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Agricultural Research and Productivity Growth in India

Robert E. Evenson

Carl E. Pray

Mark W. Rosegrant

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
2033 K STREET, N.W., WASHINGTON, D.C. 20006-1002 U.S.A.
PHONE: 1-202-862-5600 • FAX: 1-202-467-4439
E-MAIL: ifpri@cgiar.org • WEB: www.ifpri.org

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Robert E. Evenson

Carl E. Pray

Mark W. Rosegrant

International Food Policy Research Institute
Washington, D.C.

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Foreword

India's investments in agricultural research, extension, and irrigation have made it one of the largest publicly funded systems in the world. But some policymakers who perceive that the benefits to research may be declining are advocating a cutback on public spending on research. This research report, which examines the effects of research and development on productivity in India, finds that India is still benefiting from these investments. The main sources of agricultural productivity growth in India during 1956–87 were public agricultural research and extension; expansion of irrigated area and rural infrastructure and improvement in human capital were also important contributors.

The report also shows that the public benefits from private research can be substantial, indicating that private firms capture only part of the real value of improved inputs through higher prices. Private agricultural research accounted for more than 10 percent of growth of total factor productivity (TFP) during 1956–87, and in 1966–75, when India was more open to foreign technology, private research contributed 22 percent of productivity growth. Industrial policy and technology policy, including intellectual property rights policy, will require careful evaluation and reform in order to encourage private investment in agriculture. Evenson, Pray, and Rosegrant argue that barriers to technology transfer should be removed in order to stimulate technology transfer and growth.

Nevertheless, public investment in agricultural research will likely retain its primary role. Contrary to concerns that growth in TFP has decreased over time, the report finds that during 1977–87, the period when the results in regions that adopted high-yielding varieties early on could be expected to taper off, TFP growth was 50 percent higher than before the Green Revolution and 17 percent higher than in the early years of the Green Revolution, indicating that gains are far from over. The rates of return to public agricultural research are high, and it appears that the government is underinvesting in agricultural research. Expanding public investment in research and extension would lead to even greater gains.

The issues addressed in this report are part of an extensive research effort at IFPRI on the economic aspects of financing, organizing, and managing public agricultural research and development.

Per Pinstrup-Andersen
Director General

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Summary

India has one of the largest public agricultural research establishments in the world. Among developing nations, only Brazil and China have comparable levels of expenditure or numbers of professional staff. However, the economic liberalization policies of the Indian government since 1991, together with budget constraints and concerns that the returns to public research may be declining, have raised questions about how much investment in public agricultural research. How much has productivity growth contributed to the total growth of output? What have been the sources of productivity growth? Are the returns to agricultural research in India still high? These questions are examined in this report by assessing the effects that public investment in agricultural research, extension, and irrigation and private domestic agricultural research have had on the growth of total factor productivity (TFP) in the Indian crop sector.

Chapter 1 provides some background on the issues. Chapter 2 describes investment in four major productivity producing activities: Indian public research, the international agricultural research centers (IARCs), international technology transfers, and private research conducted in India. It also discusses the institutional structure of research and the policies for science and technology that affect technology transfers and private research investment and describes the activities that make these sources of technology more effective—extension, irrigation, and rural infrastructure.

The generation and adoption of new plant varieties has been the primary measure of success of Indian public agricultural research and of the IARCs. Chapter 3 examines the development of new crop varieties by source and assesses the contributions of public, international, and private crop research to the development and spread of modern varieties.

Chapters 4 and 5 provide an analysis of TFP, which is the ratio of total agricultural output to total inputs. Chapter 4 describes the methodology for measuring TFP growth in Indian crop production. It also gives TFP measures by region and period. Chapter 5 assesses the quantitative effects of agricultural research, extension, irrigation, and other public and private investments on agricultural productivity. It analyzes the trends and sources of TFP growth in India, examines the contribution of several sources of that growth, and estimates the marginal economic rates of return to public and private investments that increase TFP. The contribution to economic growth and

economic rates of return to investments in research, extension, and modern varieties are computed by time period in order to assess whether the effects of these investments change over time.

The report has several main conclusions and policy implications: Indian research programs—with support from IARCs (especially the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the International Rice Research Institute (IRRI), and the International Maize and Wheat Improvement Center (CIMMYT)—have significantly improved crop technology. These improvements are embodied in several generations of improved crop varieties.

The private sector in India also engages in extensive research and development relevant to agriculture. It has increased its investments rapidly over time. Expenditures on agricultural research and development in the private sector are approximately half those expenditures in the public sector. Much research and development conducted by the international private sector is also relevant to agriculture in India.

India's agriculture has realized substantial gains in productivity, as measured by TFP indexes. These gains have varied by period (they were highest during the Green Revolution) and by region (they are highest in wheat-producing regions and in regions with environments favorable to rice production). But virtually every district in India has seen TFP grow. TFP growth has contributed roughly 1.1–1.3 percent per year to the growth of crop production in India. Conventional inputs have contributed about 1.1 percent per year since 1956. TFP and conventional inputs have thus contributed 2.3 percent per year to the growth of crop production. They have made it possible for India to increase food production per capita despite high population growth rates and limited land resources.

The analysis in this report shows that several types of investments have been associated with and contributed to the growth of TFP. Public agricultural research (and high-yielding varieties) accounted for nearly 40 percent of TFP growth between 1956 and 1987. This study is one of the first to investigate the contribution of research and development in the private sector to productivity growth in a developing country. Private sector research and development was significant, accounting for more than 11 percent of TFP growth.

Investment in agricultural extension programs and improved rural markets have also contributed to the growth of TFP. The impact of extension has been very large, especially before the Green Revolution. Irrigation investment generated TFP growth over and above the contribution to output growth that irrigation makes as a "conventional" input. This additional contribution from irrigation comes largely by providing an improved environment for crop technology (for example, through interaction between technology and irrigation). Modern chemical inputs also generated TFP growth over and above their conventional contribution partly by complementing the high-yielding varieties.

The hypothesis that the contributions of research, extension, and irrigation to TFP growth declined over time is examined by disaggregating the effects of these factors into three periods: before the Green Revolution (1956–65), the early Green Revolution (1966–76), and the mature Green Revolution (1977–87). During the early Green Revolution, modern varieties of wheat and rice spread particularly fast in the most favorable crop environments. They were especially effective in the Punjab. During the mature Green Revolution, modern varieties were more widely adopted geographically. The marginal impact of public research on TFP was moderately higher in 1966–76 than in 1956–65. More importantly, during the mature Green Revolution, when returns might have been expected to decline as modern varieties spread more broadly, the marginal impact of research on TFP was 50 percent higher than before the Green Revolution and 17 percent higher than in its early years. The marginal impact of the expansion of irrigated area on productivity also increased over time. This improvement can be attributed to rapid growth in the proportion of private tubewell (groundwater) irrigation. No change was found in the contribution of extension to the growth of TFP.

Finally, the report estimates the marginal internal rates of return to public and private investments. The returns to public agricultural research were greater than 50 percent. The rates of return to extension, domestic private research and development, and to imported modern varieties generated mainly by the IARCs were also high. The sustained high rates of return to research and extension suggest that investment in these productivity-enhancing activities should be increased. These findings also suggest that the removal of policy constraints on private-sector research could have large payoffs.

CHAPTER 1

Introduction

India's agriculture has grown rapidly enough in recent decades to move the country from the severe food crises of the early 1960s to the food surpluses of the early 1990s, even though the population grew by 424 million people between 1963 and 1993. Underlying this growth of agriculture were massive public investments in irrigation, agricultural research and extension, rural infrastructure, farm credit, and smallholder development programs. The growth occurred despite macroeconomic and agricultural policies and market regulations that penalized agriculture and are considered highly distortionary today.

Indian agriculture faces daunting challenges, however. Despite national food surpluses, widespread poverty and hunger remain because the growth of agriculture and the national economy have not adequately benefited the poor. Moreover, with strong growth of income and a projected addition of another 375 million people by 2020, total cereal demand in India is projected to grow by nearly 85 million metric tons.[1] This is an increase of more than 50 percent from 1993 (Rosegrant et al. 1997).

India is undertaking policy reforms to liberalize the economy that should improve the terms of trade for agriculture and encourage greater private investment. Historically, Indian trade policy has consistently discriminated against agriculture through protection of the industrial sector. Policy reforms initiated in 1991, together with a process to open Indian agriculture to world markets under the General Agreement on Tariffs and Trade (GATT), should change the relative incentive structures in the economy, allowing agriculture to attract more private sector resources in the future (Pursell and Gulati 1993).

However, policy reform alone will not be enough to increase agricultural growth and to make it more equitable. The policy reforms must be accompanied by appropriate and efficient investments in public goods such as rural infrastructure, irrigation, agricultural research and extension, and the education and health of rural people. India has proven in the past that agricultural growth can be successfully achieved with the right public investments, even when economy-wide policies were unfavorable toward agri-

[1] In this report, all tons are metric tons.

culture. Thus, India's promise of the future lies in combining policy reform with the right levels and kinds of public investments. However, the current period of economic transition and policy reform is accompanied by budget constraints that motivate careful rationing of public investment funds, making it increasingly important to assess the economic rates of return to agricultural research and other public investments.

As policy reform continues, concerns are increasing that the rapid growth in agricultural production is waning. These concerns are heightened by a perception that the returns to agricultural research may be declining over time because the "easiest" gains from the Green Revolution have already been reaped through the rapid spread of modern varieties of wheat and rice, leading to high levels of modern variety adoption and high input use in many regions of India, and by the failure of domestic and foreign research to generate crop varieties with higher maximum yields than varieties produced in the 1960s (Rosegrant and Pingali 1994). Public investments in agriculture are declining, and the annual increment to gross capital formation in agriculture is now lower than in the early 1980s. This decline appears to be happening in all states, not just the poorer ones. At the same time, increasing shares of total public expenditures on agriculture have been allocated to input subsidies, rather than to productivity-enhancing investments. The share of input subsidies in public expenditures in agriculture increased from 44 percent in the early 1980s to 83 percent by 1990 (Rao 1994). During this period private investment in agriculture did not compensate for the decline in public investment. Because of the apparent high complementarity between public and private investment, and the adverse terms of trade for agriculture during the 1980s, private investment also declined through much of the 1980s before recovering modestly during the early 1990s (Rao and Gulati 1994).

The balance between input subsidies and long-term investments will be a crucial policy question as India proceeds with economic reform. Strong political forces still support subsidies for irrigation, electricity, and fertilizer, which could significantly slow the economic reform process and continue to divert funds from long-term agricultural investments with greater impacts on agricultural productivity.

Given the ongoing reform process, the concern over sources of future agricultural productivity growth, and the continuing debate over subsidies versus investments in agriculture, it is important to examine the contribution of agricultural research to agricultural productivity growth and the economic returns to agricultural research. Because of the long lags between agricultural research investments and the resulting increases in production, India's ability to meet her agricultural challenges of the next decade will depend critically on the investments that are made today.

At first glance, India seems to be well prepared for a continuation of its strong record in agricultural research. India now has one of the largest agricultural research systems in the world. Total expenditures on agricultural research by the central government, state governments, and private foundations and companies averaged Rs 2,360 million or US$189 million per year in 1983–87. The system employs about 21,300 scientists, approximately 12,300 of whom are full-time equivalent (FTE) scientists doing research. India has more FTE scientists conducting agricultural research in the public sector than the United States, although its expenditures on research and development are about one-tenth those of the U.S. government. India has more FTE scientists than any developing country except China. Its research expenditures are exceeded only by Brazil and possibly China (Pardey, Roseboom, and Anderson 1991). Nevertheless, India's investment in agricultural research, when measured as a proportion of the value of its agricultural sector, is lower than the averages for developing countries. In 1989/90, the central and state governments spent about 0.5 percent of the value of agricultural gross domestic product (GDP) on agricultural research. This figure was 0.7 percent for developing countries as a whole and 2–3 percent for developed countries.

The critical importance of effective agricultural research has been shown by Kumar and Rosegrant (1997) and Kumar, Rosegrant, and Hazell (1995), who examine the prospects for Indian cereal supply, demand, and trade using an econometrically estimated supply and demand model for India. On the supply side, production of each cereal crop is determined by crop and input prices and total factor productivity (TFP) growth, which in turn is driven by investment in research, extension, irrigation, and infrastructure. Two alternative scenarios are explored: (1) continued decline in productivity due to continued slowing in public investment; (2) sustained growth in productivity at the levels prevailing in the 1980s, through a recovery in public investment in agriculture.

Demand projections in the model are driven by growth in population, urbanization, income, and changes in income distribution. The projections assume income growth of 5 percent per year; gradual decline in population growth over the projections period; rates of urbanization consistent with the recent historically trend; and inequality in distribution of expenditures across income classes based on the 1987–88 distribution.

The scenario of continued deceleration in productivity from declining support to agriculture is cause for concern: the demand for cereals would exceed domestic production by 24 million metric tons by 2020, double the highest historical level of imports. Nearly two-thirds of these imports would be in coarse grains, due to relatively slow production growth and strong growth in the demand for livestock feed. If, instead, recent historical growth in productivity is maintained, India will be in a much stronger trade position. Exports of wheat and rice would more than offset the deficit in coarse grains, generating net cereal exports of nearly 16 million tons. These results emphasize the need for strengthening the efforts at increasing production by maintaining or increasing productivity through public investment in irrigation, infrastructure development, research, and efficient use of water and plant nutrients.

Is the research policy and investment environment in India capable of generating the necessary productivity growth to meet future demands on the agricultural sector? Much of the additional food demand in the next decades will need to be produced domestically, and the rate of TFP growth will be crucial to obtaining the necessary growth in cereal production to meet the growth demand. As will be shown below, growth in total productivity accounted for nearly one-half of total agricultural production growth between 1956 and 1987, and investments in agricultural research and extension accounted for nearly three-fourths of this TFP growth. It is therefore likely that the future rate of investment in agricultural research will have a fundamental influence on the rate of TFP and thereby on total production of cereals and other agricultural commodities.

