian cotton yields. There are several references to their importance in the available literature. One of the strongest is International Bank for Reconstruction and Development, *The Agricultural Development of Colombia* (Washington, D.C.: IBRD, 1956), p. 86: "It is the policy and program of the Cotton Institute to provide the full seed requirements for the entire cotton crop annually. Largely as a result thereof, the average yield per hectare of the cotton crop has doubled in four years."

36. This section is based on the research of Carlos Trujillo, "Rendimiento económico de la investigación en trigo," M.S. thesis (Bogota: ICA/National University Graduate School, 1974).

37. USDA, *Changes in Agricultural Production*, p. 12

38. Data on production, land area planted, and yields of wheat before 1971 are from Roger Sandilands, *Algunos problemas en la selección de datos estadísticos para trigo, cebada y papa*, Technical Report no. 14 (Bogota: ICA, 1974). Data for 1971-73 are from the National Department of Statistics, DANE, Bogota.

39. Many of the important issues involved are discussed in Roger Sandilands and Leonard Dudley, "The Side-Effects of Foreign Aid: The Case of P.L. 480 Wheat in Colombia," *Economic Development and Cultural Change*, 23:2 (January 1975), 325-336.

40. Estación Agrícola Experimental La Picota, *Informe de labores de la sección experimental e industrial realizados en 1936* (Bogota, 1937); also, Estación Agrícola Experimental La Picota, *Informe de labores de la sección experimental e industrial realizados en 1941* (Bogota, 1942).

41. Estación Francisco José de Caldas, *Influencia de las royas sobre el rendimiento del trigo*, Project I-SF-1949 (Bogota, 1951).

42. Mario Zapata, "Informe general de programa de trigo en clima cálido," mimeographed (Bogota, 1969).

43. Vaneamiento is a disease in which sterility results from sharp changes in temperature.

44. Trujillo, "Investigación en trigo," Table 2.10.

45. The price elasticity of demand estimate is from *Un método de proyectar la producción y demanda para productos agrícolas en Colombia*, Research Bulletin no. 15 (Bogata: ICA, 1971). The price elasticity of supply estimate is from Sandilands and Dudley, "Side-Effects of Foreign Aid."

46. Based on the research by Gabriel Montes, "Evaluación de un programa de investigación agrícola: El caso de la soya," M.S. thesis (Bogota: University of the Andes, 1973).

47. *Ibid.*, Table 4.

48. The price elasticity of demand estimate was suggested by the results of James P. Houck, "A Statistical Model of Demand for Soybeans," *Journal of Farm Economics*, 46:2 (May 1964), 371-372.

5

Returns to Investment in Agricultural Research in India

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The problems of measuring returns to investment in agricultural research are beset with serious difficulties, both conceptual and practical. Even with advanced methodology, researchers in the less developed countries face a serious problem: the lack of a suitable information base on key variables. Still, the growing realization of the importance of research in agricultural growth has stimulated the estimation of likely payoffs to investment in agricultural research. These estimates have become vital because of the extremely critical resource position of the LDCs and the concomitant necessity of making the most judicious investment decisions. Recognizing the significance of this issue, the Indian Council of Agricultural Research has recently formed an expert panel to investigate this problem.[1]

Two general approaches, namely, the index number approach and the production function approach, have been used for *ex-post* evaluation of agricultural research. The pioneering works of Schultz and Griliches have been followed by a fair amount of empirical and theoretical work in this area.[2] But these studies have covered mainly the developed countries.

There is very little empirical evidence to facilitate measurement of the contribution of Indian agricultural research systems to real productivity growth in Indian agriculture. Two studies, however, have recently been conducted. Evenson and Jha estimated the return to investment in Indian agriculture, using the total factor productivity approach, and obtained an internal rate of

return that exceeded 50 percent a year.[3] Karam Singh estimated returns to investment in agricultural research in the Punjab and concluded that investment of one rupee in agricultural research gives a return of twenty-seven rupees.[4] In both studies research expenditures were directly incorporated into the function.

These estimates appear to be somewhat crude because they ignore qualitative improvements that are embodied in technological changes. Moreover, a technical change, which is a proxy for research expenditure, improves the quality of inputs and outputs, changes the combination of the inputs, and has factor-augmenting effects. The importance of qualitative changes and factor-augmenting technical change was emphasized by Evenson and Jha. However, these factors were not fully incorporated in their final analysis.

The Evenson and Jha study went on to investigate the share of annual output growth accounted for by the growth in different inputs. Sawada used a similar approach in his study of the sources of the growth of aggregate production in Japan.[5] In both cases, the assumption of constant returns to scale — "homogeneity of degree one" in the production function — was made. This does not seem entirely realistic for Indian agriculture.

When the residual approach is employed, it is possible only to include selected major variables in the specified relationship. The residual will include the effects both of the omitted variables and of any measurement errors in the variables that are included in the output measure.[6] Therefore, using the residual to measure the effect of technology has some serious limitations. Technology is not the only variable included in the residual. It is difficult to isolate the effects of other excluded variables, such as management. Moreover, since few of the variables contained in the model are independent of the effect of technology, it becomes even more difficult to attribute all of the residual effect to such technology.

A further difficulty is that the magnitude of the residual is dependent upon the proper specification of the model, i.e., the specification of the variables and the specification of the type of relationship. The principle of the least-squares technique minimizes the sum of the squares of the residuals. The best specification of the model would lead to residuals of small magnitude; incorrect specification would lead to residuals of larger magnitude.

We try to avoid some of these problems in the approach presented in this chapter. Our study attempts to develop a model wherein the assumption of constant returns to scale is not considered necessary. An attempt is also made to weigh the factor share in the growth of output in Indian agriculture. The use of dummy variables makes it possible to analyze the shifts in production functions and the change in the quality of different inputs, both of which may affect the factor combinations.

The chapter is divided into two parts. The results for the country as a whole, comprising fifteen major states, are presented in the section entitled "The All-India Analysis." The second section is devoted to "State-Level Analysis." In this section, estimates of the contribution of agricultural research to gross agricultural output are presented for the four states representing the four major regions of the country: Andhra Pradesh, Bihar, Maharashtra, and Punjab. Since levels of technological progress vary considerably among states and regions, this type of analysis is expected to provide a closer understanding of the underlying relationships.

The All-India Analysis

In studying the returns to research expenditure, we used two different approaches. Each covered two periods: the pre-green revolution period (1960-61 to 1964-65) and the post-green revolution period (1967-68 to 1972-73). The first approach incorporates research expenditure (with suitable lags) as an independent variable in the types of functions already discussed. The coefficient of this variable in the production function for the two periods (with D = 0 and D = 1) gives the return to one rupee invested in agricultural research for a linear function and the percentage return to a 1 percent increase in the research expenditure for a double-log function. The use of a dummy for this variable also allows for the possibility of a shift in returns owing to the green revolution.

The second approach excludes research expenditure from the production function analysis.[7] The estimates of output for the two periods were obtained at fixed levels of the inputs. The difference between these two estimates can be attributed to the additional investment in agricultural research. This approach loses information on both the level of returns to investment in the first period and the way in which these returns increased in the second period.

The model used in the all-India analysis is outlined in Appendix 5-1. The data used and their sources are described in Appendix 5-2.

Growth Rates in Indian Agriculture

During the pre-green revolution period, agricultural output in value terms, using constant prices, increased at a compound rate of 2.66 percent annually, and the average annual increase was 61.01 million rupees (Table 5-1). These growth rates were lower than those of the post-green revolution period, when the compound growth rate was 5.80 percent a year and the linear growth rate was 182.98 million rupees a year.

The growth rate of net sown area increased from 2.20 percent in the first

Table 5-1. Output and Input Growth Rates in Indian Agriculture, 1960/61-1972/73

Variable	Linear Growth Rate[a]		Compound Growth Rate[b]		Mean	Standard Deviation
	First Period 1960/61-1964/65	Second Period 1967/68-1972/73	First Period 1960/61-1964/65	Second Period 1967/68-1972-73		
Y : Output value in million rupees	61.01	182.98	2.66	5.80	5573.28	2760.42
X_9 : Net sown area in thousand hectares	47.92	52.03	2.20	2.70	9064.99	4827.01
X_2 : Human labor in thousand persons	1073.04	148.52	5.63	2.32	7258.31	710.68
X_3 : Bullock labor in thousand numbers	1196.88	− 0.50	6.39	− 0.17	5692.15	7497.83
X_4 : Fertilizer consumption in million rupees	34.06	52.70	45.00	16.97	244.85	2704.70
X_5/X_9 : Proportion of irrigated area	0.20	0.0047	6.54	1.81	0.3360	.42
X_6 : Tractor population in thousand numbers	0.16	1.31	31.23	15.62	5.22	6.79
X_7 : Expenditure in agricultural research in thousand rupees	329.12	395.33	7.58	6.08	5030.36	3311.37

a $\left(\frac{dX_i}{dt}\right)$.

b $\left(\frac{1}{X_i} \times \frac{dX_i}{dt} \times 100\right)$.

period to 2.70 percent in the second period. However, the growth rates for human labor declined from 5.63 percent in the first period to 2.32 percent in the second period. Bullock labor declined from 6.39 percent to − .17 percent per annum.

Fertilizer consumption increased at a rate of 45.0 percent in the first period and 16.97 percent in the second period. However, this does not imply that the increase in fertilizer consumption was lower in the second period. In fact the average annual increase in the consumption of fertilizer was 34.05 million rupees in the first period and 52.70 million rupees in the second. The high rate of growth in the use of fertilizer during the first period was attributable to a very low base.

Contrary to expectation, the growth rate of the irrigated area declined during the second period. Tractor population increased from the first period to the second period, but the compound rate of growth declined from 31.23 percent to 15.62 percent.

The rate of growth in agricultural research was steady over the two periods: 7.58 percent in the first period and 6.08 percent in the second period. Annual research expenditure increased by 329.12 thousand rupees and 395.33 thousand rupees in the first and second periods, respectively.

Shift in Production Function and Qualitative Effects

The preceding section has described the growth of agricultural output and of the specified inputs. The importance and the impact of these inputs have varied from time to time and therefore it was necessary to examine the change in the contribution of various factors over time.

Owing to the problem of multicollinearity, all the factors shown in Table 5-1 could not be included in the production function. Bullock labor (X_3) was highly intercorrelated with human labor (X_2). The inclusion of both these variables in the production function resulted in large sampling variances of the estimates of the coefficients, and it was decided to omit bullock labor from the production function. Because they added nothing to the results, two other variables – number of tractors (X_6) and research expenditure (X_7) – were also excluded from the production function. The structural equation used is provided in the accompanying box.

The significance of the coefficient of the period dummy variable (0.2298) indicates an important shift in the production function associated with the green revolution. The coefficients for D log X_9 and D log (X_5/X_9), though positive in signs, were not significant in the trial functions and were, therefore, deleted from the final function. This would suggest that the impact of the net sown area (X_9) and the proportion of irrigated area to net sown area (X_5/X_9) did not change over time; hence, the elasticity coefficients of 0.3879

$$\text{Log } Y = a + b_9 \log X + b_2 \log X_2 + b_4 \log X_4 + b_5 \log (X_5/X_9) + CD + C_2 D \log X_2 + C_4 D \log X_4$$

where Y, X_9, X_2, X_4, and X_5/X_9 are the variables indicated in Table 5-1.

$$\log Y = \underset{(0.1477)}{1.5717^*} + \underset{(0.0601)}{0.3879^*} \log X_9 + \underset{(0.0581)}{0.1875^*} \log X_2 + \underset{(0.0170)}{0.0492^*} \log X_4 + \underset{(0.0423)}{0.2715^*} \log (X_5/X_9) + \underset{(0.1045)}{0.2298D^*} - \underset{(0.0355)}{0.1695^*} D \log X_2 + \underset{(0.0371)}{0.1957^*} D \log X_4$$

where $D = 0$, for pre-green revolution period

$D = 1$, for post-green revolution period

$R^2 = 0.7252^*$

$N = N_1 + N_2 = 75 + 90 = 165$

* Significant at .01 level.