This examination of the Indian experience with productivity growth in agriculture is made within this dynamic policy context. How much has productivity growth contributed to the growth of total output? What have been the sources of productivity growth? Are the returns to agricultural research in India still high? This study examines these questions by assessing how public investment in agricultural research, extension, and irrigation and private domestic and foreign research have affected the growth of TFP in the Indian crop sector.

CHAPTER 2

Investment in Productivity: The Research System, Technology Transfer, Extension, and Infrastructure

This chapter focuses on investment in activities that increase productivity in agriculture. It examines four sources of new technology—Indian government research, the international agricultural research centers (IARCs), imported technology, and private Indian research. It also examines several government programs that influence the speed with which technology is adopted—public extension, transport and communications infrastructure, and complementary agricultural inputs such as irrigation and fertilizers. The chapter summarizes data on the growth in these sources of technology and on factors that influence the diffusion of such technology. It also describes the institutions and policies that have influenced their growth.

Data on research inputs and outputs are used to assess the research done by public and private institutions and the IARCs. Imports of technology are more difficult to measure, but information on patents obtained by domestic and foreign firms can serve as a proxy for them.

Public-Sector Agricultural Research and International Centers

The Colonial Background

Government agricultural research in India started about a century ago.[2] Bombay United Provinces (now Uttar Pradesh) established experimental farms to improve crops in the 1880s and 1890s. Several other provinces also had experimental farms, but they were only temporary. Research on animal diseases started in 1890. The estab-

[2] For a detailed history of the Indian research system, see Randhawa (1979).

lishment of the Imperial Bacteriological Research Institute (IBRI) at Mukteswar in 1895 marks the beginning of agricultural research in India. Formal research to improve crop agriculture began with the establishment of the Imperial Agricultural Research Institute (IARI) in 1905 at Pusa, Bihar. In the same year, provincial departments of agriculture were established with the mandate of providing agricultural research, extension, and education in their provinces.

In the 1919 reforms of the government of British India, responsibility for agriculture was transferred to the provinces. Thus, the central government no longer had control over agricultural research, although it did retain control of IARI and IBRI. In response to the Report of the Royal Commission on Agriculture in 1927, the colonial government attempted to promote collaboration between provincial and central research institutes by establishing the Imperial Council of Agricultural Research (ICAR) in 1929. ICAR was charged with oversight of agricultural research throughout the subcontinent and establishment of a number of commodity committees. These committees were modeled after the Indian Central Cotton Committee, in which groups interested in cotton, from farmers to processors, were taxed to pay for research. In return, they had some say in the content of the research. By Independence, ICAR had helped organize committees for jute, sugarcane, coconuts, tobacco, and oilseeds.

Despite their limited budgets, the research institutions of British India had important successes. They developed improved varieties of most major crops. More than half of the jute and sugarcane crop area, and more than one quarter of the wheat and cotton crop area were planted with improved varieties (see Chapter 4). Research in the colonial period generated a rate of return of about 20 percent. This was much higher than the 3 percent interest rate at which the government was able to raise funds (Pray 1984).

Growth Since Independence

Long-term growth in government research expenditures in research and development and higher education has gone through three phases (Figure 1 and Table 1). Until 1968, growth was moderate. It was rapid from 1968 until 1980 and then slower in the 1980s. The number of research scientists followed a similar path.

Research expenditures by the IARCs of particular importance to India are also shown in Table 1. The International Rice Research Institute (IRRI) started in 1960, the International Maize and Wheat Improvement Center (CIMMYT) in 1966, and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in 1972. The last is located in Hyderabad, Andhra Pradesh. A large share of the research conducted in all three centers is aimed at regions other than India, but they all have had important effects on Indian agriculture (see Chapter 3).

The institutional structure of public agricultural research changed little from Independence until the mid-1960s. ICAR (now the Indian Council of Agricultural Research) was still, in principle, responsible for coordinating the research activities of the commodity committees, the state agricultural departments, and the 17 agricultural colleges, but the amount of coordination remained low. The Constitution of India gives the primary responsibility for agricultural research, extension, and education to the

Figure 1—Public expenditures on agricultural research and development and higher education by India and expenditures on research and development by IRRI, CIMMYT, and ICRISAT, 1960–94

Sources: The data for India are from Pal, Jha, and Singh 1997. The data for IRRI, CIMMYT, and ICRISAT are from the CGIAR Secretariat.

Notes: IRRI is the International Rice Research Institute. CIMMYT is the International Maize and Wheat Improvement Center. ICRISAT is the International Crops Research Institute for the Semi-Arid Tropics.

states but vests ultimate responsibility for agricultural development with the central government.

Three developments made the 1960s a watershed for Indian agricultural research. First, the state agricultural universities were organized with emphasis on teaching, research, and extension. Uttar Pradesh Agricultural University at Pantnagar opened in 1960. By the end of 1969, 12 such state agricultural universities were in operation. Almost all of them were successful in incorporating the research program of the state departments of agriculture, including their experiment stations, into their own departments. However, they were not successful in incorporating state extension services, These remain parts of the departments of agriculture.

Second, ICAR was reorganized in the mid-1960s. It was given the authority, manpower, and budget to supervise and coordinate the central research institutes and coordinated research projects. Most of the commodity research programs were integrated into it. The Accelerated Sorghum Improvement Scheme was inaugurated under the auspices of ICAR in 1961. It became the model used to coordinate researchers from state universities, ICAR institutes and, in some cases, the private sector. In the 1960s the number of these projects grew quickly to include all major crops. Since then, projects have been

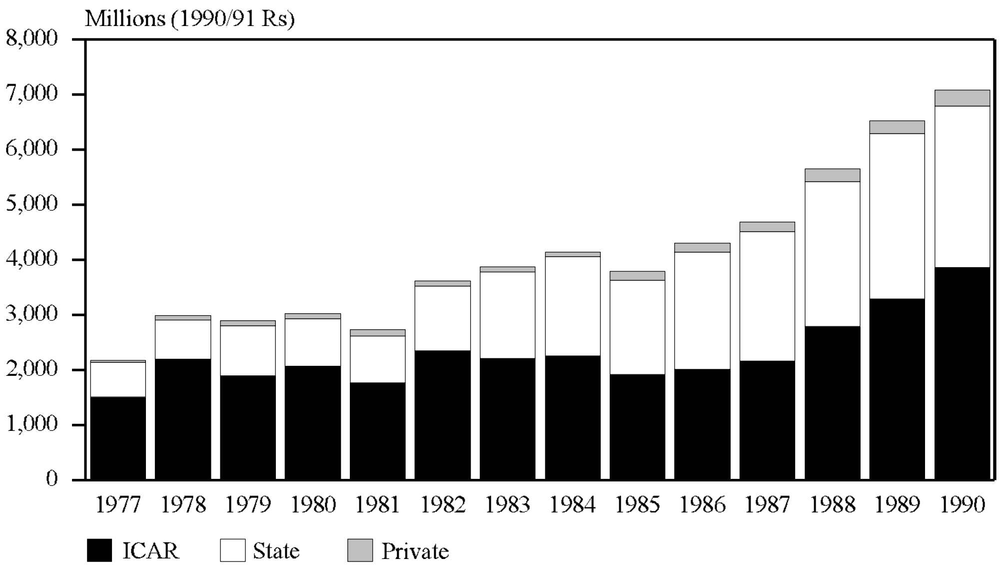
Table 1—Public expenditures on agricultural research and development and higher education by India and expenditures on research and development by IRRI, CIMMYT, and ICRISAT, 1960–94

Year	Indian public expenditures on research and development and higher education		IRRI, CIMMYT, and ICRISAT expenditures on research and development
	(1980 Rs)	(1980 US$)	(1980 US$)
1960	195.5	70.7	0.0
1961	219.9	79.6	0.5
1962	236.0	85.4	1.1
1963	258.7	93.6	2.4
1964	281.9	102.0	1.6
1965	313.2	113.3	2.5
1966	315.9	114.3	3.9
1967	262.3	94.9	5.7
1968	289.1	104.6	9.5
1969	439.3	158.9	11.9
1970	316.5	114.5	16.3
1971	316.2	114.4	18.9
1972	340.6	123.2	20.7
1973	292.9	106.0	26.0
1974	346.0	125.2	30.3
1975	436.9	158.0	37.4
1976	485.8	175.7	41.2
1977	560.3	202.7	48.4
1978	649.4	234.9	52.0
1979	597.5	216.1	53.4
1980	538.2	194.7	53.8
1981	559.1	202.2	53.4
1982	589.5	213.2	56.2
1983	642.8	232.5	54.5
1984	702.4	254.1	57.9
1985	759.9	274.9	62.0
1986	818.7	296.1	66.4
1987	818.7	296.1	74.2
1988	931.9	337.1	72.0
1989	1,047.8	379.0	70.2
1990	1,164.1	421.1	71.0
1991	1,106.8	400.4	66.7
1992	1,085.4	392.6	64.9
1993	1,154.5	417.6	61.4
1994	1,185.2	428.7	58.6

Sources: The data for India are from Pal, Jha, and Singh 1997. The data for IRRI, CIMMYT, and ICRISAT are from the CGIAR Secretariat.

Notes: IRRI is the International Rice Research Institute. CIMMYT is the International Maize and Wheat Improvement Center. ICRISAT is the International Crops Research Institute for the Semi-Arid Tropics.

Figure 2—Expenditures on agricultural research and development by type of institution, 1977–90



Source: India, Department of Science and Technology, research and development statistics.
Note: ICAR is the Indian Council of Agricultural Research.

developed for noncommodity issues such as integrated pest management. At present, ICAR has organized more than 70 all-India coordinated research projects.

The third development was the successful development and introduction of wheat and rice varieties during the early Green Revolution. These varieties, developed in the Philippines at IRRI and the University of the Philippines at Los Baños, and in Mexico at CIMMYT, showed policymakers that research could be a tool to increase food production. This in turn led to increased funding for public research in the late 1960s and the 1970s. The Green Revolution also legitimized the newly established IARCs and led to close links between the Indian research establishment and the international centers.

Since the mid-1970s, most of the growth in public research has been realized by the state governments. Figure 2 shows the trends in expenditures on research and development by type of institution between 1977 and 1990. The research expenditures of ICAR institutes did not grow between 1978 and 1987. They did grow rapidly thereafter.[3] Research expenditures by state agricultural universities tripled. Private research also almost tripled. Expenditures by ICRISAT (not included in the data for Figure 2)

[3] Although the trends in the data from the Department of Science and Technology seem to be accurate, the figures themselves are not. There was some double counting of government data, and private-sector data exclude important agricultural input suppliers, such as the pesticide industry.

grew rapidly until 1981, when its growth rate slowed in conjunction with a general slowdown in funding of the IARCs.

ICAR has added many research institutions and national centers in the past 15 years even though expenditures on research and development have grown slowly. The International Center for Genetic Engineering and Biotechnology (ICGEB), for example, was founded in 1988 and has grown rapidly since. It now has a budget of about US$5 million for research, of which about US$1 million is for plant biotechnology. In 1975, ICAR had 26 research institutes and 2 national bureaus. By 1990, it had 41 institutes, 4 national bureaus, and 20 national research centers. Table 2 shows the number of state agricultural universities in 1986/87 and total faculty in 1975/76 and 1986/87 in each state. As can be seen, research in state agricultural universities has grown both because new agricultural universities have been added and because existing universities have become bigger.

Recent breakthroughs in molecular biology have had an important effect on the structure and funding of agricultural research in India. The structure of agricultural research has changed in two ways. First, new institutions, such as ICGEB, with mandates to conduct research on plant and animal agriculture, have been established. Second,

Table 2—Number of faculty positions at state agricultural universities in India, 1975/76 and 1986/87

	Number of state agricultural universities		Total faculty	
State	1986/87	Year established	1975/76[a]	1986/87[b]
Andhra Pradesh	1	1964	372	1,155
Assam	1	1969	135	210
Bihar	2	1970, 1981	138	893
Gujarat	1	1972	151	1,036
Haryana	1	1970	187	1,292
Himachal Pradesh	2	1970	283	416
Jammu and Kashmir	1	1982	. . .	233
Karnataka	2	1964	395	1,112
Kerala	1	1972	140	531
Madhya Pradesh	2	1964	498	1,109
Maharashtra	4	1968, 1972	1,147	1,940
Orissa	1	1962	140	436
Punjab	1	1962	846	1,007
Rajasthan	1	1962	305	671
Tamil Nadu	1	1971	662	1,203
Uttar Pradesh	3	1960, 1975	483	1,344
West Bengal	1	1974	127	278
Total	26	. . .	6,009	14,766

Sources: The data for 1975/76 are from Indian Council of Agricultural Research 1978. The 1986/87 data are from the Indian Council of Agricultural Research 1989.

[a] These data include faculty members with MSc degrees and PhDs.

[b] These data include faculty members with a rank of assistant professor or greater.

research institutions that did little agricultural research have started programs in agricultural biotechnology. These institutions include general universities such as Madurai Kamaraj University in Madurai and Central University in Hyderabad, private foundations such as the Tata Energy Research Institute, and laboratories like the National Chemical Laboratory in Pune and the Region Research Laboratory in Hyderabad. Biotechnology research in turn has stimulated funding for basic plant and animal research.