Standard errors of the estimates are in parentheses.

for the net sown area and 0.2715 for the proportion of irrigated area remained the same over the two periods. It may be noted that these elasticities were significantly different from zero, which means that these factors were important for expanding output, although their impact did not change from the first to the second period.

The elasticities for human labor (X_2) and fertilizers (X_4) were positive and significant in the first period. The impact of these variables underwent a significant change, however, from the first to the second period. In the second period, though still positive, the elasticity for human labor declined to 0.0180, and it was not significantly different from zero. Fertilizer, on the other hand, experienced a positive shift of 0.1957 (significant) in the elasticity coefficient. One effect of the green revolution was to increase the productivity of fertilizer.

Factor Shares

The relative share of each factor in the growth of output for the two periods and the change in factor shares associated with the green revolution are presented in Table 5-2. These shares were calculated by utilizing the production function estimated above and the expressions (5) and (10) in Appendix 5-1.

During the first period, fertilizer and irrigation contributed 37.44 and 30.15 percent respectively to the growth of output experienced. Next in im-

Table 5-2. Factor Shares in the Output Growth Rate

Factors of Production	Pre-Green Revolution Period	Post-Green Revolution Period
X_9 : Net sown area	14.49%	18.27%
X_2 : Human labor.	17.92	0.73
X_4 : Fertilizers	37.44	72.43
X_5/X_9 : Proportion of irrigated area.	30.15	8.57
Total	100.00%	100.00%

portance were human labor and net sown area, contributing 17.92 percent and 14.49 percent, respectively.

In the second period, fertilizers accounted for 72.43 percent of the output growth, thereby making fertilizer the most important factor in the growth of agricultural output in that period. The growth rate of net sown area increased in the second period from 14.49 percent to 18.27 percent. A decline in the growth rate of the irrigated area, with elasticity remaining the same over the two periods, contributed to a decline in its relative share in output growth. Human labor remained an important factor of production, as indicated by the significance of the elasticity coefficient, but the results show that growth of labor inputs contributed very little to growth of agricultural output in the post-green revolution period.

Change in Factor Combinations

It is important to know whether the factor combination for a given level of output changed because of changes in technology. For purposes of this analysis, the output level was fixed at the overall mean of 5573.28 million rupees in both time periods. The variables that finally appeared in the production function were net sown area (X_9), human labor (X_2), fertilizers (X_4), and proportion of irrigated area (X_5/X_9).

Since the elasticity coefficient for X_9 and X_5/X_9 did not change over time, the levels for these variables were fixed and held at the mean levels indicated in Table 5-1. The levels of variables such as human labor (X_2) and fertilizer (X_4) need to be determined for given values of other variables. This again gives one equation with two unknowns, X_2 and X_4, in each time period. It was possible, therefore, to determine X_4 for varying levels of X_2 and vice versa. For example, when X_2 was held at the mean level, X_4 was estimated at 3.16 million rupees in the first period and 68.29 million rupees in the second.

Obviously, a considerable shift in the combination of factors was required to produce a fixed level of output. There was more use of human labor and less use of fertilizers in the first period. Fertilizers became a dominant factor in the second period.

Return to Investment in Agriculture

To study the contribution of research to output growth, we considered two alternative approaches at the model-building stage. However, the first approach (directly incorporating research expenditure in the function) could not be used because research expenditure had a high multicollinearity with the other independent variables. The second approach (measuring returns to autonomous public investment in agricultural research) was used to estimate the research contribution. The results are shown in Table 5-3.

Table 5-3. Return to Investment in Agricultural Research in India[a]

Output and Investment	First Period (1)	Second Period (2)	Difference (2) − (1)
Estimated output (million rupees)	6592.00	6945.00	353.00
Average investment in agricultural research (thousand rupees).	3372.05	6412.28	3040.23

[a] Return to 1 rupee invested $= \frac{353.00 \text{ million rupees}}{3040.23 \text{ thousand rupees}} = 11.61$ rupees.

An investment of one rupee in agricultural research gave a return of 11.61 rupees, with a lag of five years between research expenditure and returns. This was converted into an internal rate of return, assuming a five-year lag. The internal rate of return worked out to be 63.3 percent per annum.

Evenson and Jha also estimated the return to investment in agricultural research (within a state).[8] Their estimates gave a return of 10,650 rupees from a 1,000-rupee increase in research spending. The internal rate of return in this case was 50 plus percent per annum over a time lag of about eight years.

Owing to the weakness of the data and the estimation problems that were encountered, we do not regard the two rates of return as essentially different. Their similarity, in spite of differences in estimation procedures, tends to reinforce the conclusion that the rate of return to agricultural research in India has been high.

State-Level Analysis

Both linear and log-linear models were utilized in analyzing the data for individual states. The use of slope (or elasticity) dummies was not feasible in the state-level analysis because of the short time series available. All the period dummies, however, were included in the pooled analysis of data for all selected states. Regional dummies were also included in this analysis to account for interstate differences. Finally, a time variable (t) was introduced into the model explicitly to account for trend components. It was generally found to improve the fit.

Data and Methodology

Four states – Andhra Pradesh, Bihar, Maharashtra, and Punjab – were selected for the state-level analysis as a representative cross section of the state of agricultural development in India. These states cover the major agroclimatic zones as well as the important cropping regions for rice, wheat, sorghum, and pearl millet. It is these crops which have been most affected by the seed-based technological revolution in the country.

Ten variables were included in the production function analysis. (See the accompanying tabulation.) The research expenditure variable was used in the equations with lags varying from zero to six years, and the variable was then denoted by $R_t, R_{t-1}, R_{t-2}, \ldots, R_{t-6}$.

Variable	*Unit of Measurement*	*Symbol*
Agricultural production index	1956-57 base	Y or X_1
Annual rainfall	Millimeters	X_2
Fertilizer	Thousand tonnes	X_3
Male agricultural workers	Thousands	X_4
Literacy in rural males	Percentage	X_5
Draft bovines	Thousands	X_6
Tractors	Numbers	X_7
Total cropped area	Thousand hectares	X_8
Gross irrigated area	Percentage	X_9
Research expenditure	Thousand rupees	X_{12} or R_t

State-level time series data on these variables were used for the period 1956-57 to 1972-73. A period dummy variable (X_{10}) with the value zero up to 1965-66 and unity for subsequent years was also introduced in an attempt to capture the effects of technological change. The time trend variable was denoted by "t."

In the pooled analysis of data for all the four states, the index numbers of agricultural production were converted to value terms (in millions of rupees)

at constant 1956-57 prices and used collectively as the dependent variable. Regional dummy variables, S_1, S_2, and S_3, were also introduced to account for interstate variations. In this analysis, slope dummies were also used to examine the period-specific changes in the effects of individual variables. Further particulars about these variables, along with the sources and limitations of data, are given in Appendix 5-3.

Results and Discussion

The means and coefficients of variation (C.V.) for all the ten variables under consideration for each state are given in Table 5-4. The mean values reveal the wide interstate variability which characterizes Indian agriculture. For example, there was wide variation in the rise in the agricultural production index. From a 1956-57 baseline of 100, the index rose in Maharashtra to only 103.10 by 1972-73, but in Punjab it reached a level of 154.90. Similar differences are noticeable with respect to other variables. The coefficients of variation were the lowest, as expected, for such variables as gross cropped area, draft bovines, and male agricultural workers – the conventional inputs. Rainfall, literacy, and irrigated area lie in the medium range. For others, such as fertilizers, tractors, and research expenditure, a high temporal variability is indicated, mainly on account of substantial secular increases. The linear annual growth rate of agricultural output over the seventeen-year period was – 0.98 percent for Maharashtra, 1.30 percent for Andhra Pradesh, 4.36 percent for Bihar, and 9.73 percent for the Punjab.

To estimate the relative contribution of the input variables to agricultural productivity, both linear and log-linear regression equations, using all nine variables, were fitted to the data for each of the four states individually. For each state, seven equations were fitted, corresponding to the lags of zero, one, two, three, four, five, and six years in the research expenditure variable R_t. Out of these equations, the one showing consistent signs and a relatively lower standard error for the R_t variable was chosen for subsequent analysis. Thus, this variable had different lags, ranging between one to four years, in different states. Although there is no logical explanation for this, the crude nature of the data on research expenditures made this compromise necessary. The equations containing all nine variables are given in Appendix 5-4.

Using the usual criteria of consistency in sign, significance of regression coefficients, multicollinearity, and the closeness of fit of the model, we utilized the equations from Appendix 5-4 for a second run to arrive at the final regression functions. The results for each state are discussed separately in the following paragraphs. It was observed that with one exception (Bihar), the log-linear form was not appropriate for depicting the relationships among the

Table 5-4. Variables and Summary Statistics Used in the State-Level Analysis, 1956/57-1972/73

Variable	Unit	Parameter	States			
			Andhra Pradesh	Bihar	Maharashtra	Punjab
Index of agricultural production (Y)	Index	Mean	111.94	135.81	103.10	154.90
		C.V.[a]	10	23	14	34
Annual rainfall (X_2)	Millimeters	Mean	920.70	1,179.41	814.29	712.12
		C.V.	16	17	18	20
Total fertilizer consumption (X_3)	Thousand metric tonnes	Mean	149.12	49.41	102.41	96.06
		C.V.	68	84	78	98
Male agricultural workers (X_4)	Thousands	Mean	7,437.94	10,267.88	7,074.35	1,973.12
		C.V.	8	12	8	15
Literacy in rural males (X_5)	Percentage	Mean	24.28	26.31	36.50	29.55
		C.V.	15	8	13	14
Draft bovines (X_6)	Thousands	Mean	6,561.12	7,837.00	6,559.12	1,855.88
		C.V.	5	3	4	4
Tractors (X_7)	Numbers	Mean	2,964.94	2,794.53	2,646.88	15,088.59
		C.V.	49	67	55	95
Total cropped area (X_8)	Thousand hectares	Mean	12,713.94	10,763.76	19,081.59	5,204.06
		C.V.	5	5	1	6
Gross irrigated area (X_9)	Percentage	Mean	29.85	21.24	7.16	62.58
		C.V.	5	13	14	14
Research expenditure (R_t)	Thousand rupees	Mean	5,800.23	4,607.76	7,704.35	5,326.71
		C.V.	35	24	56	46

[a] Coefficient of variation.

variables. Hence only the linear model is discussed for the remaining three states.

Andhra Pradesh. The accompanying box indicates the way in which the final linear regression equation relating the index of agricultural production to the other input variables for the State of Andhra Pradesh was obtained. The

$$Y = -249.5412 + \underset{(0.0871)}{0.2117\, X_3{}^{*}} + \underset{(0.0186)}{0.0551\, X_6{}^{**}} + \underset{(0.0071)}{0.0086\, R_{t-3}} - \underset{(3.7884)}{9.1019\, t^{*}}$$

$$R^2 = 0.6672$$

$$\bar{R}^2 = 1 - \frac{(1 - R^2)(N - 1)}{N - K - 1} = 0.5563$$

$$F = 6.01$$

Durbin-Watson d = 1.97

* Significant at .05 level.
** Significant at .01 level.
Standard errors are in parentheses.

Durbin-Watson test revealed an absence of serial dependence in the residuals. The value of R^2 was rather low, for the model explains only 55 percent of the observed variation in Y. In this case, the period dummy variable (X_{10}) was found to be nonsignificant and thus could not be entered in the final equation. These findings indicate the lack of any positive contribution by the green revolution to the agricultural productivity of the state.

Other variables included in the equation with the corresponding standard partial regression coefficient values (β_i) are given in the accompanying tabulation. It can be seen that fertilizer consumption made the greatest contribu-

	Variable	β_i
X_3	: Total fertilizer consumption	1.8886
X_6	: Draft bovines	1.5687
R_{t-3}	: Research expenditures	1.5543

tion to the dependent variable, followed by draft animal power and lagged research expenditure. The last variable, however, was not statistically significant. The marginal product of R_{t-3} came to 32.40 rupees. This can be interpreted as the external rate of return to investment in agricultural research.

Bihar. The accompanying box indicates the results of the final regression

Linear

$$Y = -1053.8380 + \underset{(0.0381)}{0.0814\ X_4{}^{**}} + \underset{(0.0073)}{0.0417\ X_8{}^{***}}$$
$$+ \underset{(14.7080)}{9.3249\ X_{10}} + \underset{(0.0120)}{0.0187\ R_{t-4}{}^{*}} - \underset{(11.4729)}{20.6002\ t^{**}}$$

$R^2 = 0.9161$ $\bar{R}^2 = 0.8780$

$F = 24.02$ 'd' = 2.02

Log-linear

$$\text{Log } Y = -19.0693 + \underset{(0.6890)}{1.2076 \log X_4{}^{*}} + \underset{(0.4817)}{3.8297 \log X_8{}^{***}}$$
$$+ \underset{(0.0424)}{0.0111\ X_{10}} + \underset{(0.2109)}{0.2855 \log R_{t-4}{}^{*}} - \underset{(0.0818)}{0.1547 \log t^{**}}$$

$R^2 = 0.9405$ $\bar{R}^2 = 0.9135$

$F = 34.82$ d = 2.09

* Significant at .10 level.
** Significant at .05 level.
*** Significant at .01 level.
Standard errors are in parentheses.

equations for Bihar. The values of 'd' were not significant in either equation. Fairly high R^2 values suggested reasonably good fit. The period dummy variable (X_{10}) here, as in Andhra Pradesh, was found to be nonsignificant. This means that the post-1966 period did not reveal any positive impact on agricultural production.

For the linear equation, the other variables included in the equation and their corresponding standard partial regression coefficient values (β_i) are given in the accompanying tabulation. It is clear that the highest contribution to

	Variable	β_i
X_4	: Male agricultural workers	3.1282
X_8	: Total cropped area	0.7621
R_{t-4}	: Research expenditure	0.6556

the dependent variable was made by male agricultural workers, followed by total cropped area and the lagged research expenditure. Converting the marginal product of R_{t-4} in the linear equation into value terms, we found that every rupee invested in research gave a return of 63.75 rupees. The variable in question is significant at the 10 percent level of probability.

Maharashtra. The accompanying box indicates the way in which the final re-

$$Y = -2065.9382 - \underset{(0.0187)}{0.0464\, X_2^{**}} + \underset{(0.0155)}{0.0671\, X_6^{***}}$$
$$+ \underset{(0.0211)}{0.0760\, X_8^{***}} + \underset{(19.5667)}{72.0594\, X_9^{***}} + \underset{(7.3289)}{24.0126\, X_{10}^{***}}$$
$$+ \underset{(0.0021)}{0.0034\, R_{t-1}^{*}} - \underset{(4.1988)}{26.3015\, t^{***}}$$

$R^2 = 0.8932$ $\bar{R}^2 = 0.8101$

$F = 10.74$ $d = 2.80$

* Significant at .10 level.
** Significant at .05 level.
*** Significant at .01 level.
Standard errors are in parentheses.

gression equation relating the index of agricultural production to input variables was obtained. The value of 'd' was found to be nonsignificant at the 5 percent level, indicating the absence of any autocorrelation in the residuals. The values of R^2 were quite high, the model explaining nearly 81 percent of the variation in Y. The period dummy variable (X_{10}) was found to be highly significant, indicating marked differences in agricultural productivity in the state owing to changes in technology in the two periods.

Other variables included in this equation and their corresponding standard partial regression coefficient values (β_i) are provided in the accompanying tabulation. Here irrigation percentage made the greatest contribution to the

	Variable	β_i
X_2	: Annual rainfall	− 0.4628
X_6	: Draft bovines	1.1615
X_8	: Total cropped area	1.3771
X_9	: Irrigation percentage	4.9152
R_{t-1}	: Research expenditures	0.9725

dependent variable, followed by total cropped area and draft bovines. The research expenditures variable was also significant, at the 10 percent level of probability. Converting the marginal product of R_{t-1} into value terms, we find that every rupee invested in agricultural research in the state yielded a return of 14.28 rupees.

Punjab. The final regression equation for this state gave the results shown in the accompanying box. The value of 'd' suggested lack of serial dependence. The value of R^2 in this case was the highest among all states, accounting for nearly 97 percent of the total variation in Y. Moreover, the period dummy

$$Y = -891.4295 + \underset{(0.1527)}{0.2341\, X_3{}^{*}} + \underset{(0.2398)}{0.2509\, X_4}$$
$$+ \underset{(10.5703)}{22.1758\, X_5{}^{**}} + \underset{(1.4941)}{2.2428\, X_9{}^{*}} + \underset{(9.9899)}{20.4666\, X_{10}{}^{**}}$$
$$+ \underset{(0.0048)}{0.0113\, R_{t-2}{}^{**}} - \underset{(15.8339)}{37.2636\, t^{**}}$$

$R^2 = 0.9864$ $\bar{R}^2 = 0.9758$

$F = 93.53$ $d = 1.96$

* Significant at .10 level.
**Significant at .05 level.
Standard errors are in parentheses.

variable (X_{10}) was significant at the 5 percent level, indicating significant change in the state productivity level in the two periods as a result of the introduction of new agricultural technology.

The standard partial regression coefficient values (β_i) are provided in the accompanying tabulation. It can be seen that the highest contribution to the

	Variable	β_i
X_3	: Total fertilizer consumption	0.4613
X_4	: Male agricultural workers	1.3753
X_5	: Literacy in rural males	1.6809
X_9	: Irrigation percentage	0.3833
R_{t-2}	: Research expenditures	0.5279

dependent variable was made by literacy, followed by labor and research. The last variable (R_{t-2}) was significant at the 5 percent level of probability. The results indicate that every rupee invested in agricultural research in the state gave a return of 15.93 rupees.

Pooled Analysis. The results of the pooled state-level analysis, which aimed at providing additional information on the impact of the pre- and post-green revolution periods through the incorporation of slope dummies, were totally unsatisfactory. The regression coefficients turned out to be both nonsignificant and inconsistent. The results could not, therefore, be interpreted meaningfully. The results presented and discussed above reveal the inherent weakness of aggregative analysis of this sort. It is quite clear that the great heterogeneity of the environment of agricultural production makes it very risky empirically to estimate a unique functional specification for all states. Indeed, even a state is too heterogeneous a unit. In view of this fact and the usual errors of measurement and aggregation of inputs, the relatively poor results are

not surprising. We can, however, draw from the individual state-level analyses some conclusions regarding the importance of different input variables in different states with implications for *ex-ante* assessments.

Conclusions from State-Level Analysis

In analyzing the rainfall and irrigation results, it is helpful to recognize that Maharashtra and Punjab are relatively dry regions while Andhra Pradesh and Bihar are areas of generally sufficient rainfall. Rainfall appeared as a significant variable only in Maharashtra, and even there it had a negative sign. At the same time, for Punjab the contribution of irrigation was positive and significant. The explanation for this apparent contradiction may lie in the high sensitivity of the dry region crops to the distribution of rainfall and to the improvement in water management following the development of irrigation.

In Andhra Pradesh and Bihar, irrigation did not appear to be significant. This means that in areas of sufficient rainfall irrigation is more an adjustment mechanism to control periodic insufficiences in the amount of rainfall than a direct stimulant to output. It also underscores the importance of the development of irrigation in the relatively drier regions.

In Bihar and Maharashtra, fertilizer did not appear to be significant. Literacy was significant only in Punjab, whereas a positive contribution by labor was indicated in Bihar and Punjab. The draft animals variable was significant in Andhra Pradesh and Maharashtra. Tractors, used as a representative measure for machines in general, did not appear to be significant in any state. Bihar and Maharashtra had a significant positive coefficient for total cropped area. The research expenditures variable was found to have a significant positive impact on output in all states except Andhra Pradesh.

The period dummy variable was significant only in Maharashtra and Punjab, indicating an upward shift in production function in the post-1965/66 period in both cases. The traditional rice-growing states of Bihar and Andhra Pradesh did not show this effect. The trend variable emerged significant in all cases and carried a negative sign.

The overall impression one gets from these results is that the conventional factors of production play a more dominant role in states like Andhra Pradesh, Bihar, and Maharashtra. Only in the Punjab do the nonconventional input factors seem to be of relatively greater importance.

The research expenditures variable is the primary focus of this chapter. It is, as stated earlier, difficult to explain the differences in lags between different states. Still, we do have enough basis to suggest that agricultural research does make a positive and substantial contribution. The state-level analysis tends to support the results of the national analysis in confirming that agri-

cultural research is a productive investment. The range of the estimated marginal returns is 14.28 rupees in Maharashtra, 15.93 rupees in Punjab, 32.40 rupees in Andhra Pradesh, and 63.75 rupees in Bihar. It seems apparent that whether one normalizes research investment on a per worker or on a per hectare basis, there is not enough investment in agricultural research in Bihar relative to Punjab.

It is important to bear in mind that these figures are, at best, very rough indicators. Besides errors which crop up as a result of data limitations, another important source of bias is our inability to account for the pervasiveness of research findings by the diffusion of research information from one region to another. We have avoided attempting to derive internal rates of return because we lack knowledge of lag structures. The data limitations are obvious. Further improvements in the quality of the data and specifications of the type of relationship among the variables should improve the quality of the results.

The returns to investment worked out in this study are, in fact, returns to both research and development expenditures. Since the data on development expenditure were not available, the returns were estimated on expenditure in agricultural research only. To the extent that the development expenditure is ignored, the estimated returns to investment in agricultural research are inflated. The results, however, are sufficiently promising and the issue of research productivity is so important that an effort to push this line of work forward with better data and improved models should be pursued.

APPENDIXES

Appendix 5-1. The Model

We start with a general production function in which Y is the output and X_1, $X_2, \ldots, X_n$ are n different inputs:

$$Y = f(X_1, X_2, \ldots, X_n) + e \tag{1}$$

where the e's are stochastic residual terms with standard least-squares properties.