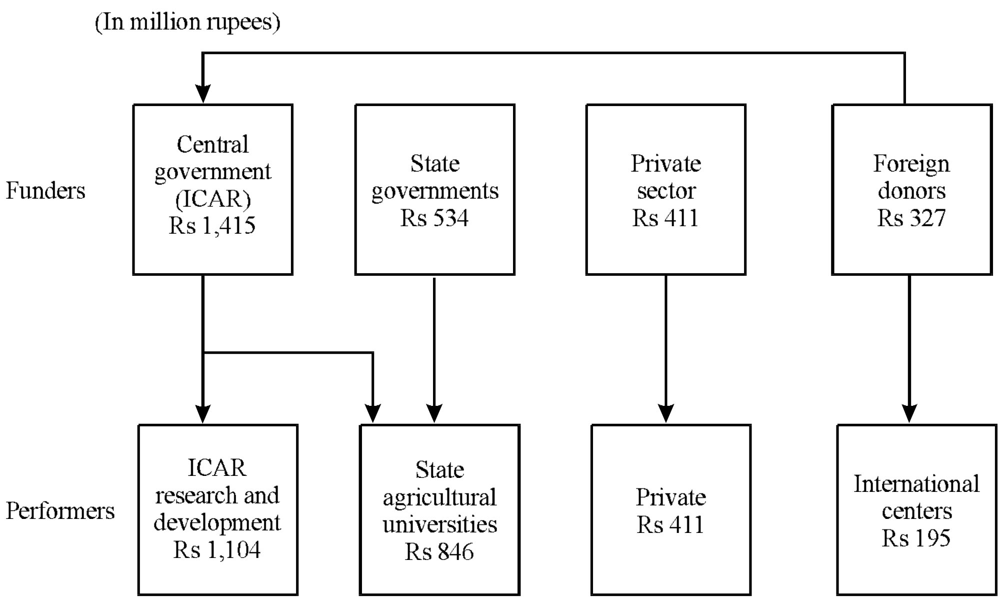
Most of the increase in funding has come from the government's Department of Biotechnology (DBT), which is part of the Ministry of Science and Technology. In 1991, the DBT distributed about US$30 million of research funds for medical and agricultural biotechnology. Some of the funds for agricultural research and development at universities, private foundations, laboratories, and ICAR have been shifted into biotechnology research. Private firms are funding in-house biotechnology research and establishing research foundations that are funded jointly by the industry and the DBT. Foreign donors are also financing biotechnology research in India. For example, the United Nations Industrial Development Organization (UNIDO) and the Italian government have provided money for ICGEB, the Rockefeller Foundation is funding biotechnology research on rice in Indian institutions, and the European Union funds the Tata Energy Research Institute.

Current Size and Structure of the Public Research System

Figure 3 shows the major funding and performing institutions in India and the flow of funds between them in the mid-1980s. Funding comes from four main sources: the central government provides about 50 percent; state governments, about 20 percent; private companies and cooperatives, 16 percent; and foreign donors provide the rest. All foreign resources, except those for international centers in India, go through the central government (this is shown by the arrow from foreign donors to ICAR in the figure). ICAR funds central institutes and channels funds to state agricultural universities, primarily through all-India coordinated research projects. In addition to ICAR, financing for agricultural research also comes from central government departments such as the Ministry of Commerce, which includes the Silk Board, the Coffee Board, the Rubber Board, and the Tea Board, and the Ministry of Science and Technology, which includes the Department of Biotechnology. These departments financed a small amount of research in the mid-1980s.

ICAR institutes conduct about 43 percent of the research done in India; the state agricultural universities, about 33 percent; the private sector, about 16 percent; and international centers, about 8 percent (Figure 3). In addition to the funds received by state governments, the state agricultural universities receive more than Rs 300 million from ICAR annually. Other government organizations also conduct agricultural research. They include general universities, the Indian Institute of Technology at Kharagpur, the Indian Institute of Management at Ahmedabad, and the research institutes of the silk, tea, coffee, and rubber boards. About 16 percent of Indian agricultural research is in-house research of private companies and private, nonprofit foundations. (ICGEB did not start until 1988, so its expenditures are not included in Figure 3).

Figure 3—Major funders and performers of agricultural research and development, 1985/86



Sources: Computer printouts from the Indian Council of Agricultural Research; data on the private sector from the Indian Department of Science and Technology; and budget data from the Indian Council of Agricultural Research.

The regional distribution of research resources includes expenditures by ICAR institutes and by the state agricultural universities in each region (Table 3). The northern region has the most resources, as measured by actual resources and as a percentage of agricultural GDP. The southern region is second. The central region replaced the western zone as third in the Seventh Five-Year Plan. The amount of expenditures in the northern zone reflects both the location of central research in Delhi and Haryana and strong state support for research in this region. In contrast, neither state governments nor the central government provide much support for research in the eastern zone.

The only evidence available on the allocation of research resources by commodity over time is from data on the number of publications by Indian scientists. Table 4 shows the number of publications by Indian research institutions classified by commodity. The numbers indicate that the major foodgrains have received the highest attention from Indian scientists since the 1940s. The one major change is for cotton. This was the second most important commodity in the early 1950s, but it received less attention in the late 1960s. The other noticeable pattern is that livestock has gained in importance, even though during the last period there were fewer publications on livestock than on the major grains.

Table 5 shows the allocation of expenditures by ICAR and the all-India commodity research programs (AICRPs) in the 1980s by crop. These expenditures include

Table 3—Average real annual research and development expenditures by region, 1980–85 and 1985–90

Region/state	Sixth Plan (1980–85) Expenditures	Sixth Plan (1980–85) Share of agricultural GDP	Seventh Plan (1985–90) Expenditures	Seventh Plan (1985–90) Share of agricultural GDP
	(million Rs)	(percent)	(million Rs)	(percent)
Central zone	208.5	0.193	372.0	0.260
Uttar Pradesh	165.7	0.226	284.2	0.296
Madhya Pradesh	42.8	0.124	87.8	0.186
Eastern zone	168.2	0.145	253.4	0.148
Assam	45.3	0.284	62.3	0.301
Bihar	48.1	0.125	73.5	0.121
Bengal	42.5	0.109	57.4	0.098
Orissa	32.4	0.145	60.2	0.192
Northern zone	346.6	0.654	543.6	0.708
Haryana	108.3	0.602	180.9	0.731
Himachal Pradesh	36.8	1.134	46.3	0.998
Jammu and Kashmir	6.3	0.133	15.5	0.223
Punjab	50.6	0.198	71.9	0.191
New Delhi	144.7	9.751	229.0	8.083
Southern zone	334.2	0.334	450.2	0.354
Kerala	100.2	0.604	122.8	0.568
Andhra Pradesh	100.0	0.246	135.9	0.283
Tamil Nadu	65.3	0.421	91.4	0.407
Karnataka	68.7	0.251	100.1	0.285
Western zone	288.7	0.279	330.5	0.291
Gujarat	72.4	0.248	116.2	0.448
Maharashtra	155.5	0.349	114.4	0.218
Rajasthan	60.7	0.204	99.9	0.286

Source: Indian Council of Agricultural Research 1989.

only those made by states to match ICAR funding for commodity programs. Thus, they miss most of the state funding for research. Nevertheless, these are the only published data on expenditures broken down by commodity. Cash crops and horticulture account for a larger share of research expenditures than foodgrains. The research intensity for these crops is also higher than for foodgrains, which suggests that greater emphasis has been placed on cash crops and horticulture.

Technology Imports and Private Sector Research

Technology imports and private research are closely related. They can sometimes be substitutes. If inexpensive and effective fertilizers are available on the world market, for example, there is no need to reinvent them with local research. Imported technology usually stimulates local research, however. For example, imported fertilizers require adaptive research to find out how they can be used most effectively, importers

Table 4—Average number of publications from Indian research institutes, 1948–54 to 1984–88

Period	Major food-grains	Pulses	Oil-seeds	Cotton	Potato	Tomato	Sugarcane and beets	Beverages and tobacco	Dairy	Basic plant and animal[a]
1948–54	67	10	n.a.	51	11	2	36	7	49	116
1955–61	93	19	n.a.	56	9	4	35	12	64	234
1962–68	160	27	n.a.	62	22	7	37	19	88	482
1969–73	283	45	n.a.	30	12	11	22	14	134	727
1974–78	369	59	11	28	2	1	16	11	260	1,373
1979–83	312	88	11	28	0	2	16	11	220	2,001
1984–88	355	181	17	38	7	9	18	13	282	2,223

Sources: For 1948–73, Boyce and Evenson 1975. For 1974–88, data were compiled from an on-line computer search by the authors of Commonwealth Agricultural Bureau Plant Breeding Abstracts and Biological Abstracts.

Note: Where n.a. appears, data were not available.

[a] Plant pathology, plant physiology, soil science, animal biology.

may commission research to see if the fertilizer can be produced locally, and producers may develop ideas about how to develop new kinds of fertilizer.

Government policies have been important in determining the mix of imports and local private research in India. This mix was originally influenced by the appropriateness of foreign technology and by India's capacity for research during the colonial period and the first decades of independence. Later, however, policy became the major determinant. This section first reviews the patterns for agricultural technology imports and private research and then examines the policies that influenced these patterns.

Trends in Imports and Private Research

During the colonial period, the British government attempted to transfer technology from different parts of the world to India through a system of botanical gardens and later through the Department of Agriculture. There were a few successes in tea, coffee, and groundnut varieties. Yet most of the plant varieties and machinery tested were not well-adapted to Indian conditions.

Private-sector research consisted primarily of research on crop management and processing technology. The plantation industry worked on pest problems and crop management in tea and coffee production. The processing industry conducted research to adapt American tobacco varieties to Indian conditions and to improve the technology of processing cotton and producing and processing jute. Some experiments were also carried out by fertilizer firms on the economics of chemical fertilizer use. Overall, private research continued to be limited until Independence.

Since then, Indian firms in most agricultural input industries have progressed from importing inputs to conducting research on them. Imports have been more important in

Table 5—Real expenditures on research and development (R&D) by crop, 1980–85 and 1985–90

Crop	1980–85			1985–90		
	Average annual expenditure	Share of total crop R&D	R&D as a share of the value of the crop	Average annual expenditure	Share of total crop R&D	R&D as a share of the value of the crop
	(million Rs)	(percent)		(million Rs)	(percent)	
Foodgrains	65	21	0.028	107	21	0.037
Rice	32	10	0.026	50	10	0.031
Wheat	12	4	0.018	19	4	0.023
Barley	4	1	0.146	6	1	0.080
Maize	8	2	0.071	6	1	0.236
Millets	6	2	0.071	6	1	0.236
Minor millets	n.a.	n.a.	n.a.	4	1	0.070
Sorghum	5	2	0.027	8	2	0.048
Pulses	20	6	0.053	44	9	0.093
Oilseeds	24	8	0.043	45	9	0.068
Forage crops	13	4	n.a.	24	5	0.037
Cash crops	109	35	0.122	167	33	0.153
Sugarcane	20	6	0.052	32	6	0.065
Sugarbeet	n.a.	n.a.	n.a.	n.a.	1	1.376
Cotton	27	9	0.139	41	8	0.210
Jute	17	6	0.488	29	6	0.735
Tobacco	18	6	0.379	23	5	0.129
Plantation crops	27	9	0.119	41	8	0.458
Horticulture	79	25	0.120	116	23	0.113
Fruits and vegetables	49	16	n.a.	70	14	n.a.
Tubers	6	2	n.a.	10	2	n.a.
Potatoes	19	6	n.a.	29	6	n.a.
Floriculture	4	1	n.a.	6	1	n.a.
Mushrooms	1	0	n.a.	2	0	n.a..
Crop total	310	100	0.062	504	100	0.074

Source: Indian Council of Agricultural Research; India, Ministry of Agriculture, various years.

Notes: Data are for expenditures by the Indian Council of Agricultural Research (ICAR) and the all-India commodity research programs (AICRPs), which can be disaggregated by commodity because most institutes and AICRPs do research on only one or a few crops. Funds from international agricultural research institutes were allocated by the number of scientists working on each crop. Disaggregated data on R&D expenditures by state agricultural universities are not available. States should provide 25 percent of the funds going to AICRPs; ICAR should provide 75 percent. AICRP expenditures by ICAR were increased to one-third to account for state contributions. This still omits most of the state funds. Where n.a. appears, data were not available.

the fertilizer, pesticide, and agricultural machinery industries, and less important in the seed industry because of agroclimatic differences between India and the West. Table 6 shows imports and local production of tractors and fertilizers. Before 1960 almost all tractors were imported. In 1961/62, 880 tractors were produced, but during the 1960s 2,400 tractors were imported each year, on average. In 1973 all imports of tractors were

Table 6—Imports and local production of tractors and fertilizer, 1961–90

Year	Tractors		Fertilizer	
	Imports	Production	Imports	Production
			(1,000 million tons of N, P_2O_5, and K_2O)	
1961	2,997	880	179	220
1962	2,616	1,414	302	282
1963	2,349	1,983	269	327
1964	2,323	4,323	339	374
1965	1,989	5,714	498	357
1966	2,591	8,816	845	455
1967	4,038	11,394	1,490	610
1968	2,508	15,437	1,078	776
1969	304	18,120	762	955
1970	12,032	20,009	633	1,061
1971	9,917	18,100	970	1,239
1972	3,077	20,802	1,218	1,385
1973	574	24,425	1,256	1,374
1974	652	31,088	1,608	1,518
1975	2	33,146	1,051	2,340
1977	37	34,729	1,485	2,670
1978	2	53,046	1,993	2,951
1979	101	60,142	2,005	2,983
1980	5	67,627	2,759	3,005
1981	0	84,320	2,042	4,093
1982	0	66,000	1,132	4,413
1983	0	75,920	1,355	4,556
1984	0	84,967	3,625	5,235
1985	0	75,591	3,314	5,753
1986	0	80,476	2,275	7,074
1987	n.a.	n.a.	984	7,132
1988	n.a.	n.a.	1,615	8,965
1989	n.a.	n.a.	3,113	8,543
1990	n.a.	n.a.	2,754	9,044

Sources: The data on tractors for 1961–76 are from Binswanger 1978; for 1977–83, from India, Ministry of Science and Technology, Department of Scientific and Industrial Research 1985; and for 1983–86, from India, Ministry of Industry, Directorate General of Technical Development 1988. The data on fertilizer are from the Fertilizer Association of India 1992.

Notes: Where n.a. appears, the data were not available.

banned (Binswanger 1978). Imports of engines and pumps for irrigation went through a similar cycle. Imports were important until a capacity for producing them locally was established, then imports were severely restricted.