The assumption that the intercept term, as well as the input coefficients, may change over time was incorporated by introducing a dummy variable D with the value zero to represent the pre-green revolution period (1960-61 to 1964-65) and the value one to represent the post-green revolution period (1967-68 to 1972-73). With the incorporation of dummy variables, the functional form (1) takes the form:

$$Y = f(X_1, X_2, \ldots, X_n, D, DX_1, \ldots, DX_n) + e. \tag{2}$$

Here Y and all the X's are functions of the time variable t. The total derivative of Y with respect to t can be written as

$$\frac{dY}{dt} = \sum_{i=1}^{n} \frac{\partial f}{\partial X_i} \frac{dX_i}{dt} + \sum_{i=1}^{n} \frac{\partial f}{\partial (DX_i)} \times \frac{d(DX_i)}{dt} . \tag{3}$$

Estimates of $\partial f/\partial X_i$ can be used as weights in the summation of input growth rates dX_i/dt on the right-hand side of (3). Expressed in percentages, the relative share of different input growth rates can be obtained from the rate of growth of output. This was done for the two periods separately by substituting the values of the dummy variables. The difference in the growth rates of output over the two periods can be attributed to the change in the level of technology. Relative change in the factor share over the two periods can be considered to be the effect of technological changes on the factor share.

Assuming that the distribution can be either normal or log normal, we used both linear and Cobb-Douglas forms of functions.

Linear Relationship

With two subperiods, the general linear production function may be written as:

$$\begin{aligned} Y = a + b_1 X_1 + b_2 X_2 + \ldots + b_n X_n \\ + C_0 D + C_1 D\ X_1 + \ldots + C_n D X_n \end{aligned} \tag{4}$$

so that,

$$\frac{dY}{dt} = \sum_{i=1}^{n} b_i \frac{dX_i}{dt} + \sum_{i=1}^{n} C_i D \frac{dX_i}{dt} . \tag{5}$$

Here b_i's are the partial regression coefficients, and C_i's are the coefficients of dummy variables which represent the shift in the coefficients of X_i's owing to qualitative and technological change. The coefficient C_0 measures the change in the intercept of the production function, and the coefficients C_i measure the shifts in the slopes of the linear production function (or shifts in the elasticities of the double-log function). Further, the b_i's may be treated as weights in estimating the factor share in the output growth rate of the first period and $(b_i + C_i)$ as the weights for the second period. Substituting the values for the dummy variable, we get the expressions for the two periods in the following form:

$$\left(\frac{dY}{dt}\right)_1 = \sum_{i=1}^{n} b_i \left(\frac{dX_i}{dt}\right)_1 \tag{6_a}$$

and

$$\left(\frac{dY}{dt}\right)_{II} = \sum_{i=1}^{n} (b_i + C_i) \left(\frac{dX_i}{dt}\right)_{II} \qquad (6_b)$$

The relative share of each growth factor was worked out as:

$$b_i \frac{dX_i}{dt} \Big/ \sum_{i=1}^{n} b_i \frac{dX_i}{dt}$$

for the first period and

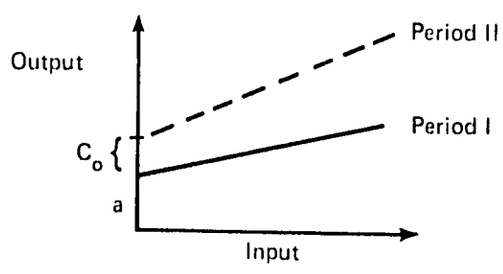
$$(b_i + C_i) \times \frac{dX_i}{dt} \Big/ \sum_{i=1}^{n} (b_i + C_i) \frac{dX_i}{dt}$$

for the second period.

The average annual increase in output owing to the green revolution is given by

$$\left(\frac{dY}{dt}\right)_{II} - \left(\frac{dY}{dt}\right)_{I} . \qquad (7)$$

The significance and positive sign of the coefficient C_0 of the dummy variable in (4) will indicate an upward shift in the intercept term, whereas the significance of the coefficients C_i indicates the shift in the slope owing to technological change. For the input X_i, the shift is expected to be of the type shown in the following manner:



Double-Log Relationship

$$\log Y = a + \beta_1 \log X_1 + \ldots + \beta_n \log X_n + \gamma D + \gamma_1 D \log X_1 + \ldots + \gamma_n D \log X_n. \qquad (8)$$

Differentiating with respect to time on both sides:

$$\frac{1}{Y} \times \frac{dY}{dt} = \sum_{i=1}^{n} \beta_i \frac{1}{X_i} \cdot \frac{dX_i}{dt} + \sum_{i=1}^{n} \gamma_i D \cdot \frac{1}{X_i} \cdot \frac{dX_i}{dt} \quad (9)$$

$$G_Y = \sum_{i=1}^{n} \beta_i G_{X_i} + \sum_{i=1}^{n} \gamma_i D G_{X_i} \quad (10)$$

where G_Y and G_{X_i} are the compound rates of growth for output and inputs. Here the elasticities for the first period β_i and $(\beta_i + \gamma_i)$ for the second period serve as weights in pooling the growth rates of inputs. The relative factor share of X_i can be expressed as

$$\beta_i G_{X_i} \Big/ \sum_{i=1}^{n} \beta_i G_{X_i}$$

in the first period, and

$$(\beta_i + \gamma_i) G_{X_i} \Big/ \sum_{i=1}^{n} (\beta_i + \gamma_i) G_{X_i}$$

in the second period.

The coefficient γ for the dummy variable gives the shift in the production function, whereas γ_i's are the shifts in the elasticities. The shift in the compound growth rate (G_Y) of output can be written as

$$(G_Y)_{II} - (G_Y)_I . \quad (11)$$

Qualitative changes in the inputs can be studied with the help of either of the two forms of production function. New farm technology, which leads to qualitative changes in the various inputs, can be interpreted through the coefficients C_i's and γ_i's, which were earlier used as shifts in weights but here represent the shifts in the slopes of the linear function and shifts in the elasticities of the double-log function. The change in the quality of variables leads to change in factor combinations. A comparison of factor combinations that produce the same output in the pre- and post-green revolution periods can represent the factor-augmenting effects.

Appendix 5-2. All-India Data

The dependent variable Y in the production function analysis is the agricultural output in value terms. The output indices for the fifteen states (excluding the newly formed states of Himachal Pradesh, Meghalaya, and Nagaland) were taken from *Growth Rates in Agriculture* for 1965. The data on output

by state for later years were obtained from *Agricultural Situation in India* and *Estimated Area and Productivity of Principal Crops in India.*[9]

These indices were converted to output values (at constant prices for 1956-57) in absolute terms. This step was necessary to account for interstate variation. Whereas year-to-year variation is maintained in the use of index numbers, the interstate variation is lost because of the difference in the base for each state. Evenson and Jha used state indices not only for output but for inputs as well. Insofar as the results are presented at the state level, the use of index numbers or the product in absolute terms does not affect the results. But in the second part of the study, where the major objective is to estimate the returns to investment, the use of index numbers does not seem appropriate.

The data for the input variable of net sown area (X_9) and percentage of irrigated area ($X_5/X_9 \times 100$) were taken from *Statistical Abstracts, India.*[10] Fertilizer data were collected from *Fertilizer Statistics*, and N, P, and K were pooled by using prices as weights.[11]

Human labor (X_2) comprises the population of male cultivators + male agricultural laborers + 0.67 of female agricultural laborers. The census figures for 1961 and 1971 were used to estimate the human labor for the remaining years by working out the compound growth rates. Female cultivators were not included because the definitions and concepts used in the census of 1971 had changed from those used in the census of 1961.

The cattle used only for work formed the bullock labor (X_3). These figures were taken from the *Livestock Census* data for 1961 and 1966 and from the *Agricultural Census* in India for 1972 (see note 9). The data on the number of tractors (X_4) were obtained from the same source. The estimates for X_3 and X_4 were worked out for the remaining years.

The figures for the expenditure on research in agriculture (X_7) were taken from Evenson and Jha. An important point in the use of this variable was the time-lag. Evenson reports that the mean time-lag between expenditures on research and its effect on production in the United States was between six and seven and a half years. For our study, we have considered the time-lag to be five years, which became obvious from the jump in research expenditure during 1961-62 and the jump in agricultural production in 1966-67. In the states that did not experience a sudden jump in the investment in agricultural research, the time-lag did not matter, but for the sake of uniformity we used a five-year lag for all states.

Appendix 5-3. Data Used and Sources for State-Level Analysis

The dependent variable Y (or X_1) in the production function analysis is the usual Laspeyres Index of Agricultural Production with constant base year prices used as weights. In the present series of state indices, the farm harvest prices for 1956-57 were used as weights. The data were taken from the publication *Growth Rates in Agriculture, 1949-1950 to 1964-1965* and other related sources for subsequent years (see note 9). For the purpose of pooled analysis, these output indices were converted into absolute value terms to take into account the interstate variations in the value of production in the base year. For the reorganized state of Punjab, the relevant information was collected from *State Statistical Abstracts* for 1972 and earlier years.[12]

Data on X_2, the average annual (agricultural year) rainfall, were compiled from the rainfall figures for subdivisions published by the India Meteorology Department. They were weighted by the geographical area of the subdivisions to arrive at the rainfall values for the states.

Data on total fertilizer ($N + P_2O_5 + K_2O$) consumption (X_3), total cropped area (X_8), and gross irrigated area were available from published reports of the Ministry of Agriculture. The irrigated area was converted into the percentage (X_9) of the total cropped area. In some cases extrapolation on the basis of trend became necessary.

The variable X_4, male agricultural workers, is composed of the population of male cultivators and male agricultural laborers as reported in the census data for 1951, 1961, and 1971. The female working force had to be excluded because of changes in the definition of a "worker" in the three population censuses. Data on X_5, the literacy percentage in rural males, is based on 1 percent sample tabulations of the census information. Values for intermediate years were estimated on the basis of observed compound growth rates.

Data on the number of draft bovines (X_6), including both cattle and buffalo, and on the number of tractors (X_7) were compiled from *Livestock Census* for the years 1956, 1961, 1966, and 1972 (see note 9). For the reorganized state of Punjab, the data had to be compiled from the detailed tables for individual districts. The remaining values were estimated by means of interpolation in the census figures.

Data regarding expenditure on agriculture research (X_{12}, or R_t) were taken from the paper by Mohan, Jha, and Evenson.[13] This series extends only to 1968. Figures for subsequent years were estimated on the basis of trends in each state in the number of agricultural science publications selected for abstraction in *Indian Science Abstracts*.[14]

Appendix 5-4. First Run Linear Equations with All Variables[a]

Variables/ Parameters	States			
	Andhra Pradesh	Bihar	Maharashtra	Punjab
Constant	− 1,732.0878	− 6,125.1833	− 845.0994	− 1,508.2228
X_2	0.0021	− 0.0167	− 0.0382	0.0094
	(0.11)[a]	(0.67)	(1.62)	(0.40)
X_3	0.1072	− 0.6844	0.0666	0.2036
	(0.83)	(1.41)	(0.62)	(1.02)
X_4	− 0.0860	0.2858	− 0.0052	− 0.1770
	(0.86)	(1.23)	(0.02)	(0.51)
X_5	− 44.3513	− 103.3886	−28.2030	11.1348
	(1.34)	(1.27)	(0.70)	(1.10)
X_6	0.4838	1.0323	0.0423	0.5826
	(1.27)	(1.23)	(0.70)	(0.79)
X_7	0.0105	− 0.1786	0.0146	0.0048
	(0.26)	(1.17)	(0.29)	(0.58)
X_8	0.0183	0.0566	0.0697	0.0601
	(2.19)	(3.87)	(2.67)	(1.49)
X_9	0.2503	0.1952	48.5763	4.8419
	(0.06)	(0.04)	(1.81)	(2.48)
D[b]	− 0.4341	53.6893	15.1439	7.0628
	(0.04)	(1.36)	(1.36)	(0.57)
$R_{t-\tau}$[c] or X_{12}	0.0167	0.0522	0.0049	0.0056
	(2.26)	(1.46)	(1.54)	(1.04)
R^2	0.88	0.94	0.88	0.99
F	4.31	10.12	5.12	68.29

[a] Figures in parentheses are t values for the regression coefficients.

[b] D is the period dummy variable.

[c] $R_{t-\tau}$ is the lagged research expenditures variable with τ = 3, 4, 1, 2 respectively for the four states.

NOTES

1. *Progress Report of the Special Panel for the Study of Return on Investment in Agricultural Research* (New Delhi: Indian Council of Agricultural Research, 1974).

2. T. W. Schultz, *The Economic Organization of Agriculture* (New York: McGraw Hill, 1953). Z. Griliches, "Research Costs and Social Returns: Hybrid Corn and Related Innovations," *Journal of Political Economy*, 66 (1958), 419-431. For other excellent accounts of work in this area see A. R. Prest and R. Turvey, "Cost-Benefit Analysis – A Survey," *Surveys of Economic Theory*, vol. III (London: Macmillan, 1968); Walter L. Fishel, ed., *Resource Allocation in Agricultural Research* (Minneapolis: University of Minnesota Press, 1971); and R. E. Evenson, "Technology Generation in Agriculture," Bellagio Conference, Yale University, 1973.

3. R. E. Evenson and D. Jha, "The Contribution of Agricultural Research Systems to Agricultural Production in India," *Indian Journal of Agricultural Economics*, 28 (1973), 212-230.

4. Karam Singh, "Returns to Investment in Agricultural Research in the Punjab,"

Progress Report of the Special Panel for the Study of Return on Investment in Agricultural Research (New Delhi: Indian Council of Agricultural Research, 1974).

5. Shujiro Sawada, "Technological Change in Japanese Agriculture: A Long-Term Analysis," *Agriculture and Economic Growth: Japan's Experience*, eds. Kazushi Ohkawa, Bruce F. Johnston, and Hiromitsu Kaneda (Princeton, N.J.: Princeton University Press, 1970), pp. 136-154.

6. J. Johnston, *Econometric Methods* (New York: McGraw Hill, 1963).

7. Singh, "Returns to Investment."

8. Evenson and Jha, "Contribution of Agricultural Research Systems."

9. Publications of the Directorate of Economics and Statistics, Ministry of Agriculture and Irrigation, Government of India, New Delhi: *Growth Rates in Agriculture, 1949-1950 to 1964-1965*; *Agricultural Situation in India* (a journal); *Estimated Area and Productivity of Principal Crops in India*; *Livestock Census*; *Agricultural Census*.

10. Central Statistical Organisation, Ministry of Planning, *Statistical Abstract, India* (New Delhi: Government of India).

11. *Fertilizer Statistics* (New Delhi: Fertilizer Association of India).

12. *State Statistical Abstracts*. Issued by Bureaus of Economics and Statistics, individual state governments, India.

13. Rakesh Mohan, D. Jha, and R. E. Evenson, "The Indian Agricultural Research System," *Economic and Political Weekly*, 8:13 (March 31, 1973), A21-A26.

14. *Indian Science Abstracts* (New Delhi: Indian National Scientific Documentation Centre).

6

Measuring Economic Returns to Agricultural Research[1]

Reed Hertford and Andrew Schmitz

Economists have devoted a considerable amount of effort to estimating the economic payoff from agricultural research. Many of their early studies focused on agricultural activities in the United States. Results showed that past research had yielded impressive rates of return. Similar conclusions are now available for a number of other countries.

The framework used in estimating the rates of return to agricultural research was introduced almost a century ago by Alfred Marshall.[2] It involved the concept of an economic surplus. Since Marshall's time, numerous debates have arisen among economists over the theoretical validity of this concept. Unfortunately for the practitioner, there is no consensus at present on either its validity or its usefulness in economic analysis.

The purpose of this chapter is to review briefly the methods currently used by economists to estimate the rates of return to agricultural research and to suggest some modifications in those methods which would expand their usefulness. We do not attempt to resolve the debate over the validity of the concept of economic surplus. Also included in the chapter are some comments about why those rates of return to research estimated in the past have been so high.

Methods

The concept of economic surplus underlies the methods used by economists to estimate the benefits of agricultural research.[3] Such methods involve deriv-

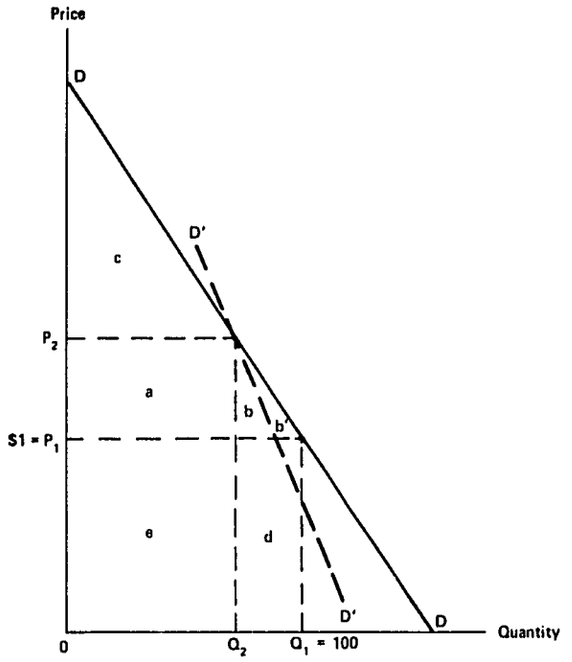


Figure 6-1. Consumers' surplus.

ing a total annual benefit from research by aggregating the separate surpluses of consumers and producers. Annual benefits are then compared with the annual costs of research by finding that rate of interest (the internal rate of return) which equates the discounted value of benefits and costs.

Consumers' Surplus

The concept of consumers' surplus was introduced by Dupuit[4] over a century ago, later popularized by Marshall,[5] and ultimately extended by Hicks[6] in the 1940s in ways which expanded and clarified its range of applicability. Consumers' surplus is measured with reference to demand curves.

Consider Figure 6-1, where D represents a compensated demand curve (CDC) showing the maximum prices a consumer would be prepared to pay for successive, additional units of a commodity. If he were to pay such maximum prices until he had obtained, say, 100 units, he would have made a total expenditure equal in value to the area under the demand curve and left of Q_1. If, on the other hand, he were to purchase the 100 units on the market

at a single average price of $1.00 per unit, he would save a value equal to the area under the demand curve above the $1.00 price line (area a + b + b′ + c). It is this saving which is termed "consumers' surplus." For a group of consumers, or a "market," the consumers' surplus is generally the sum of the individual surpluses of consumers.

Any factor which increases the market price of the good from P_1 of $1.00 to, say, P_2 would reduce the consumers' surplus by the area a + b + b′ in Figure 6-1. This area can be shown to equal

$$KP_1Q_1 \quad (1 - \frac{1}{2}Kn) \tag{1}$$

where K is $(P_2 - P_1)/P_1$ and n is the absolute value of the price elasticity of demand.[7] If K is associated with the reduction in the average costs of a commodity resulting from a new yield-improving technique generated through research, then this formula can provide a direct estimate of the value to consumers of that research in a particular year, provided estimates are also available for P_1Q_1 and n.

This method of attributing a value or product to a research activity has been criticized on the grounds that the value of n generally estimated is not exactly equal to the value of the price elasticity of demand on the CDC.[8] When the price of a commodity falls, the consumer with a given money income is better off in terms of total utility or welfare because his real income rises. Since the CDC abstracts from this increase in real income, although an "ordinary" demand curve does not, the price elasticity of demand as usually estimated can be expected to overstate the CDC price elasticity. If, for example, the solid sloped line in Figure 6-1 were actually an ordinary demand curve, instead of a CDC as it has been represented to this point, the CDC would correspond to the broken line with less slope which passes through the point (P_2Q_2). The implication would be that any estimate of the value of research to consumers based on equation (1) would be biased upward by the value of the triangle b′. Although this is the usual situation, the actual direction of the bias, as well as the slope of the CDC in relation to the ordinary demand curve, depends on the sign of the income elasticity of demand for the commodity. One could argue that the bias is probably not substantial. First, the bias is small in the sense that the value of the triangle b′ is small in relation to the value of the total change in consumers' surplus, a + b. Second, the magnitude of the bias is even smaller when the commodity in question either has a small income elasticity of demand or represents a small proportion of total expenditures on all commodities.[9] It has been argued that the kinds of agricultural commodities for which research returns have been quantified using the consumers' surplus concept have, in fact, low income elasticities and represent a small proportion of total consumer expenditures.[10]

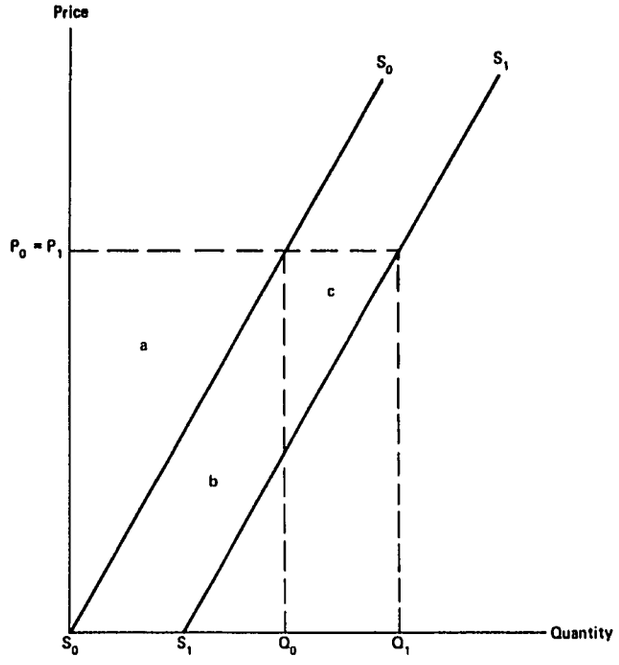


Figure 6-2. Producers' surplus.

Producers' Surplus

The concept of producers' surplus is analogous to that of consumers' surplus and refers, in general, to a difference between what is actually received from the sale of a good and the minimum amount required to induce a seller to part with it. Consequently, producers' surplus has been equated with an area – like area a in Figure 6-2 – between the prevailing price of a good and its supply curve since the latter has been traditionally defined as a locus of minimum prices at which quantities will be sold. If the supply curve shifts to a position like S_1 as a result of the adoption of a new production technique generated through agricultural research, then the benefit of that research to producers has been taken equal to area b + c.

Because there are sellers of input services, for example labor and capital, as well as sellers of final products, all of whom could theoretically earn a "surplus," some confusion has arisen over what producers' surplus and changes in it really measure. Is only the surplus of producers included, as the term implies, or are surpluses earned by factors of production also included? Marshall,

the author of the concept, was himself not clear on this point. It is of crucial practical significance, since any estimate of the returns to agricultural research would be incomplete if it included only benefits to consumers and producers and overlooked those accruing to factors of production.