Local fertilizer production and imports grew at about the same speed until 1980, when local production increased rapidly while imports remained constant. All of the potassium fertilizer, 25 percent of the nitrogen fertilizer, and 40 percent of the phosphorus fertilizer were imported in the mid-1980s. Pesticide imports and production followed a similar pattern. At first, finished pesticides were imported. Then, India developed the ability to formulate the final product using active ingredients imported from abroad and to produce active ingredients of some of the older insecticides. Nowadays, India produces the active ingredients of a number of pesticides and formulates most of the rest. Only active ingredients and finished pesticides of the most recent pesticide versions are now imported.

Private research developed in response to trends in imports and local manufacture. Multinational and local tractor firms conducted trials of different models beginning in the 1950s. As they started manufacturing, most firms had to do applied research to work out problems in the production process. Most firms also established applied research and development programs to adapt tractors to local conditions. Agricultural chemical firms started by testing different types of fertilizers and pesticides for their effectiveness under Indian conditions. Fertilizer firms also tested fertilizers in different soils, climates, and crops around the country. Most pesticide research continues to consist of the testing of new pesticides that were developed outside India for efficacy against pests and for health and environmental effects to meet regulatory requirements. Union Carbide established a program to develop new active ingredients, but closed it down after the Bhopal disaster. A few Indian firms conduct research to develop new processes for producing popular pesticides.

Data on research expenditures by private and government-owned firms in the pesticide, fertilizer, agricultural machinery, and seed industries are shown in Table 7. The data on fertilizer and agricultural machinery are the research expenditures of firms that have research and development registered with the Department of Science and Technology. Research on agricultural machinery is conducted primarily by private firms. It grew rapidly between 1970 and 1984 and then leveled off. Public firms conduct most fertilizer research They also produce most of the fertilizers. The expenditures on research and development for fertilizers grew rapidly in both the public and private sectors until 1989.

The data on research and development for seeds are based on interviews with private seed firms (Ribeiro 1989). Public seed corporations do not spend money on plant

Table 7—Research and development expenditures by public and private input firms, annual averages for 1970–74 to 1985–89

	Pesticides		Fertilizer		Agricultural machinery		Seeds
Period	Private	Public	Private	Public	Private	Public	Private
				(million 1980 Rs)			
1970–74	n.a.	n.a.	2.9	n.a.	5.2	0.0	1.3
1975–79	n.a.	n.a.	5.4	32.4	20.6	1.2	3.1
1980–84	97.0	6.0	13.1	52.7	41.7	6.2	7.6
1985–89	123.0	6.0	17.4	95.3	45.9	13.4	16.6

Sources: The data for pesticides, fertilizers, and agricultural machinery are from India, Ministry of Science and Technology, Department of Scientific and Industrial Research 1988. The data on seeds are from Ribeiro 1989.

Note: Public input firms are firms owned by the government but managed as private firms. Where n.a. appears, the data were not available.

breeding because they depend on plant breeding by ICAR and the state agricultural universities. Private research and development grew rapidly through 1987, the last year in the data series. Hindustan Lever Ltd. and Cargill entered the seed industry in that same year. They have been followed by most of the large Indian and foreign companies like ITC, Sandoz, Hoechst, and Ciba-Geigy. Thus, research and development in seeds has grown even more rapidly since 1987. Private firms concentrated their research efforts on crops for which hybrids are important. Table 8 shows the distribution of private plant breeding by crop in 1987. The first five crops in the table plus vegetables, which are of interest to the private sector, are all hybrids. Now that it is becoming possible to produce hybrid rice commercially, several firms have added hybrid rice research programs.

Patents provide another measure of private research and development output and technology transfer. Table 9 shows the number of patents for agricultural machinery and agricultural chemicals and the percentage of patents issued to Indian firms or individuals. Patenting in all three categories grew during the 1970s, but fell in the 1980s. More than half of the patents are for pesticides, and most of them represent a transfer of technology from foreign firms. The percentage of pesticide patents granted to Indian firms grew steadily throughout this period. However, the percentage of patents by Indian firms is much higher in machinery and fertilizers than in pesticides.

Indian Science and Technology Policy

The pattern of private research and development and technology transfer is partially the result of government policy. India has gone through two major phases in its

Table 8—Private research and development expenditures by public and private input firms, 1987

Crop	Number of companies with research and development expenditures on crops	Research and development expenditures by crop
		(million Rs)
Pearl millet	12	3.7
Sorghum	10	3.4
Sunflower	10	3.5
Cotton	9	2.1
Corn	6	2.1
Vegetables	5	0.9
Fodder	2	1.0
Pigeon pea	2	1.0
Safflower	2	0.7
Mustard	1	0.4
Sesame	1	0.7
Total	. . .	19.5

Source: Pray, Ribeiro, Mueller, and Rao 1991.

Table 9—Annual average patenting by agricultural input firms, 1972–75 to 1984–87

	Agricultural machines		Pesticides		Fertilizers		Total	
Period	Number	Share Indian	Number	Share Indian	Number	Share Indian	Number	Share Indian
		(percent)		(percent)		(percent)		(percent)
1972–75	2.75	55	16.75	9	3.75	33	28.75	15
1976–79	6.50	77	23.00	12	7.75	52	40.75	33
1980–83	5.00	60	23.50	15	7.75	52	40.00	29
1984–87	3.75	47	9.50	32	2.50	60	17.50	39

Source: Indian Patent Office data compiled by Fikkert (1994).

approach to technology policy. It appears to be moving into a third phase in the 1990s. In the early years after Independence, Nehru articulated India's technology policy as follows (Nayar 1983):

> Although a self-reliant industrial system must be India's long-term objective, the short-term objectives have to be somewhat different. . . . Accordingly, India must rely on a liberal import of technology and, given the wide scope of industrialization necessary, do so on a broad front. Where feasible, India should go in for the licensing of such technology but, where necessary, foreign investment may be allowed, especially given the shortage of foreign exchange resources.

The government adopted a strong import substitution policy for goods, but a liberal policy for the importation of technology. Nayar (1983) argues that this set of ideas, along with the obvious weakness of technology in Indian industry at Independence and in the 1950s, led entrepreneurs and the government to favor imported technology over indigenous technology.

The growth of indigenous technological capacity and the shift of public opinion against foreign investment and technology led to a drastic policy change in the late 1960s and early 1970s. The new policy placed many more restrictions on the importation of foreign technology and foreign investment:

> The year 1973, when the Foreign Exchange Regulation Act (FERA) was passed and a comprehensive Industrial Licensing Policy was issued, marks the divide both symbolically and substantially between the earlier relatively permissive orientation and the subsequent more restrictive one in respect of technology import and foreign investment (Nayar 1983, Vol II, 244).

The new policy principles, in effect since 1970, were explicitly stated in the 1983 Technology Policy Statement of the Government of India:

> In a country of India's size and endowments, self-reliance is inescapable and must be the very heart of technological development. . . .

The basic principles governing the acquisition of technology will be:

> (a) Import of technology, and foreign investment in this regard, will continue to be permitted only on a selective basis where: need has been established, technology does not exist within the country, the time taken to generate the technology would delay the achievement of development targets. . . .
>
> the onus will be on the seeker of foreign technology, be it industry or a user Ministry, to demonstrate to the satisfaction of the approval authority that import is necessary (India 1983).

At the same time, the government sought to encourage development of local technology by investing in research and development by government organizations and providing incentives for research and development by public and private firms. The effect of this policy on public agricultural research was described above. Firms owned by government institutions were given targets for expenditures on research and development. Private firms were offered tax incentives if their research programs were certified by the government.

Technology transfer and private research were both constrained by restrictions on large and foreign-owned firms. In 1969, Indian firms that had more than Rs 1 billion in assets were restricted to "core" industries.[4] In 1973, the same restriction was placed on firms with more than 40 percent foreign equity.[5] The seed and agricultural equipment industries were not classified as core industries. However, large tractor manufacturers were forbidden to sell implements.

Private research and development on agriculture may have been discouraged further by a change in the patent act in 1972 that eliminated product patents on chemicals, pharmaceuticals, and any products related to food and agriculture. At Independence, India chose to continue the patent system it inherited from the British. The new patent law was passed in an attempt to prevent foreign firms from restricting the flow of technology into India. The law explicitly forbids patenting of

> . . . a method of agriculture or horticulture, . . . any process for the medicinal, surgical, curative, prophylactic, or other treatment of human beings or any process for the similar treatment of animals or plants to render them free of disease or to increase their economic value or that of their products; . . . or any substance intended for use, or capable of being used as food or medicine or drug [Indian Patent Law, Article 3(h), (i); Article 5(a)].

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[4] Such companies fall under the Monopolies and Restrictive Trade Practices Act of 1969 (MRTP Act). They are sometimes referred to as MRTP companies.

[5] These companies fall under the Foreign Exchange Regulation Act (FERA) 1973. They are known as FERA companies.

Processes for producing pesticides and pharmaceuticals, but not the products themselves, can be patented for five to seven years.

These industrial licensing policies discouraged research because under them the inventor might not be allowed to commercialize the product. In the words of the former head of Hindustan Lever Ltd., which has one of the largest private research laboratories in India (Thomas 1981:203):

> . . . there is no incentive for Indian companies to do basic R&D [research and development]. Even when an Indian private sector company evolves a process or a product through its own R&D, there is no assurance that the company can get an industrial license or clearance under various other enactments such as the Monopolies and Restrictive Trade Practices Act, to take up a manufacturing venture based on R&D.

The policies of liberalization that started July 1, 1991, appear to be a dramatic rejection of the policies of the past that were designed to foster self-reliance in technology.[6] First, industrialists can now purchase whatever technology they wish without obtaining the approval of the Industries Ministry. There may still be some problems acquiring foreign exchange and firms still may have to pay high duties on imports, though even these have been reduced. Second, the amount of red tape needed to approve foreign collaboration agreements has been drastically cut. These agreements used to require approval from at least 15 departments. This system was replaced in September 1991 by one that simply requires the approval of the Reserve Bank of India. Third, movements toward full convertibility of the rupee will make India more attractive to foreign investors. The 1972 patent law, however, remains unchanged, and commercial imports of agricultural machinery, seeds, and formulated pesticides are still effectively banned.

Community Development, the Intensive Agricultural District Program, and Extension

During the 1950s and early 1960s, extension and rural development were emphasized over technology and research. This emphasis arose in part from a conviction that the agricultural research conducted in the several decades before Independence had developed the technical solutions to low agricultural output, so that all that remained was to change farmers' attitudes and persuade them to adopt those solutions.

In the early 1950s, state Departments of Agriculture had responsibility for research, extension, and the provision of farm inputs. Researchers in these departments acted as specialists to an extension system that consisted of an agricultural officer and agricultural assistant in the district, with a subinspector and one or two field men in the *tehsil* or *taluka.*

With the advent of the Community Development Program in the mid-1950s, a National Extension Service was established. Extension activities were vested primar-

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[6] This description is based on "A Year of Reforms" in *Business India,* July 6–19, 1992, pp. 52–60.

ily in village-level workers. They were expected to possess many skills and were responsible not only for agriculture but also for public health, home economics, and, to some extent, literacy, social reform, and small-scale village industry. The Community Development Program expanded to cover nearly all the nation's half-million villages. The Panchayati Raj program was also introduced in an effort to reform local governance and to engage as much of the rural population as possible in self-motivated development activity.

A severe crop failure in 1957/58 (and another but less severe drop in production in 1959/60) cast doubt on the emphasis placed on community development. In response, the Indian government decided to concentrate extension and input supply in a few high-potential areas, where farmers were to be induced to adopt a package program using improved seeds, improved farming practices, and several complementary inputs. This package program, called the Intensive Agricultural District Program (IADP), began in 1960/61. In the following five years, IADP expanded to cover another 100 districts under the renamed Intensive Agricultural Areas Program (IAAP).

In 1965, the Government of India established a national program to demonstrate technology on farmers' fields and to bring scientists into direct contact with farmers. These demonstrations were successful in disseminating to farmers the new varieties developed through the Green Revolution.

In the early 1970s, a number of special efforts focused on particular rural problems and contained formal extension components. The most prominent of these efforts were the Drought Prone Areas Program, the Small Farmers Development Agencies, the Hill Areas Development Program, the Command Area Development Program, and the Voluntary Action Schemes.

In 1977, India adopted a new paradigm for extension. With encouragement and financial support from the World Bank, India began to use the training and visitation (T&V) model of extension. This model employed workers whose only responsibility was to provide agricultural extension services. In 1987, in 17 major states, more than 95,000 workers took part in this effort. Table 10 shows the allocation by state of Village Extension Workers (VEWs), the people directly in contact with farmers. It also shows the number of VEWs per 1,000 farms in 1980. As expected, the northern region had the highest VEW density.The high intensity of VEWs in Orissa, however, is a surprise.

ICAR research institutions and the state agricultural universities engage in extension activities as well, partly to disseminate their discoveries, partly to test and verify those discoveries in a variety of local conditions, and partly to obtain information from farmers that might help researchers improve the relevance and focus of their efforts. ICAR sponsors 48 national demonstrations, 152 operational research projects, 89 Krishi Vigyan Kendras, or farm science centers, and 107 "Lab-to-Land" centers.

Infrastructure

Infrastructure includes investments in physical structures that allow farmers access to inputs such as water, fertilizers, and electricity. It also includes structures that enable farmers to respond more efficiently to price signals or help to transmit those price sig-

Table 10—Extension workers by state, mid-1980s

Region/state	Village extension workers	Village extension workers per 1,000 farms, 1980
Central zone	24,349	1.00
Madhya Pradesh	5,614	0.88
Uttar Pradesh	18,735	1.05
Eastern zone	14,289	0.63
Assam	2,444	1.06
Bengal	1,923	0.33
Bihar	3,455	0.31
Orissa	6,467	1.94
Northern zone	5,140	2.51
Haryana	1,457	1.44
Jammu and Kashmir	983	0.95
Punjab	2,700	2.65
Southern zone	12,856	0.56
Andhra Pradesh	3,905	0.53
Karnataka	3,129	0.73
Kerala	1,790	0.43
Tamil Nadu	4,032	0.56
Western zone	13,286	0.93
Gujarat	3,318	1.13
Maharashtra	5,614	0.82
Rajasthan	4,354	0.97

Source: World Bank 1988.

nals. It includes the government irrigation systems, rural electrification, roads and railroads, and government investments in regulated markets These investments consist of physical improvements of markets, the provision of price information, and regulation of trading practices.