As it turns out, the composition of producers' surplus is dependent upon the specification of the supply curve. When variable inputs of production are available to a competitive industry at prices that are independent of the level of output, it is well known that (1) the supply curve of the industry is the lateral sum of the marginal cost (or supply) curves of the individual firms, (2) the area under the industry's (firm's) supply curve represents the total costs of all variable inputs of production, and (3) the area above the industry's (firm's) supply curve and below the prevailing price of the product is a return to all other inputs – namely, all fixed factors of production including inputs physically associated with producers, like their labor and "entrepreneurial capacity," as well as other fixed inputs. By definition these fixed inputs are specific to the industry or firm under consideration in the sense that they cannot produce anything else in the economy. Therefore, on a broader view, there are no real costs associated with their employment, and any return to them would be an economic rent or surplus. Since producers' surplus has been given the same definition, we may conclude that producers' surplus is, in fact, a return to the producer as well as to other fixed factors of production, and that there is a direct correspondence between the concept at the level of the firm and the industry when prices of variable inputs are invariant with respect to changes in output.

When some variable factors of production are supplied at prices that are not constant but increase with the level of an industry's output because their supply curves slope upward, this simple interpretation of producers' surplus disappears. Assume that the sum of the marginal cost curves of an industry, S_0 in Figure 6-2, for example, shifts down to S_1 at the level of output Q_0 as a result of the adoption of a cost-saving, improved technique generated through research. The value of costs saved, given our definition of the supply curve, would be the area b. These savings, of course, would permit the industry to expand its output beyond Q_0. However, any output expansion achieved through increased employment of variable factors of production would now tend to bid up their prices to the industry and make their costs exceed the area under the new industry sum of marginal costs curve, S_1, at any level of output above Q_0 since the supply curves depicted in Figure 6-1 assume that unit costs of variable inputs are constant. Therefore, as output expands in the industry, the sum of marginal costs curve, S_1, begins to slip back to the position of initial supply curve, S_0. Its final position of equilibrium would approximate that of the initial supply curve if all variable inputs of

production were subject to very inelastic supply curves. In that case the initial saving created by adoption of the new production technique would have accrued mostly to the variable inputs of production as a surplus. Area b of Figure 6-2 would then approximately equal the change in surplus obtained by variable factors of production from the cost-saving improvement in production techniques resulting from research. The surplus of producers and other fixed factors of production would be practically unchanged as would the level of industry output (Q_0).

The final position of the supply curve of the industry would normally result in an output somewhere between Q_0 and Q_1 of Figure 6-2; that is, some variable inputs of production would be available at somewhat higher prices to the industry and, as output expanded, the supply curve would shift equivalently from S_1 but not return to its initial level, S_0. The area between this final position of the curve and the sum of marginal costs curve, S_1, up to the final level of industry output would then measure the increase in expenditures by firms in the industry on variable inputs as a result of increases in their unit prices.

Although such increased expenditures would represent very real increases in resources devoted to production by firms in the industry, they would not all be increases in real resources devoted to production from the point of view of the economy at large since a part would accrue to some sectors of the economy – namely, to variable inputs or variable input suppliers – as surpluses above their positively sloped supply curves and below their prevailing prices. A surplus, of course, should be accounted for as such and should be added to other estimated products or returns to research. To estimate such surpluses exactly, however, would require data on the demand and supply curves for variable inputs employed by the industry. Since they are not generally available, the most that can usually be said is that the area between the final position of the sum of marginal costs supply curve of the industry up to the new level of output and the sum of marginal costs curve that would have prevailed had input prices been invariant with respect to output represents the increase in returns to variable inputs and their suppliers associated with employment of the improved technique of production. The area between the initial and the final sum of marginal costs curve up to the product price line would then be a measure of the returns of the new technique captured by producers and other fixed factors of production.

If the point of intersection of the vertical line through Q_0 with the supply curve S_1 were connected with the point of intersection of the new equilibrium level of industry output with the price line P_1, the resulting line would define a new supply curve which was adjusted for the kinds of input price changes just discussed. This "adjusted" industry supply curve would have a smaller

slope than the "unadjusted" sum of marginal costs curve of the industry or the relevant curve when prices of all variable factors of production are invariant with respect to output. If there are only two factors of production, the elasticity of supply approximately equals $a_1e_1 + a_2e_2$ where $a_1 = 1 - a_2$ is the first input's share in total production costs and e_1 and e_2 are the two inputs' price elasticities of supply. From this expression, it follows directly that the supply curve will be less elastic when input supply curves are less elastic.

To recapitulate: Area b + c in Figure 6-2 is an unambiguous measure of the increase in the surplus of all fixed factors of production, including the surplus of producers from their self-employment, when variable inputs of production are available at prices that do not change with output. If variable input prices change with changes in output, then area b becomes a reasonable measure of increases in surpluses of variable inputs when their supply curves are very inelastic. If variable input supply curves are neither very elastic nor inelastic, then the area b + c is normally an upper-bound estimate of the changes in surpluses of fixed and variable factors of production since it includes some increases in real resource costs to the economy. Finally, two industry supply curves have been identified: (1) the unadjusted sum of marginal costs curve relevant when prices of all variable inputs are invariant with respect to output and (2) an adjusted supply curve, normally more inelastic, connecting points on unadjusted supply curves after adjustments for input price changes have taken place.

Combining Surpluses

To estimate the returns to research, consumers' and producers' surpluses are combined. Figure 6-3 contains a normally sloped demand curve, D, and an initial supply curve, S_0, which shifts to the position S_1 as the result of the on-farm employment of a new or improved input developed through research. Before this shift, consumers' surplus equaled area a; afterward, it is given by a + b + c. Thus, the net gain to consumers from the research-induced shift in supply is b + c. Similarly, before the supply shift, the surplus b + d corresponded to producers and to other production inputs; afterward, their surplus corresponds to f + d. Their net gain from the supply shift is then f − b. The sum of the gains in surplus to both groups is b + c + f − b = c + f. It can be shown that this latter area approximately equals

$$kP_1Q_1 \left(1 + \frac{1}{2}\frac{k}{n+e}\right) \tag{2}$$

where k is defined as the percentage increase in production attributable to research (the horizontal distance between the two supply curves divided by the value of final production Q_1); P_1 is the price of the commodity after the sup-

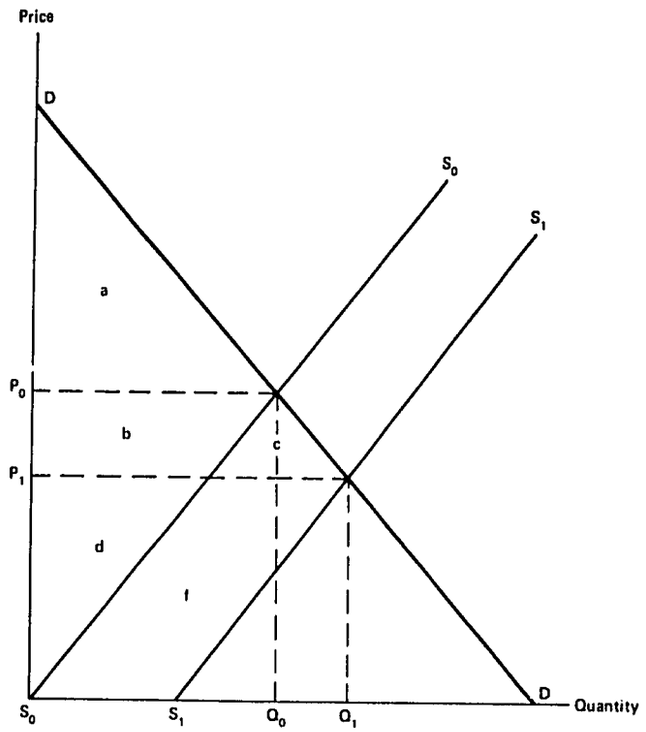


Figure 6-3. Combined consumers' and producers' surplus.

ply shift; and n and e are, respectively, the price elasticities of demand and supply. This formula, of course, can be disaggregated into its primary components, consumers' and producers' surplus, for purposes of quantifying the distribution of gains accruing to each group. Corresponding to (2) are the following expressions:

$$\text{Consumers' surplus} \quad \frac{kP_1Q_1}{n+e}\left(1 - \frac{1}{2}\frac{kn}{n+e}\right) \tag{3}$$

$$\text{Producers' surplus} \quad kP_1Q_1\left\{1 - \frac{1}{n+e}\left[1 - \frac{1}{2}k\left(\frac{2n+e}{n+e}\right)\right]\right\} \tag{4}$$

These reveal that the larger the consumers' surplus, ceteris paribus, the smaller the price elasticity of demand, and that the larger the producers' surplus, the larger the price elasticity of demand. Such results support the notion that

research on basic subsistence commodities would particularly benefit consumers, while research on more price elastic commodities – for example, rubber, cotton, and perhaps coffee – would be especially remunerative for producers, input owners, and certain factors of production. (See chapter 24 for elaboration of this point.) Note further from (3) and (4) that, although consumers' surplus will always be positive-valued because $2(n + e) > kn$, producers' surplus could be negative-valued if $e + n < 1$. Nevertheless, the sum of the surpluses is always positive-valued according to (2). Expressions for the surplus generated by research in the special cases in which one or both of the price elasticity parameters assume extreme values can easily be derived from the general cases just developed.

More complicated formulas for the values of the combined surplus of producers and consumers have been suggested by Ardito Barletta and Peterson to allow for the possibility that the demand and supply relationships may not always be linear.[11] However, the differences in the estimates of benefits provided by the more complicated formulations and those presented here are small for usual values of the key parameters. The main reason is that *in all formulations the critical determinant of the value of the benefits derived from research is simply* kP_1Q_1 *or the percentage change in the value of production attributable to research*. Other parameters combine to produce a value which is small by comparison.[12] This is an important point to keep in mind when considering the empirical relevance of theoretical controversies that have been sparked by the concept of economic surplus.

The Theoretical Controversy

The concept of economic surplus occupies a controversial place in economic theory. For example, Samuelson has said that consumers' surplus is of "historical and doctrinal interest with a limited amount of appeal as a purely mathematical puzzle."[13] More recently, Bergson has stated: "Despite theoretic criticism, practitioners have continued to apply consumer's surplus analysis through the years. As some have urged, that must already say something about the usefulness (as well as the use) of such analysis, but just what it says has remained more or less in doubt."[14] However, Hicks has disagreed:

> But enough has been said to show that consumer's surplus is not a mere economic plaything, a *curiosum*. It is the foundation of an important branch of Economics, a branch cultivated with superb success by Marshall, Edgeworth, and Pigou, shockingly neglected in recent years, but urgently needing reconstruction on a broader basis. Beyond all doubt it is still capable of much further development; if economists are to play their part in shaping the canons of economic policy fit for a new age, they will have to build on the foundations of consumer's surplus.[15]

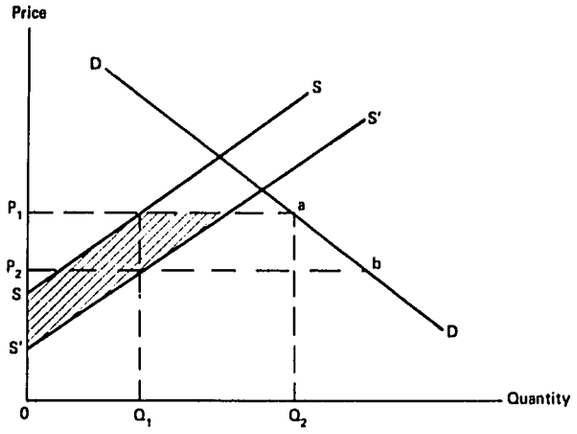


Figure 6-4. Research: The case of a traded good.