Not enough consistent data on the number of rupees invested in the creation and maintenance of infrastructure in all states is available to construct a long-term time series. Instead, the infrastructure data available measures the existing stocks or the flows of services (in the case of irrigation). Table 11 shows the growth in some of the key infrastructure variables. Railroads are not included because India's present railroad system was essentially in place by the 1950s, and there was little growth afterward. The major increase in transportation infrastructure has been in roads. The mileage paved with a hard surface almost doubled between 1970 and 1988, and unsurfaced roads more than doubled. Only 3,000 villages were electrified in 1951. That number increased to 111,000 by 1971. By 1989, 454,000 villages—78 percent of all villages—were electrified.

The British had also made major investments in canal irrigation, so that the growth of irrigation after Independence was less dramatic than the growth of roads or

Table 11—Growth of selected infrastructure, 1951–89

Year	Roads		Villages[a] electrified	Irrigation		Markets
	Surfaced	Unsurfaced		Canals	Tanks	
	(thousand kilometers)		(thousands)	(million hectares)		
1951	n.a.	n.a.	3	8.3	3.6	n.a.
1961	n.a.	n.a.	22	10.4	4.6	n.a.
1968	n.a.	n.a.	n.a.	n.a.	n.a.	1,430
1971	338	376	111	12.8	4.1	2,754
1976	460	525	n.a.	n.a.	n.a.	3,631
1979	519	643	n.a.	n.a.	n.a.	n.a.
1981	n.a.	n.a.	267	15.3	3.2	n.a.
1982	541	639	n.a.	n.a.	n.a.	n.a.
1984	n.a.	n.a.	342	n.a.	n.a.	n.a.
1985	n.a.	n.a.	n.a.	15.9	3.3	5,695
1988	717	1,049	n.a.	n.a.	n.a.	n.a.
1989	n.a.	n.a.	454	n.a.	n.a.	n.a.

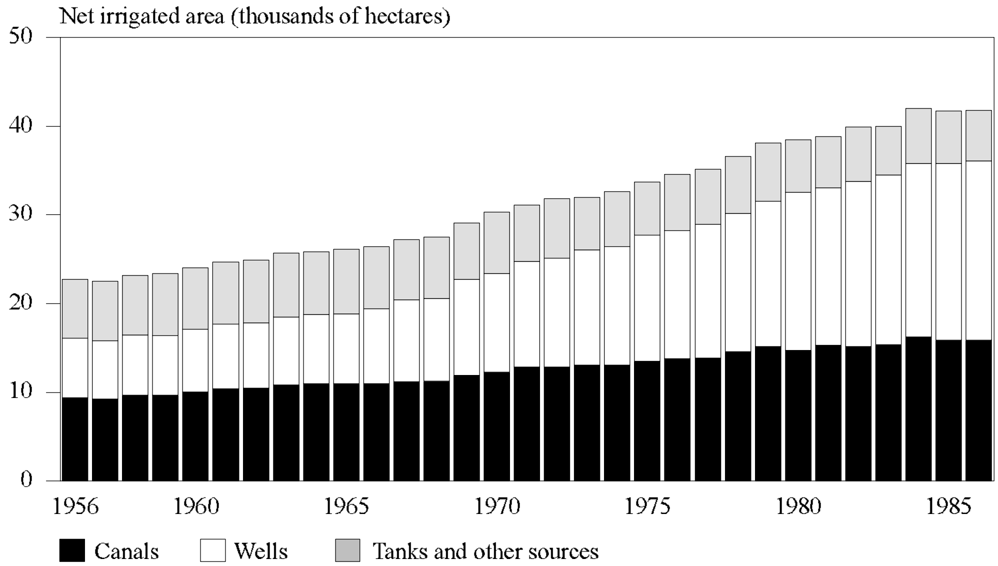
Sources: India, Ministry of Agriculture various years; India, Central Statistical Organisation 1982; India, Central Statistical Organisation 1986; and India, Central Statistical Organisation, 1990.

Note: Where n.a. appears, data were not available.

[a] Communities with populations under 5,000.

electricity. The Indian government made large additions to the canal systems between 1951 and 1981. Since then, the growth rate has slowed. The area irrigated by tanks, which are maintained through a combination of public and private funds, has actually declined since 1961. However, private investment in tubewell irrigation contributed to continuous growth in the total area irrigated. As Figure 4 shows, the share of tubewells in net irrigated area increased from less than one-third in 1956 to nearly one-half in 1986. Finally, the number of government-regulated markets and submarkets has grown steadily since Independence.

Figure 4—Net irrigated area by source, 1956–86



Sources: India, Ministry of Agriculture various years; India, Central Statistical Organisation 1982; India, Central Statistical Organisation 1986; India, Central Statistical Organisation 1990.

CHAPTER 3

The Development and Spread of Modern Crop Varieties

New plant varieties and the area they cover have been the primary measure of success for Indian public agricultural research and the IARCs. This chapter examines the development and spread of improved varieties in order to answer several questions: What has the Indian public sector contributed to the Green Revolution? Is it still contributing anything to Indian agriculture? Chapters 4 and 5 provide further answers to these questions by examining the effects on crop productivity of research and other investments.

As national programs have grown and varieties with local names have replaced the varieties developed during the early Green Revolution, questions have been raised about the amount of money invested in IARCs. Are IARCs still contributing to agricultural growth in poor countries like India? Should they continue to be funded at their current level? The sections on wheat and rice in this chapter trace the genealogy of successful, commercial varieties. They describe and measure the indirect effects of IARC research on Indian plant-breeding programs through the incorporation into widely used Indian varieties of IARC germplasm or varieties from other countries by the system of international trials that is organized and partially financed by the IARCs.

Many government scientists and bureaucrats say that private research has not contributed to agricultural productivity in India, implying that the private sector is not likely to contribute much in the future. The final section on coarse grains shows, however, that private research has developed new varieties and that these varieties now cover large areas of India. This section also shows that private plant-breeding research depends on the Indian public sector and ICRISAT research, supporting the argument that private research complements public research.

Modern Varieties: History and Overview

By the beginning of World War II, Indian breeders had made significant advances in the varieties of four crops: wheat, cotton, jute, and sugarcane. The first locally improved varieties of cotton, sugarcane, and wheat and other crops were introduced before 1920 (Table 12). The use of locally improved varieties grew rapidly so that by the late 1930s they covered about a quarter of the land planted with wheat, two-thirds of the area planted with jute, and three-quarters of the land under sugarcane. Also by the late 1930s, about one-third of the area planted with cotton was sown with improved varieties bred locally to provide longer-staple fibers for India's extensive textile industry. Improved varieties of most other major crops had also been introduced by the 1930s, but did not spread as widely. Improved rice varieties covered about 5 percent of sown area, sorghum (*jowar*) less than 1 percent, and groundnuts about 3 percent.

Plant breeding has been one of the major activities of ICAR and the state agricultural universities. These institutes developed new varieties of virtually all important crops. Table 13 shows the number of varieties released for different groups of crops. The major grains (wheat, rice, maize, sorghum, and pearl millet) had the largest number of varieties, but there were also large numbers of varieties of oilseeds, pulses, and cotton.

Improved varieties had their greatest effect on the productivity of the major cereal grains. Modern, fertilizer-responsive varieties of wheat and rice were the basis of the Green Revolution in India. Data on the spread of modern varieties is regularly collected for five major grain crops. Estimates of the share of area planted with modern varieties of these crops are presented in Table 14 and Figure 5.

In 1992/93, about 70 percent of the area planted with rice, 90 percent of the area planted with wheat, and 50 percent of the area planted with coarse grains were covered by modern varieties. Modern varieties of grain have spread to almost all areas of India with irrigation or assured rainfall and no flooding. The area under modern varieties of major grain crops is growing steadily (Figure 6) and by now exceeds irrigated area significantly. The growth rate of area under modern varieties of wheat slowed in the late

Table 12—Improved crop varieties sown before Independence, 1920/21 and 1937/38

	1920/21		1937/38	
Crop	**Area sown of crop**	**Share of total area sown**	**Area sown of crop**	**Share of total area sown**
	(thousand hectares)	(percent)	(thousand hectares)	(percent)
Rice	53	0.2	1,497	5.3
Wheat	731	8.9	2,766	25.8
Sorghum	18	0.2	74	0.9
Groundnuts	3	0.5	85	3.3
Sugarcane	2	0.2	1,143	76.3
Jute	23	2.3	720	62.5
Cotton	399	7.2	2,147	34.5
Foodgrains	801	1.4	4,491	7.0
Nonfoodgrains	428	3.3	4,094	24.0

Sources: Imperial Council of Agricultural Research 1921 and Imperial Council of Agricultural Research 1938.

Table 13—Crop varieties released by the Central Seed Committee, 1970–74 to 1985–89

Period	Major grains	Pulses	Oilseeds	Cotton	Potatoes	Tomatoes	Total
1970–74	47	16	10	14	6	6	99
1975–79	181	42	63	23	1	8	318
1980–84	151	117	67	38	5	5	383
1985–89	194	66	76	25	0	6	367

Source: India, Ministry of Agriculture and Development, Central Seed Committee 1989. These unpublished data were provided to Carl Pray.
Note: The official term for "released" is "notified."

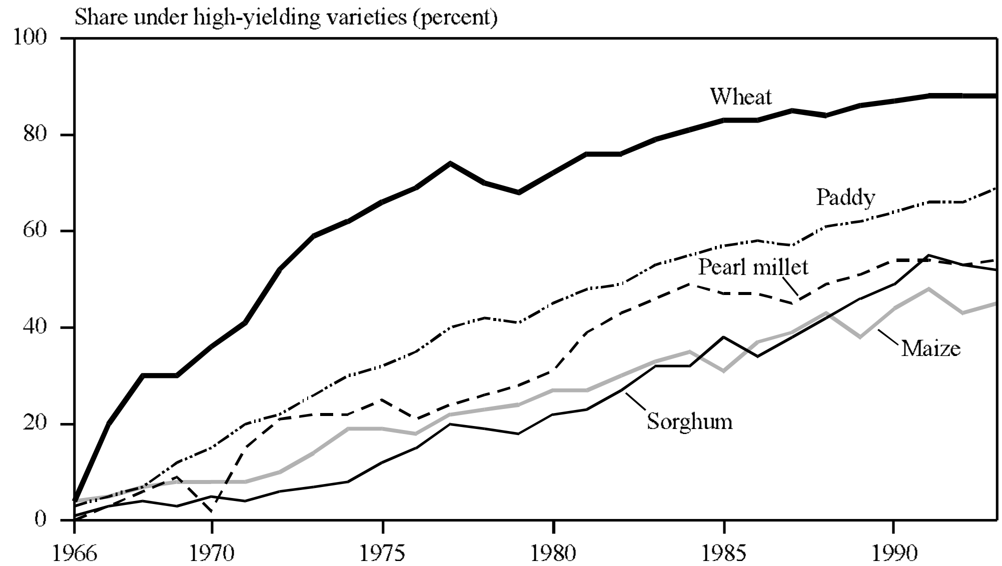
1970s, but the area under modern varieties of rice has continued its steady climb. The percentages of area in major regions of the country covered with modern varieties of rice, wheat, and maize are shown in Table 15. Modern varieties of some oilseeds have also been successful. Soybeans and sunflowers were introduced to India after 1960, so that all varieties of these crops are improved. A hybrid castor cultivar was developed in Gujarat and accounts for the area of that crop covered with modern varieties. There are almost no modern variety pulses, although improved varieties of rapeseed started to spread in the early 1990s. Some new varieties of pulses are of shorter duration, which allows them to be planted during short fallow periods. Some are resistant to disease and pests, but no variety has greatly increased potential yields.

Table 14—Share of crop area sown with modern varieties, by crop, 1987/88 and 1992/93

Crop	1987/88	1992/93
	(percent)	
Wheat	87	91
Rice	54	68
Sorghum	35	53
Pearl millet	40	53
Maize	35	42
Oilseeds		
Groundnuts	15–20	n.a.
Rape and mustard	10	n.a.
Soybeans	100	n.a.
Sesamum	0	n.a.
Sunflower	100	n.a.
Safflower	0	n.a.
Castor	33	n.a.
Pulses	<10	n.a.

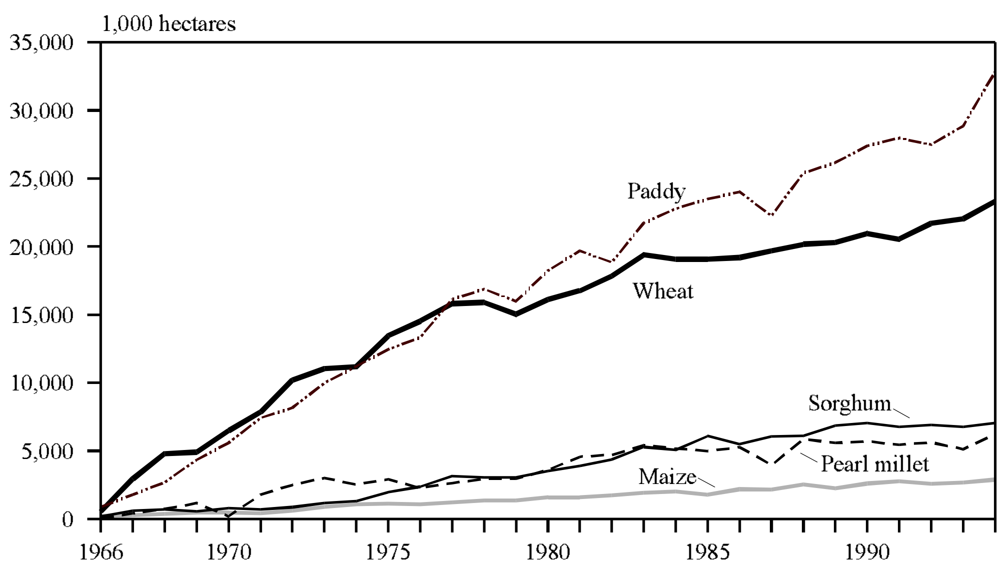
Sources: The data on foodgrains are from the Fertilizer Association of India 1994 and India 1992. The estimates for oilseeds are from scientists at the Indian Council of Agricultural Research.
Note: Where n.a. appears, data were not available.