Although we acknowledge the place of this controversy in economic theory, we believe that most shortcomings of studies of returns to research arise not from the concept of economic surplus but from overlooking or mistreating practical characteristics of the real world. Such characteristics imply a need to introduce some modifications in the methods used to calculate the returns to research, and to those we now turn.

Modifications

Methods used to estimate the returns to agricultural research should (1) treat products, and research itself, as traded goods if appropriate, (2) consider problems of unemployment, (3) distinguish between intermediate and final goods, and (4) account for the income distributional effects of research. This section briefly discusses these problems and how they can be handled.

Traded Commodities

Consider Figure 6-4 where, at a price of P_1, imports are Q_1Q_2. If the supply curve shifts from S to S' and the "small country" assumption is used – that is, the price remains unchanged – there is no gain to consumers, but producers gain the crosshatched area. The result is a smaller surplus, ceteris paribus, attributable to research than had the commodity not been traded at a constant world price. However, if the country under question is a large trader and the price drops to P_2 owing to the increase in supply, producers actually lose while consumers gain area P_1abP_2. Thus, the effects of research

on a traded good are critically dependent upon the extent to which its world price is affected by changes in supply. One can easily work out the case for a good that is exported.

A related point to consider is that technology can be developed by one country but transferred to another at nominal cost. Such international spillover effects may enhance the estimated returns to research of those countries with newer programs which can benefit from the prior investments of older programs in other countries.

Resource Unemployment

Research can result in the unemployment of agricultural resources. If, for example, a new technology generated through agricultural research favors certain producers of a commodity, others may be forced out of business as supply expands and prices decline. The resources released may not find employment elsewhere; if this is not taken into account, it can lead to errors in estimating the benefits of research.

Suppose an industry is made up of producers on nonirrigated land (Type 1) and irrigated land (Type 2). In Figure 6-5, S_1 represents the supply of the good produced on Type 1 land and S_2 the supply of the good produced on Type 2 land. In equilibrium, Q_1 of the commodity is produced at price P_1. Suppose now that a new technology is applied to Type 2 land which causes the supply curve to shift to S_2'. The corresponding equilibrium price and quantity are P_2 and Q_2. However, note that although the net gain (measured in producers' surplus) is positive, there is a loss to producers on the Type 1 land because the good cannot be grown there at P_2. If the resources (except land) were employed elsewhere and if all the surplus originally accrued to landowners, the crosshatched area would represent the loss to the owners of Type 1 land.

Now let us assume that resources formerly equal in value to the area under the unirrigated supply curve up to Q^* fail to find alternative employment when the unirrigated farms go out of business. These resources do not include such industry-specific fixed factors of production as producers, family members, and farmland since the losses they sustain are fully reflected in the area of producers' surplus. Rather, they refer to other "normally variable" factors of production like hired labor, machinery, implements, other forms of farm power, livestock capital, and perhaps even such things as fertilizers, insecticides, and seeds. Were such resources to become unemployed, their equivalent value – the area under the unirrigated supply curve up to Q^* – would have to be subtracted from the benefits of research estimated in the usual way where the assumption is made that all "normally variable" factors of production find employment elsewhere in the economy.

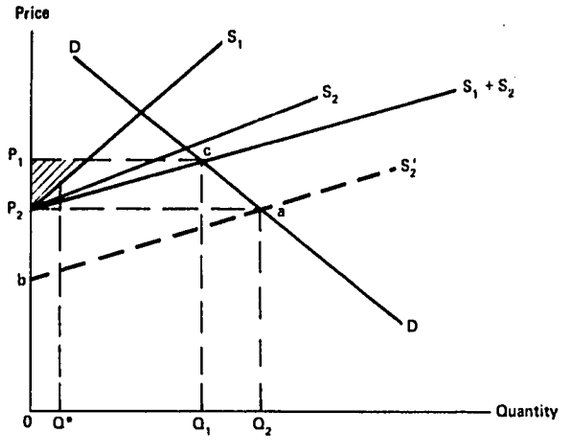


Figure 6-5. The resource unemployment effect from research.

Of course, all that has really happened is that "normally variable" factors of production have become equivalently fixed factors in the face of falling prices. This has altered the division of total revenues between fixed and variable factors. In particular the loss of returns to fixed factors specific to the industry and the lack of employment alternatives elsewhere have turned out to be larger than the crosshatched shaded area above the supply curve, and the value of variable factors of production finding employment elsewhere in the economy is smaller than the area under the supply curve. The implication is that the supply curve corresponding to Type 1 land is more inelastic than that shown in Figure 6-5.

A related case was analyzed by Schmitz and Seckler.[16] They looked at the mechanical tomato harvester as an innovation of agricultural research which had resulted in the unemployment of farm workers. They first estimated the benefits of the research on the harvester in the usual way. A side calculation was then performed in which the returns to laborers who were unemployed because of the introduction of the harvester were deducted from benefits. An alternative approach would have been to reduce the area of surplus generated by the introduction of the harvester by decreasing the elasticity of the new supply curve of tomatoes.

Because past studies have not sufficiently emphasized the "unemployment" effect from research activities, the previous discussion has neglected to indicate that research leading to technological change may, under some circumstances, result in an increase in the employment of resources. For ex-

ample, many developing countries that export agricultural commodities may add to the employment of labor through technological change made possible by research.

Derived Demand Curves

The demands for farm workers, mechanical harvesters, and hybrid corn involve largely derived, not final, demand curves; yet past research has not made this distinction. The demand for hybrid corn, for example, is largely derived from the demand for grain-fed beef – in this instance, a principal final product for corn.[17] In Figure 6-6A the derived demand for corn is shown, and it is assumed that all the corn is fed to cattle. As the result of a new technique generated by research, the price of corn drops from P_0^C to P_1^C. This induces a downward shift from P_0^B to P_1^B in the price of beef in Figure 6-6B. Are the shaded areas in the two diagrams of equal value as has been implicitly assumed?

If there is one other input in beef production besides corn and its supply is elastic, then it can be easily shown that

$$\frac{P_0^B - P_1^B}{P_1^B} = a_c\left(\frac{P_0^c - P_1^c}{P_1}\right)$$

where a_c is corn's share of the costs of producing beef. An implication is that the rectangles between the two price lines in both diagrams up to the new equilibrium quantities are of equal value. The size of the triangles between the two price lines below the demand curves could still be different, however, as a result of different price elasticities for corn and beef.[18] This would imply different values of consumers' surplus measured with reference to the final and derived demand curves. Also, at the macro-level the supplies of inputs are usually not perfectly elastic. When they are not, the relationship between surpluses estimated under final and derived demand curves is further complicated.

Distributional Effects

How realistic is it to aggregate all consumers and producers of a given product and to look at only these two groups when estimating the rates of return to research? If, for example, the welfare consequences of the well-known Russian wheat transaction were considered, a meaningful analysis would include its effect on grain producers, landowners, livestock producers, consumers of various farm products (both high- and low-income groups), machine manufacturers, fertilizer producers, and so on. A partial analysis

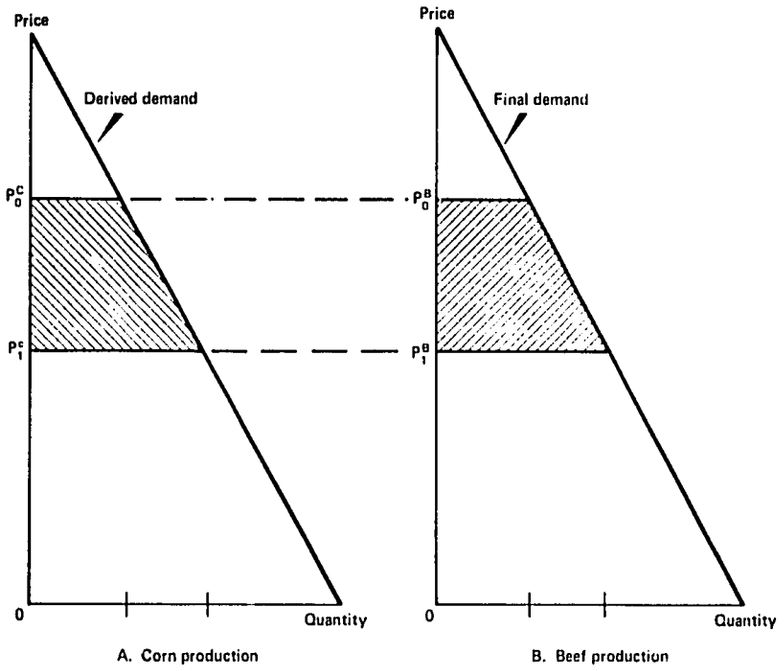


Figure 6-6. Derived and final demand: Corn and beef.

would include only grain producers and consumers. But this would leave out a great deal. Similarly, for research, a great deal is overlooked if the effects on farm workers, profits, farm size, and land values are not considered.

Because of a tendency to deal with aggregative models, the distributional effects from research have not commonly been considered. For example, there are many types of producers of a given commodity – small-scale farmers, large-scale farmers, landowners, sharecroppers, and farmers with unmechanized and mechanized units. An aggregate producers' surplus sheds little light on how research affects each group. It is not enough to know that the rate of return is high or low. Generally we also want to know who will benefit and who will lose within the producing and consuming sectors.

One reason is that a dollar of benefits need not equal a dollar of losses in the context of economic welfare. There is no reason why a 1:1 welfare scheme is superior to any other weighting system. For example, 2:1 weights might be assigned losers and gainers, respectively, or perhaps 4:1 weights. Obviously,

negative rates of return could result from assigning different welfare weights to losers and gainers even though, with the usual 1:1 arrangement, rates of return are highly positive.

Why Are Returns So High?

Economic studies now available for a number of countries point to high rates of return to programs of agricultural research.[19] One cannot help but view this evidence as unusual and ask, why? In fact, this issue did engender a heated discussion at the Airlie House conference; S. J. Webster pointed out, for example, that the literature on agricultural research is almost unanimous in presenting rates of return that are astronomically high by normal standards. This fact alone should bring the methods employed in arriving at the results under the closest possible scrutiny.

The preceding section of this chapter has suggested some possible answers to this question when: the fact that agricultural products are traded is not taken into account; international spillover effects of research are overlooked; the effects of research on intermediate and final products have been confused; the costs of resource unemployment induced by research have been omitted; and inappropriate welfare weights have been assigned to the gains and losses underlying calculations of the returns to research. Not mentioned, but of possible relevance, are the problems associated with properly accounting for research projects that have produced "dry holes" and with determining how much money has actually been spent developing particular technological or biological breakthroughs. The costs of administration and of other complementary, supporting programs are extremely difficult to impute to individual research projects.

The purpose of this section, however, is to suggest that two factors associated with the agricultural research "delivery system" – the mechanism that assists in transferring new technology from research centers to farms – may explain more generally why estimated returns to agricultural research have been so high. Although it is hypothesized that the influence of these two factors has been pervasive, there is no intention of leaving an impression with the reader that past estimates of the returns to research have been grossly inflated. The evidence in this regard appears to be overwhelming: agricultural research does pay handsome rewards, indeed.

Traditionally, in making calculations on the cost side of the equation, past economic studies of the returns to research have included outlays incurred in developing and sustaining the research program under appraisal plus the differential costs to farmers of purchasing the resulting technology. A great deal of care has generally been taken to include among costs of the program the

direct expenses of the research (mainly salaries and supplies), the costs of complementary inputs from such collaborating programs as agricultural extension, and the costs of indirect inputs like staff training and management.[20] Not included, however, have been the costs of transferring technology to farmers which are borne either by organizations largely unrelated to the research program or by farmers themselves.

In the case of developing countries, the first of these two omissions may have been of minor consequence. Most of the relevant costs of transferring technology to farmers are probably captured by imputing to the research program some portion of the costs of the agricultural extension service. In the case of developed countries, however, the omission may have been of some greater consequence because of the existence of a complex and sophisticated network of organizations and facilities in rural areas which form part of the delivery system. Those of us from rural areas of developed countries tend to take for granted such things as agricultural banks, newspapers, radios, television, city libraries, and programs of continuing education. All, however, assist in their own way to transfer new technology to farms at costs which may not be fully reflected in the expenses of research and extension programs, in the prices paid for new techniques of production, or in the area below a product supply curve. The implication, of course, would be that the real costs to society of research programs in developed countries may have been much larger than was estimated by past studies of the returns to agricultural research.

Boyce and Evenson have recently provided some data which relate very directly to this proposition.[21] They show in a multicountry study that there is a strong *positive* correlation between the level of development of a nation and the proportion of the total agricultural product devoted to agricultural research, whereas there is an equally strong but *negative* correlation between the level of development and the proportion of the agricultural product spent on extension. Noting that extension workers are paid generally less than researchers, Boyce and Evenson conclude that developing countries may have been lulled into thinking they can increase agricultural production more cheaply by emphasizing extension activities. An equally plausible explanation, however, is that agricultural programs in developing countries have been forced to pay part of the price of deficient delivery systems by investing in agricultural extension services. Programs in developed countries, on the other hand, have been able to avoid such costs by piggybacking on a delivery system constructed at a substantial cost to society at large.

A second component of the costs of the delivery system not usually taken into account in reckoning the returns to agricultural research includes the farmer, his family workers, and hired laborers.[22] In most settings of dynamic

change, some labor time must be allocated to searching for, learning about, experimenting with, and ultimately adopting new techniques generated through research. Needless to say, time spent in these ways decreases when the productivity of the research establishment itself is low. It may also be lower, however, precisely where the delivery system is highly developed and functioning efficiently. In developed countries, technology is practically laid at the farmer's doorstep in prepackaged and pretried forms. By contrast, in developing countries, where levels of formal schooling are low and the delivery system is not well developed, a substantial share of total labor time may be required to adjust to new technologies released by the research establishment. Such time cannot be ignored among the costs of research from society's point of view unless agricultural labor at the margin is unemployed.

In most countries the proportion of the value of agricultural production spent on research and extension is quite small – less than 2 percent.[23] Agricultural labor's share of the value of production, on the other hand, is large, commonly falling into the 40 to 60 percent range.[24] This means that a small fraction of total farm-level labor time bulks large in relation to research expenditures. If it is assumed, for example, that the labor time of searching, learning, experimenting, and adopting activities associated with new agricultural technologies absorbs just 2 percent of total labor time each year, the costs of research could be increased by 50 percent were labor's share of final output 50 percent.

It should be pointed out that both of the usually omitted costs of the delivery system discussed in this section – those associated with the activities of organizations largely unrelated to the research program, especially in the developed countries, and those associated with the labor time absorbed by adopting improved technologies, especially in developing countries – would not be included in assessments of the returns to research done from the more restricted point of view of the research administrator or the research agency. The reason is that the delivery system, including the labor time of farmers, is not usually an item in the budget of agricultural research programs. However, precisely because the probabilities of success of a research program are enhanced by a delivery system that hastens the adoption of improved practices, strategies chosen for research may capitalize on better delivery systems through the particular selections of commodities to be studied and/or geographical areas to be emphasized. Such strategies are obviously at variance with the social interest by not taking into account their full cost to society. The remedy would be to internalize the costs of the delivery system in the budget of the research program and thus close the gap between returns to research as viewed by the research agency and by society at large. Internalizing costs in this way could lead to some interesting changes in the allocation of

resources for research. For example, a research agency might choose to initiate work in a depressed area of small farmers rather than in an irrigated region with a more highly developed delivery system.

Concluding Remarks

Estimates of the economic returns to past agricultural research can be most helpful in highlighting commodities and programs that have represented low risk, high payoff endeavors. Rates of return calculations are also useful in pointing up and appraising the value of some unanticipated side effects of agricultural research that might merit additional study. An example is the effect of the tomato harvester on the unemployment of farm labor. Further, where major funds have not yet been committed to a national agricultural research program – as is the case in some developing countries – estimates of the returns to past research may be of assistance in securing financing by demonstrating the objective value of research to society. Consumers in such settings do not typically pressure for agricultural research because they lack firsthand knowledge of its effects, and pressures exerted by producers are viewed as self-serving and are frequently ignored. For each of these reasons, calculations of the returns to agricultural research are an important means of helping to produce a better allocation of society's scarce resources.

This chapter has reviewed the methods used to estimate such returns and has alerted the reader to modifications which should be introduced in particular situations. It was suggested that calculated returns could be biased upward if these modifications are not made where appropriate. It was also suggested that the returns to research may be generally overstated if the full costs of getting technology from the research center to farms are not taken into account. Emphasized in this regard were the costs of using a highly sophisticated infrastructure of delivery services in rural areas of developed countries and the costs of farmers' time absorbed in finding and adopting a new technology in developing countries. Further applications of the methods discussed in this chapter to appraisals of research programs should point out other refinements needed to improve estimates of the economic returns to research.

NOTES

1. This paper has benefited especially from comments and suggestions made by Vernon Ruttan of the Agricultural Development Council, Tilo L. V. Ulbricht of the Agricultural Research Council in London, and S. J. Webster of the Ministry of Overseas Development in London.

2. Alfred Marshall, *Principles of Economics*, 8th ed. (London: Macmillan, 1930).

3. The development and use of the concept of economic surplus has been dealt with in detail by J. M. Currie, J. A. Murphy, and A. Schmitz, "The Concept of Economic Surplus and Its Use in Economic Analysis," *Economic Journal*, 81:324 (December 1971), 741-800.

4. J. Dupuit, "On the Measurement of the Utility of Public Works," *Annales des Ponts et Chaussees*, 2nd series, 8 (1844), 14-28.

5. Marshall, *Principles of Economics*.

6. J. R. Hicks, "The Rehabilitation of Consumers' Surplus," *Review of Economic Studies*, 8:2 (February 1940), 108-116.

7. The area a + 2 (b + b′) in Figure 6-1 equals KP_1Q_1 and the area b + b′ equals $\frac{1}{2}(Q_1 - Q_2)(P_2 - P_1) = \frac{1}{2}K^2P_1Q_1n$. The difference between these two quantities is equal to (1) and the area a + b + b′ in Figure 6-1. Note that this area is always positive-valued.

8. For a recent example of this criticism, see Wolfgang Bonig, "Comment," *American Journal of Agricultural Economics*, 56:1 (February 1974), 177.

9. This statement reflects the exact expression for the price elasticity of demand of an ordinary demand curve, $n_{xp}^{*} - k_x n_{xI}$, where the terms are, respectively, the price elasticity of demand along the CDC, the proportion of income spent on the commodity "x" in question, and the income elasticity of demand for x.

10. See, for example, Harry W. Ayer and G. Edward Schuh, "Reply," *American Journal of Agricultural Economics*, 56:1 (February 1974), 175-176.

11. Nicolas Ardito Barletta, "Costs and Social Benefits of Agricultural Research in Mexico," Ph.D. dissertation (Chicago: University of Chicago, 1971), Appendix C has provided the following formula for the surplus:

$$kP_1Q_1 \left\{1 + \frac{k}{2n}\left[1 - e\,\frac{(1-n)^2}{n+e}\right]\right\}.$$

Willis Peterson, "Returns to Poultry Research in the U.S.," *Journal of Farm Economics*, 49:3 (August 1967), 656-669, has suggested:

$$kQ_1P_1 + k^2\,\frac{P_1Q_1}{2n} - \frac{Q_0k^2P_1}{2}\left(\frac{P_1}{P_0}\right)\left(\frac{en}{n+e}\right)\left(\frac{n-1}{n}\right)^2.$$

12. If, for illustrative purposes, we assume k = 0.1, n = 0.3, and e = 0.5, then the value of the term that multiplies kP_1Q_1 in Ardito Barletta's formula, as well as the formula defined here by equation (2), is 1.1.

13. Paul A. Samuelson, *Foundations of Economic Analysis* (New York: Atheneum, 1967), p. 195.

14. Abram Bergson, "A Note on Consumer's Surplus," *Journal of Economic Literature*, 13:1 (March 1975), 43-44.

15. Hicks, "Rehabilitation of Consumers' Surplus," p. 116.

16. A. Schmitz and D. Seckler, "Mechanized Agriculture and Social Welfare: The Case of the Tomato Harvester," *American Journal of Agricultural Economics*, 52:4 (November 1970), 569-578.

17. The research on rates of return from hybrid corn research was done by Zvi Griliches, "Research Costs and Social Returns: Hybrid Corn and Related Innovations," *Journal of Political Economy*, 66:5 (October 1958), 419-432.

18. Under the assumptions made to this point, it can be shown that the price elasticity of demand for corn equals

$$-[a_1 n + a_2 \sigma]$$

where $a_1 = (1 - a_2)$ is the first input's share of production costs, $-n$ is the price elasticity of demand for beef, and σ is the elasticity of substitution between corn and other inputs in beef production. (This elasticity of substitution is equivalent to the percentage change in the inverse ratio of their prices. Thus, the elasticity is positive-valued and ranges in value from zero to infinity.) We see that this elasticity would equal $-n$ if $n = \sigma$. Although the equality is unlikely to obtain exactly, it seems reasonable to expect that $n - \sigma$ would usually be small. If this is true, consumers' surplus measured under final or derived demand would be quite similar.

19. Several of these are listed and discussed by James K. Boyce and Robert E. Evenson, "Agricultural Research and Extension Systems," Department of Agricultural Economics, mimeographed (Los Baños: University of the Philippines, 1975), Tables 6.1 and 6.2.

20. These are outlined, for example, by Reed Hertford, et al., chapter 4 in this volume.

21. Boyce and Evenson, "Agricultural Research," chapter II.

22. We are indebted to our colleague, Carlos Benito, for suggesting this point. See his "Peasants' Response to Rural Development Projects – With Special Reference to the Puebla Project," Department of Agricultural Economics, Rural Development Project Working Paper no. 1 (Berkeley: University of California, 1974).

23. Boyce and Evenson, "Agricultural Research," chapter I.

24. For the United States, a labor "share" of roughly 50% was implied by the regression results of Zvi Griliches, "Research Expenditures, Education, and the Aggregate Agricultural Production Function," *American Economic Review*, 54:6 (December 1964), 961-974. For a developing country, see Reed Hertford, *Sources of Change in Agricultural Production, 1940-65*, Foreign Agricultural Economic Report no. 73 (Washington, D.C.: Economic Research Service, USDA, 1971).