Figure 5—Percentage of area planted with high-yielding varieties, 1966–93



Sources: Fertilizer Association of India various years.

Figure 6—Area planted with high-yielding varieties, 1966–93



Sources: Fertilizer Association of India various years.

Table 15—Share of crop area sown with modern varieties, by region, 1992/93

Region	Paddy	Wheat	Maize	Five grains[a]
		(percent)		
East	60	100	84	67
North	80	96	39	88
South	85	30	94	70
West	64	73	31	61

Source: Calculated from data in Fertilizer Association of India 1993.

Notes: East: Assam, Bihar, Orissa, and West Bengal.
North: Haryana, Himachal Pradesh, Jammu and Kashmir, Punjab, and Uttar Pradesh.
South: Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu.
West: Gujarat, Madhya Pradesh, Maharashtra, and Rajasthan.

[a]In addition to paddy, wheat, and maize, the five grains include pearl millet and sorghum.

Improved varieties of some cash crops, such as cotton, have been important. Improving the quality and increasing the length of fibers have been major goals of cotton research. India has been successful in meeting these goals. In recent years Indian public and private scientists have developed cotton hybrids.

Modern Varieties of Wheat

Wheat breeders before and immediately after Independence produced varieties with higher quality for breadmaking. They increased yields 10 to 15 percent.[7] These varieties were either pureline selections from landraces or crosses of Indian landraces.[8]

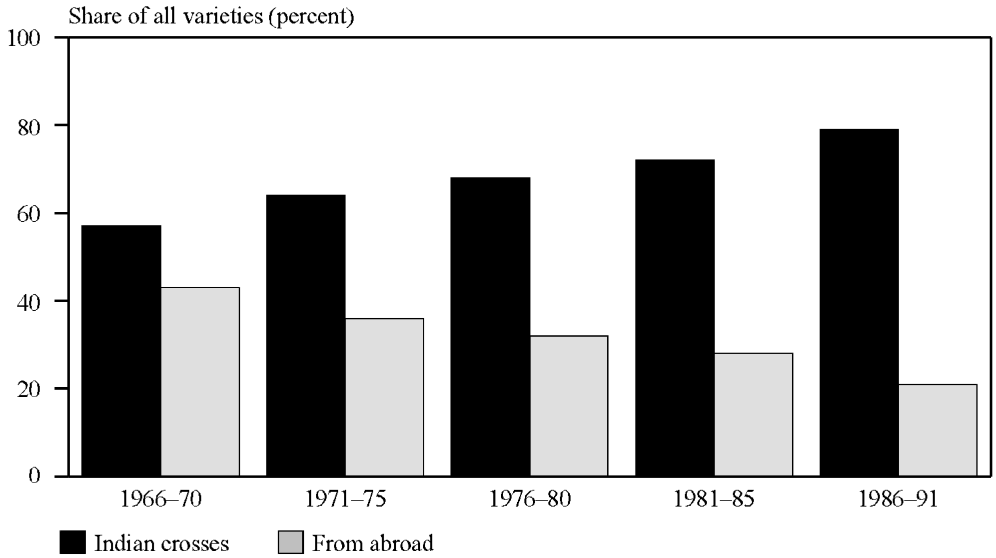
It was not until semi-dwarf varieties were introduced in the mid-1960s and fertilizer use increased that wheat yields really took off. The genetic sources for the semi-dwarf characteristics were Japanese wheat varieties that reached India via Washington State University and CIMMYT in Mexico. The first semi-dwarf varieties released in India were pureline selections from CIMMYT crosses. The main role of Indian breeders was to conduct field tests to ensure that the Mexican varieties could produce high yields under Indian conditions of soil, climate, pests, and diseases and to select varieties that would fit Indian tastes.

Varieties developed abroad reached a high of over 40 percent of all varieties released in India in 1966–70 (Figure 7). After that Indian wheat breeders replaced foreign varieties with varieties that they developed through their own crossing programs. Both before and after semi-dwarf wheat varieties were introduced, Indian breeders used foreign varieties extensively in their crossing program (Figure 8). In 1966–70, 14 percent of Indian varieties had two Indian parents, 71 percent had an Indian parent and a foreign parent, and 14 percent had two foreign parents. In 1986–91, 36 percent

[7] The material in this section is based on Byerlee and Moya 1993.

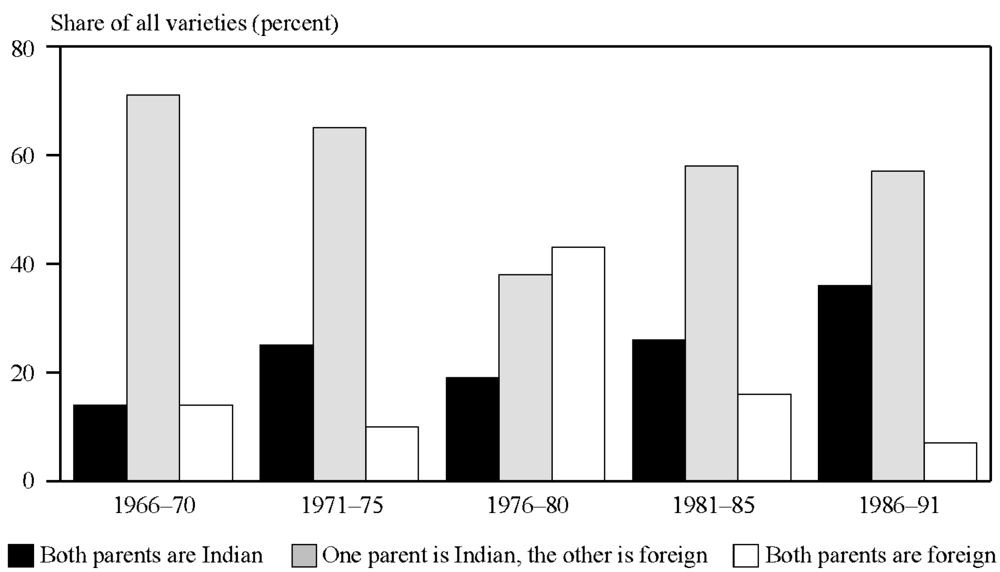
[8] The term “landrace” refers to subspecies or types selected by farmers.

Figure 7—Origins of Indian wheat varieties, 1966–70 to 1986–91



Source: Byerlee and Moya 1993.

Figure 8—Parentage of Indian wheat crosses, 1966–70 to 1986–91



Source: Byerlee and Moya 1993.

of the crosses had two Indian parents, 57 percent had an Indian and a foreign parent (mostly from CIMMYT), and 7 percent had two foreign parents.

Jain (reported in Byerlee and Moya 1993) examined the effects of breeding on the yield potential of wheat. He found that experimental yields of successful modern varieties increased by about 1 percent annually in both irrigated and rainfed trials in the Northwestern irrigated regions between 1966 and 1991. In irrigated trials in the Northeast zone (West Bengal, Bihar, and eastern Uttar Pradesh), and the Central zone, the yield potential grew between 0.75 and 0.79 percent annually. In unirrigated trials, research generated little additional yield potential. In farmers' fields this potential, combined with large increases in fertilizer and irrigation, led to increases in yield of 3.6 percent per hectare annually from 1966 to 1987.

Modern Varieties of Rice

Before 1960, Indian breeders for the most part followed a strategy of crossing local tall Indica varieties, but they made no major breakthrough.[9] Some new genetic material was introduced through the FAO Indica-Japonica program of the late 1950s, but no breakthrough was made until the introduction of semi-dwarf rice varieties from IRRI in the mid-1960s.

As with wheat, the early modern varieties of rice released in India were bred in IARCs, IRRI in the case of rice. Soon after the first generation of IRRI varieties were introduced, the process of developing varieties through crossing material from IRRI with local material began. In recent years the percentage of varieties in which both parents are local varieties has risen to 35 percent.

Since the early 1960s, 643 cultivars have been released as varieties (or were sufficiently advanced to qualify as modern varieties) by 23 rice breeding programs in India. These cultivars may be regarded as belonging to different "generations" of modern rice varieties. The releases from 1965 to the early 1970s were the first generation IR-8 type semi-dwarf rices. Releases after the early 1970s were second generation types with disease and insect resistance incorporated systematically. Varieties released since the 1970s have incorporated more "traits" from Indian landrace materials.

Table 16 summarizes the 643 varieties released since the beginning of the Green Revolution in the mid-1960s by the genealogy of each variety. Fifty-three of the Indian releases (8.1 percent) were actually crossed at IRRI (although some selection may have been made in India). In 1975, the International Network for Germplasm Evaluation (INGER), a network of international nurseries was established to evaluate advanced "lines" from IRRI and other research institutes. Most IRRI varieties were first identified as potential parents or varieties from their appearance in INGER after 1975. Varieties that originated at IRRI accounted for 17.8 percent of the area sown with modern varieties between 1965 and 1990.

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[9] This section is based on Evenson and Gollin 1994.

Table 16—Rice varietal productions by origin of cross, parents, grandparents, 1960–70 to 1986–91

Variety/source	Number of new varieties released 1960–70	1971–75	1976–80	1981–85	1986–91	Share of total varieties released	Share of total area planted
						(percent)	
Origin of cross							
IRRI	6	11	8 (6)	9 (9)	19 (17)	8.1	17.8
Other NARs	3	2	3 (1)	3 (2)	1 (1)	2.0	7.4
Indian NARs	68	123	128	113	146	89.9	74.8
Indian crosses by origin of parents							
IRRI	24	64	68 (25)	44 (43)	58 (47)	40.1	23.8
Other NARs	19	28	13 (5)	19 (17)	15 (10)	14.6	23.1
Indian NARs	25	31	47	50	73	35.0	28.0
Indian crosses by origin of grandparents							
IRRI	1	6	18 (3)	14 (5)	25 (4)	10.0	9.1
Other NARs	2	8	12 (0)	9 (0)	11 (0)	6.5	2.6
Indian NARs	22	17	17	27	36	18.5	16.3
All releases	77	136	139	125	166	100.0	100.0
Landraces	3.8	5.3	8.1	7.5	7.3	n.a.	n.a.

Source: Evenson and Gollin 1994.
Notes: NARs are national agricultural research institutes. The numbers in parentheses are the varieties, parents, and grandparents selected directly from the International Network for Germplasm Evaluation (INGER) established by the International Rice Research Institute (IRRI) in 1975. Where n.a. appears, data were not available.

Thirteen Indian varieties originated in other national programs and were identified in INGER. Evenson and Gollin (1994) report that Indian crosses were also the origin of 13 varieties released in other national programs. While the Indian varieties from other national agricultural research institutes (NARs) accounted for only 2 percent of releases in India, they accounted for 7.4 percent of modern variety area.

Of the Indian releases, 578 (89.9 percent) were selected from crosses made in Indian programs. IRRI contributed at least one parent to 40.1 percent of the Indian releases. Other NARs contributed at least one parent to 14.6 percent of the Indian releases. For 35.0 percent of Indian releases, both parents were from India. INGER was the major source of parents after 1975. (Evenson and Gollin [1994] report that Indian NARs contributed 444 parents to other NARs.)

IRRI and other NARs contributed substantial numbers of grandparent and other varieties for the 119 Indian crosses with Indian parents. The international nature of rice breeding is made evident by the contribution by IRRI of 8.1 percent of the crosses, at least one parent to 40.1 percent of the releases, and other ancestors to another 10.0 percent of Indian releases. Other NARs contributed 2.0 percent of the crosses, at least one parent to 14.6 percent of the releases, and other ancestors to another 6.5 percent of the releases. Thus only 18.5 percent of modern varieties in India are truly “all Indian.”

Until recently, rice research in India has been exclusively the domain of the public sector. However, as IRRI and the Indian government hybrid rice programs reduced the cost of hybrid rice seed production by 1992, at least three firms have started hybrid rice breeding programs in India. A hybrid rice variety was released for on-farm testing in 1992, and four additional hybrid rice varieties were released in 1994.

Modern Varieties of Coarse Grains

The Indian government and international centers play a somewhat different role for coarse grains—maize, sorghum, and pearl millet. ICAR and the state agricultural universities have worked to develop hybrids using exotic germplasm since the late 1950s. By the mid-1960s, they had successfully developed hybrids, which were diffused in the late 1960s but never adopted widely (see Figures 5 and 6). CIMMYT provided germplasm to produce open pollinated varieties of maize, which met with some success. ICAR and the state agricultural universities now place more emphasis on hybrids, but they have not achieved a major breakthrough. Thus, just over 40 percent of the area under maize is sown with modern varieties. Twenty-five private firms that are working to develop improved maize hybrids finally seem to be developing superior hybrids. Singh, Pal, and Morris (1995) report that the area sown with privately developed hybrids exceeded the area under publicly developed hybrids in 1992 and continues to grow rapidly.

In the 1980s, ICRISAT successfully developed open pollinated varieties and hybrids of pearl millet. These cultivars were developed using a combination of germplasm from the Indian national program and collections of germplasm from Africa and elsewhere. The varieties and inbred lines developed by ICRISAT have in turn been used successfully in recent years by private firms to produce high-yielding, disease-resistant hybrids.

ICRISAT has been less successful in producing improved varieties or hybrids of sorghum. Most hybrid-sown sorghum area is planted with public hybrids, but in recent years the private sector has started producing hybrids that are replacing them. Sales of privately developed hybrids of pearl millet and sorghum grew rapidly from a small base during the three years for which data are available (1985–87, see Table 17). By 1987, privately developed hybrid seed for pearl millet was planted on about 660,300 hectares. Privately developed hybrid seed for sorghum was planted on 258,000 hectares.

Private breeding programs depend heavily on the Indian public sector and ICRISAT for inbred lines and earlier generations of germplasm. All of the private pearl millet hybrids and two of the four sorghum hybrids that were sold commercially in 1987 had at least one line from ICRISAT; the other sorghum hybrids contained Indian public lines (Pray et al. 1991). Table 18 shows that firms with pearl millet and sorghum breeding programs use ICRISAT and ICAR/state agricultural university (All-India Coordinated Sorghum Improvement Project/All-India Coordinated Millet Improvement Project and university) germplasm extensively. Two companies used germplasm from foreign firms. Firms received ICRISAT's germplasm primarily through the distribution of basic seed rather than nurseries or germplasm from the Genetics Resource

Table 17—Private seed sales of pearl millet and sorghum and area covered, 1985–87

Crop/type of variety	Sales 1985	Sales 1986	Sales 1987	Area covered 1985	Area covered 1986	Area covered 1987
	(metric tons)			(1,000 hectares)		
Pearl millet						
Private hybrids	220	1,557	2,651	55	389	663
Public hybrids and varieties	10,862	10,541	11,182	2,716	2,636	2,796
Sorghum						
Private hybrids	257	847	2,067	32	106	258
Public hybrids and varieties	20,661	n.a.	n.a.	2,583	n.a.	n.a.

Source: C. E. Pray, Ribeiro, Mueller, and Rao 1991.
Note: Where n.a. appears, data were not avaiable.

Unit. This suggests that the firms primarily used ICRISAT's inbreds to produce new hybrids rather than early-generation material that would take longer to use but might produce hybrids much different from the hybrids released by ICRISAT.

The recent history of pearl millet breeding shows some of the advantages of having many different breeding programs. Simultaneous plant breeding by private companies and the public sector reduces the risk of disease or pest susceptibility by broadening the

Table 18—Private companies using pearl millet and sorghum breeding material from the public sector, 1987

Source of breeding materials used or hybrids developed	Pearl millet	Sorghum
	(number of companies)	
Source of materials used		
ICRISAT	16	6
AICSIP/AICMIP	6	3
University	6	3
Foreign company	0	2
Other Indian company	4	2
Own collection	7	5
Source of ICRISAT germplasm received		
Genetics Resource Unit material	8	6
Nurseries	7	4
Breeders' seed	19	10
Source of hybrid developed		
ICRISAT germplasm	11	3
Private sources	5	4

Source: Pray, et al. 1991.
Notes: ICRISAT is the International Crops Research Institute for the Semi-Arid Tropics, AICSIP is the All-India Coordinated Sorghum Improvement Project, and AICMIP is the All-India Coordinated Millet Improvement Project.

genetic base. In 1981, the private sector produced a hybrid, MBH-110, that was less susceptible to downy mildew than the public hybrids BJ 104 and BK 560, which were the most widely used improved pearl millet varieties. In 1985 and 1986, after BJ 104 and BK 560 became susceptible to downy mildew, private companies started to sell a number of new hybrids based on ICRISAT downy-mildew-resistant male-sterile lines 81 A, 834 A, or 843 A. ICAR/state agricultural universities and AICPMIP, which have equal access to ICRISAT material, did not produce resistant hybrids at that time. Thus, in the absence of private breeding, no resistant hybrids would have been available. Two public hybrids based on ICRISAT male-sterile lines and a few resistant varieties were recently released. These public-bred varieties are becoming popular in districts where MBH 110 resistance to downy mildew has broken down.

Conclusions

This analysis of the genealogies of major foodgrain crops in India indicates how interdependent public research and IARC research have become. It shows that purely foreign varieties have rarely made up a large share of Indian wheat and rice varieties and that their share is declining. Indian public plant breeding was important even during the Green Revolution. It has grown in importance since. The early experience with pearl millet and sorghum shows how important national research would be if there were no IARCs.

The genealogy analysis also shows the importance of foreign germplasm as parents and grandparents of Indian varieties: since 1985 about 60 percent of the wheat varieties have had a CIMMYT parent, and 50 percent of the rice varieties had an IRRI variety as a parent or grandparent. The rice data show the importance of IRRI’s network of trials, INGER, which transferred the germplasm used in half of the Indian varieties.

The cases of pearl millet and sorghum, much like wheat and rice, indicate the importance of Indian public research. Modern varieties were developed with some assistance from Rockefeller Foundation scientists who brought in foreign germplasm and expertise. Indian public hybrids accounted for most of the area covered with modern varieties of pearl millet and sorghum until the mid-1980s, when ICRISAT pearl millet varieties became popular. Then private hybrids based on ICRISAT and Indian public material captured important parts of the market. Indian public sorghum hybrids continued to make up almost all of the modern varieties of sorghum until the late 1980s, when private hybrids started to capture some of the market.

Evidence about the spread of private hybrids produced by private-sector plant breeding of pearl millet and sorghum shows that private research can affect agricultural productivity. The history of private hybrids indicates that private research in India is based on strong public-sector research. The public sector did the basic research on how to produce hybrids of these crops adapted to Indian conditions, provided the germplasm that became the basis of private hybrids, and trained the scientists who run the private research programs.

CHAPTER 4

Total Factor Productivity in the Indian Crop Sector

Productivity in crop agriculture is most often assessed by measures of crop yield. These measures, expressed as product per unit of land, are useful for agricultural studies. They have a clear physical basis and allow both cross-section and time-series comparisons. They are, however, incomplete as measures of economic efficiency because they do not consider the use of factors other than land (that is, labor, fertilizer, animal power, tractors, and so forth). Changes in the use of these factors will cause a change in yields, but at a real cost. Consequently, yield measures are not true measures of efficiency.

Total factor productivity (TFP), sometimes referred to as multifactor productivity, is a true measure of economic efficiency. It can be interpreted as a measure of change in cost of producing a unit of product, holding all factor prices constant (Evenson and Pray 1991). Alternatively, it can be interpreted as a measure of the change in output relative to a weighted combination of all inputs, where the weights are factor shares. This latter definition of TFP is used here, with TFP defined as the ratio of aggregate output to aggregate input.

This chapter begins with a discussion of methods used to compute measures of TFP. It then discusses data issues (the Appendix discusses additional issues about data). Measures of TFP are then reported and summarized by period and by political and geoclimatic region.

Methods

TFP provides a measure of the increase in total output that is not accounted for by increases in the quantity of inputs. It is computed as the ratio of an index of aggregate output to an index of aggregate inputs. Growth in TFP is therefore the growth in total output less the total increase in inputs. The analysis here uses the Tornqvist-Theil TFP index, which can be expressed in logarithmic form as

$$\ln(TFP_{t+1}/TFP_t) = \tfrac{1}{2}\sum_j (R_{jt+1} + R_{jt}) \ln(Q_{jt+1}/Q_{jt}) - \tfrac{1}{2}\sum_j (S_{it+1} + S_{it}) \ln(X_{it+1}/X_{it}), \quad (1)$$

where R_{jt} is the share of output j in revenues, Q_{jt} is output j, S_{it} is the share of input i in total input cost, and X_{it} is input i, all in period t. Specifying that the index is equal to 1.00 in a particular year and accumulating the measure based on equation (1) provides the TFP index.

The Tornqvist-Theil index has several useful properties. It is a superlative index that is exact for a linear homogeneous translog production function (Diewert 1976). Furthermore, Caves, Christensen, and Diewert (1982) have shown that Tornqvist-Theil indexes are also superlative under general production structures, that is, when returns to scale are nonhomogeneous and nonconstant. They should, therefore, provide consistent aggregation of inputs and outputs across a range of production structures (Antle and Capalbo 1988). Because current factor prices are used to construct the weights, quality improvements in inputs are incorporated, to the extent that these are reflected in higher wage and rental rates (Capalbo and Vo 1988). However, as noted in Chapter 5, the prices of improved inputs purchased from the private sector often do not reflect the full improvement in quality. This has important implications for the social benefits generated by private research. In addition, when new inputs undergo the initial diffusion process, farmers use too little of them. This results in a productivity contribution greater than prices indicate.

Data Issues

Data sources are documented in the Appendix. This section briefly describes the major data issues in the construction of TFP indexes for India.

Production Data

Production data are the annual data for each district. They refer to harvested production. Data were collected for the period 1956/57 to 1987/88 in 271 districts covering 13 states. The convention that 1956 refers to the crop year 1956/57 is used. District farm harvest prices for each crop were also obtained for each year.

The output index includes only production of crops. It does not include livestock production. It includes the 5 major foodgrains—maize, pearl millet, rice, sorghum, and wheat—and 13 minor crops—barley, cotton, groundnuts, gram, other pulses, potatoes, rapeseed and mustard, sesomum, sugar, tobacco, soybeans, jute, and sunflower.

Output changes are computed for each district. These changes are cumulated, and the cumulated index is set equal to one to give the average of the 1956–59 period in each district.

Factor Data

The factors included are unirrigated land, irrigated land, human labor, animal labor, tractors (serving as a proxy for all machinery), fertilizers (a proxy for all chemicals), and irrigation capital.

The procedures for handling these factors are critical because the wrong weights, that is, the $C'_j(s)$ can produce changes in TFP that are not capturing the contribution of inputs.

It should first be noted that annual data are only available for the variables for land and fertilizers. Data for animal labor, tractors, and irrigation capital are only available from the five-year censuses of agriculture. They are interpolated for the intervening years. Data for human labor are available only from the censuses of population. These too are interpolated for the intervening years.

The variable for human labor, as noted, is interpolated between censuses. This interpolation is probably not a serious source of error as labor changes slowly. Labor includes both male cultivators and male agricultural laborers. Estimates for the number of days spent on crop labor in each state are used to adjust for crop and livestock production. Labor shares are based on agricultural wage data. The wages of cultivator laborers are presumed to be equivalent to those of agricultural laborers.

The animal labor variable is based on quinquennial livestock census data. The stock of castrated male cattle over the age of three years used for rural work is used as the quantity series. Cost shares are based on the price series for bullocks converted to a rental share basis.

The tractor series is based on livestock census data that provides tractor inventories. Different horsepower sizes are converted into a constant horsepower size unit. The cost share is based on the service flow of tractors and other machinery. Thus, the tractor quantity index is a proxy for other machinery services.

The fertilizer series is based on annual data for the amount of nitrogen, phosphorus, and potash fertilizer consumed in each district, weighted by national prices.

The contribution of irrigation to production was handled in two ways. First, estimates of relative land prices for unirrigated and irrigated land in different states (see the Appendix) were used to create land stock in irrigated area equivalent. In addition, a pump irrigation factor was created from data on rural electric pumps, rural oil pumps, and rural Persian wheels included in the livestock census data. Data for factor shares were then estimated to reflect capital service flows (depreciation plus interest plus maintenance for these items).

The treatment of price data to create factor shares is critical. For capital stock variables (animal labor, tractors, and irrigation capital) this required the development of prices for service flow from data on stock prices. The procedures adopted here rely as much as possible on evidence from micro-cost studies to construct these flows. The estimates for factor shares by district were then validated against shares measured in the micro-level studies.

In order to provide the reader with a basis for judging the reasonableness of the weights for own-product and cost shares, the mean output shares and cost shares of factors were summarized for three periods (see Table 19). These share data show significant changes in both product and factor shares over time. The shares of the main crops—especially rice—fell significantly from 1977 to 1987, mostly owing to the decrease in prices for wheat and rice. On the factor side, land and bullock shares fell, while the shares of fertilizers, tractors, and labor rose.

Table 19—Output shares and factor shares: Total factor productivity computation, all India, 1956, 1967, 1977, and 1987

Item	1956	1967	1977	1987
Output shares				
Wheat	0.146	0.155	0.199	0.137
Rice	0.323	0.287	0.306	0.193
Pearl millet	0.044	0.057	0.036	0.017
Sorghum	0.098	0.089	0.074	0.033
Maize	0.033	0.060	0.035	0.025
Factor shares				
Bullocks	0.305	0.263	0.319	0.173
Tractors	0.001	0.003	0.010	0.024
Labor	0.421	0.406	0.419	0.564
Fertilizer	0.003	0.014	0.042	0.066
Unirrigated land	0.197	0.220	0.135	0.106
Irrigated land	0.073	0.093	0.076	0.066

Source: Authors' calculations.

Measures of TFP

Using the procedures set forth above, TFP indexes were constructed for each of 271 districts in 13 states for the 1956–87 period. Cross-section comparisons, which are subject to a number of complications, were not attempted. Accordingly, the TFP data was summarized in terms of the annual percent rates of change for different periods and for different political and agroclimatic regions.

Aggregate Indexes of Output, Inputs, and TFP

As a first step for a discussion of the evidence on TFP, the annual growth rates of aggregate crop output, aggregate crop inputs, and TFP are shown in Table 20. The growth rates show that India did realize substantial growth in TFP. Annual changes in output, and to a lesser extent in inputs, are clearly affected by weather-related shocks, as is typical in agricultural data series. The drought years 1965 and 1966 and the poor weather years 1986 and 1987 were particularly affected.

Therefore, two computations of the growth rates are presented. They use different methods for smoothing the effects of weather. It is useful to examine growth in these indexes for specific periods where year-to-year fluctuations in weather are averaged out and where the periods have a policy context. For this purpose, three periods were chosen: 1956–65, the period before the Green Revolution; 1966–76, the early Green Revolution; and 1977–87, the mature Green Revolution.

The first set of growth rates in Table 20 is based on three-year moving averages of the indexes of aggregate crop output, aggregate crop inputs, and TFP, centered on the end points shown in the table. The second set is based on annual values, but deletes the

Table 20—Annual growth rates in crop output, inputs, and total factor productivity, 1956–65, 1966–76, 1977–87, and 1956–87

Item	1956–65	1966–76	1977–87	1956–87
		(percent)		
Based on three–year moving averages				
Crop output	2.18	2.68	2.07	2.25
Crop inputs	1.08	1.28	1.00	1.11
Total factor productivity	1.10	1.39	1.05	1.13
Based on "normal" years [a]				
Crop output	2.35	2.77	2.15	2.40
Crop inputs	1.10	1.31	1.02	1.14
Total factor productivity	1.27	1.49	1.14	1.31

Source: Authors' calculations.
Note: "Normal" years excludes years of drought and poor weather: 1965, 1966, 1986, and 1987.

drought and bad weather years of 1965/66 and 1986/87, in order to assess "normal" growth rates.

The patterns of growth for crop output, inputs, and TFP are consistent for the two methods of computation. The method of deleting bad weather years yielded higher growth rates, but the pattern of growth was consistent across time. TFP growth accounted for more than half of output growth in all three periods. The significance of the early and mature Green Revolution periods was discussed in Chapter 3 and will be further addressed in Chapter 5, where the sources of TFP growth will be investigated. Here, the results show that the early Green Revolution saw rapidly increasing use of inputs. During the mature Green Revolution, the rate of growth of inputs fell. Evenson and Rosegrant (1993) note that the contribution of land expansion fell relative to yield increases over time as well. India now realizes almost all of its production gains from increases in the amounts of inputs supplied per hectare cropped and from the growth of TFP. Along with the rapid growth in inputs, TFP growth also increased significantly during the Green Revolution and then declined after 1976.

TFP Growth by Political Region

A comparison of growth rates in TFP diaggregated by region is given in Table 21. It gives estimates of the growth rates for the major political regions in India using three-year moving averages. The eastern region has become a source of concern in recent years in that it is perceived to be falling behind other regions in India. The data show that in fact the eastern region had the highest growth of TFP before the Green Revolution but has had the lowest growth since.

The west-central region had the most rapid growth of TFP during the early Green Revolution. The north had the highest rate of growth of both output and inputs during the Green Revolution, hence its TFP grew more slowly during the early Green Revolution than in the west-central region. But over the full period of the study, the north

Table 21—Annual growth rates in total factor productivity in the crop sector, by region, based on three-year moving averages

Region	1956–65	1966–76	1977–87	1956–87
		(percent)		
North	1.33	1.32	1.57	1.40
South	0.62	1.01	1.50	1.07
East	1.50	0.75	0.70	0.75
West-Central	1.03	1.60	0.39	0.84
India total	1.10	1.39	1.05	1.13

Source: Authors' calculations.

Note: North includes Haryana, Punjab, and Uttar Pradesh; South includes Andhra Pradesh, Karnataka, and Tamil Nadu; East includes Bihar, Orissa, and West Bengal; and West-Central includes Gujarat, Madhya Pradesh, Maharashtra, and Rajasthan.

had the highest rate of growth of TFP. During the mature Green Revolution, the south performed particularly well. This was consistent with a process of catching up as it had been slow to adopt the technology earlier in the Green Revolution.

TFP Growth by Geoclimatic Region

Geoclimatic characteristics are important because they can be used to distinguish regions that are homogeneous in their technology distance. And technology distance is a critical issue in the specification of the models for the sources of TFP used in Chapter 5 of this report. A formal definition of technology distance is

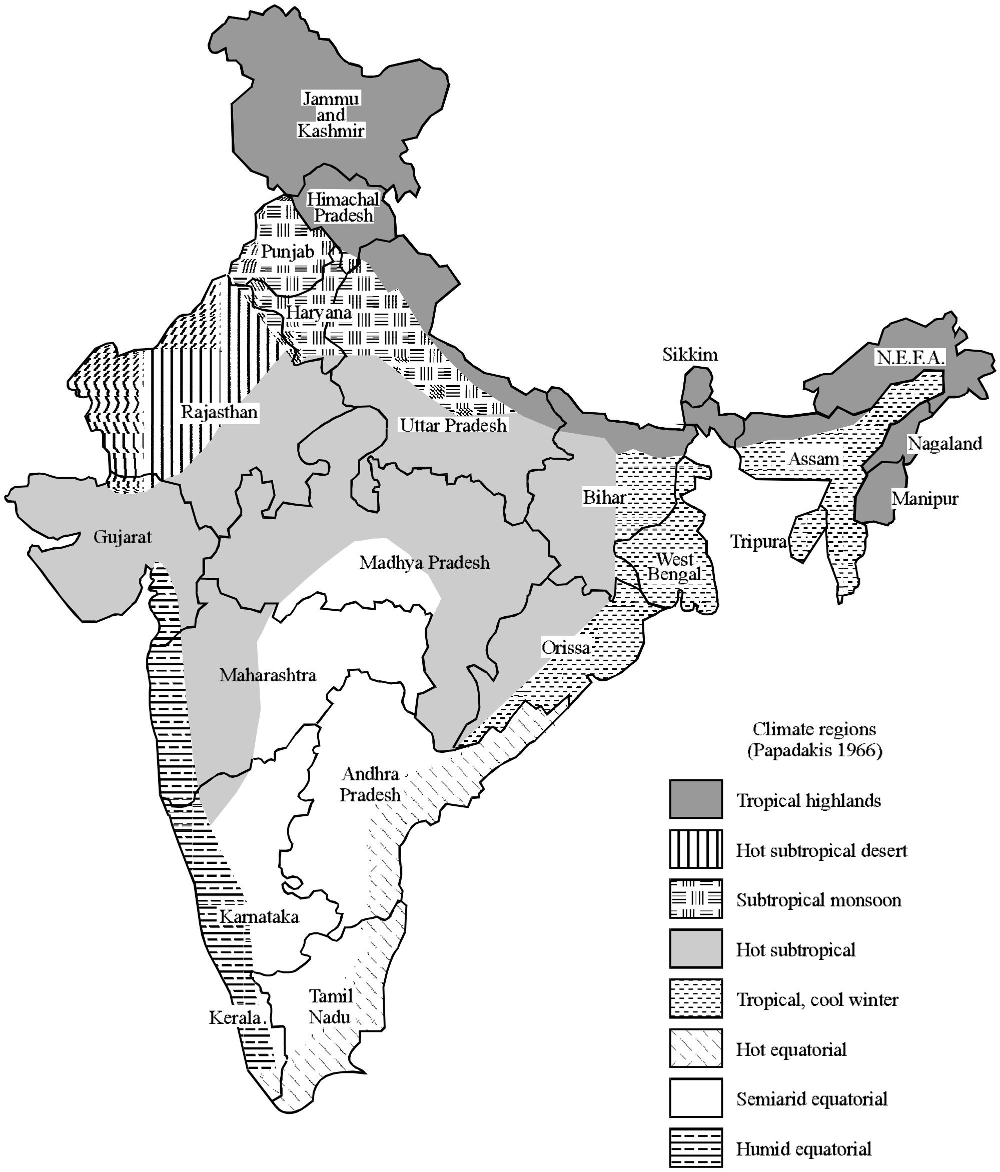
$$D_{ij} = C_{ij}/C_{ii}\,, \qquad (2)$$

where D_{ij} is the technology distance between locations *i* and *j; C_{ii}* is the minimized cost of producing a unit of product in location *i* using the best technology currently available to location *i,* where the best technology is the cheapest at the factor prices in that location; and C_{ij} is the minimized cost of producing a unit of product in location *i* when producers are constrained to use location *j*'s cost-minimizing technology (technology includes crop varieties, types of chemicals, and farming practices). If $C_{ij} = C_{ii}$, that is, if the same technology minimizes costs in both locations, there is no technology distance between the two locations. For most agricultural technology, however, differences in soil quality and type, rainfall, and so forth, influence technology. A variety of rice, for example, that performs well in location *i* may perform poorly in location *j* because of these interactions.

Agricultural research systems are designed with technology distance in mind. Research programs in these systems are targeted to particular agroclimatic zones. Such zones are intended to delineate regions with similar conditions of soil and climate, and hence similar technology distance.

Figure 9 shows a system of geoclimatic zones taken from Papadakis (1966). This system of zones is international and makes it possible to identify comparable zones in

Figure 9—Climate zones in India



Source: Evenson and Kislev 1975.

Table 22—Annual growth rates in total factor productivity in the crop sector, by agroclimatic zone, based on three-year moving averages, 1956–65, 1966–76, 1977–87, and 1956–87

Agroclimatic zone	1956–65	1966–76	1977–87	1956–87
		(percent)		
Tropical highlands	1.46	1.22	1.07	0.81
Hot subtropical desert	0.89	1.70	–1.94	0.23
Subtropical monsoon	1.14	1.80	1.45	1.38
Hot subtropical	0.71	1.62	0.89	0.94
Hot equatorial	0.52	1.29	1.26	0.95
Semi-arid equatorial	0.50	1.47	1.50	1.02
Humid equatorial	0.50	1.47	1.50	1.02
Humid equatorial	1.88	1.57	0.50	1.08
Tropical, cool winter	2.26	0.74	0.77	0.75
India total	1.10	1.39	1.05	1.13

Source: Authors' calculations.
Note: Agroclimatic zones shown in Figure 9 are taken from Evenson and Kislev 1975.

other countries. The Papadakis zones are useful for demarcating zones that determine the diffusion potential of most new agricultural technology (see Chapter 5 for more on the relationship of technology with this potential).

Table 22 presents the growth rates of TFP by agroclimatic zone. It shows that the subtropical monsoon region in which northern wheat is grown had the highest TFP during the entire period. The tropical cool winter region did well before the Green Revolution, but poorly later.

Conclusion

India has made significant gains in TFP. The high-yielding varieties of wheat and rice introduced in the late 1960s certainly contributed to these gains. So did modern varieties of maize and other crops introduced before and after the Green Revolution. But modern varieties are only one source of increases in TFP. The next chapter will identify and quantify the contributions that these varieties and other investments have made to the growth of TFP.

CHAPTER 5

Sources for the Growth of Total Factor Productivity in Indian Agriculture

This chapter assesses the contribution made by several sources to the growth of TFP in India. It also presents estimates of the marginal economic rates of return to public investments in research, extension, and irrigation that result in TFP growth. Estimates are given by time period for the contribution to growth of investments. Several developments have raised concern in India that the returns to research and irrigation have fallen over time. These developments include the rapid spread of modern varieties of wheat and rice, which have led to rates of adoption of modern varieties and input use that might be too high to sustain for some crops in many regions of India. They also include the failure to generate crop varieties with higher maximum yields than varieties produced in the 1960s (Rosegrant and Pingali 1994) and rapid increases in the capital costs of irrigation in India (Rosegrant and Svendsen 1993). The decomposition of the effects of research and irrigation by time period makes it possible to test the hypothesis that the returns to agricultural investment have fallen.

Methods

The method used to measure TFP does not by itself suggest what determines changes in TFP. Nor does it suggest an underlying TFP production process that might make it possible to derive functional form restrictions that can be used in statistical specifications. TFP growth in its simplest sense is a residual. That is, it is the difference between an actual change in production and a change in production predicted by weighted factor changes.

The substantial literature that decomposes TFP and analyzes its sources (Evenson [1993] reviewed more than 78 such studies) shows that the TFP, as a residual, cannot be considered to be simple technical or technological change. It is produced by changes in infrastructure, skills, and institutions as well as technology. And it is also clear that accounting practices, while important, cannot fully account for TFP growth by measuring growth in both the quantity and quality of inputs. This is because accounting methods cannot capture general changes in institutions or infrastructure.

It is also because of a fundamental problem in pricing newly invented and developed inputs. The first prices observed by an accountant for such new inputs usually understate their real production value. This means that input growth will be undercounted. This leads to growth in TFP and is the chief mechanism by which private sector research and development contributes to the growth of TFP in agriculture.

The Logic of TFP Determination

It is convenient to appeal to a general or "meta" transformation function argument to discuss the logic of a specification of TFP determinants. The term "meta" is used to indicate that variables that would normally be held constant are incorporated in the transformation function. These include variables measuring technology (T), the skills of farmers (S), characteristics of farms (Z), and infrastructure (I).

Let the transformation function be defined as

$$G(Y_1, Y_{2,\ldots}, Y_n, X_1, X_{2,\ldots}, X_k, T, I, S, Z). \quad (3)$$

The conventional TFP measure defined in Chapter 4 is based on a share-weighted output index, Y, and a share-weighted input index, X. The rate of change in TFP is defined as

$$\hat{T} = \hat{Y} - \hat{X}. \quad (4)$$

$\hat{T} = 0$ only if technology (T), infrastructure (I), farmers' skills (S), and farm characteristics (Z) remain constant. If these meta variables change, they will produce TFP growth, that is,

$$\hat{T} = W_T \hat{T} + W_I \hat{I} + W_S \hat{S} + W_Z \hat{Z}. \quad (5)$$

There are two problems in specifying equation (5). First, the weights W_T, W_I, W_S, and W_Z are not known a priori, but must be estimated. Second, and probably more serious at least for research, there is no direct measure of either T or I; nor is there necessarily a good measure of S or Z. What can be measured are investments in research and extension that are designed to produce new technology (T) and better information and better infrastructure (I).

This forces the researcher to address the implicit process of production by which investments that take place in different periods and locations produce increments to T, I, and other variables for the observed unit of TFP (in the case presented here, for a specific district over a specific year). Accordingly, two important issues must be addressed. The first is the time between investments and changes in TFP. This is basically a question of creating data for capital stock from investment data with the right service flow. The second is the spatial technology distance that relates research and extension or other investments made in location *j*, and presumably targeted to location *j*, to changes in TFP in location *i* and elsewhere.

Timing

The lags between the time research, extension, and other investment expenditures are made and when they have their effects must be specified. Previous studies have estimated the timing weights (Evenson and Pray 1991). The distributed lag between expenditures and economic impact has three segments: a segment when the value of the investment increases after the expenditures are made; a segment when the value of the investment remains constant; and a segment when the value of the investment falls as its effects depreciate.

Five alternative time-weights were constructed for this study. They range from three years in each of the time-segments to nine years. The alternative weighting schemes are described in more detail in the appendix. Both the nature of agricultural crop research and the statistical goodness-of-fit of the TFP decomposition equations indicate that the scheme with the longest lags—nine years in all three segments—is preferable. As Alston, Norton, and Pardey (1995) point out, research takes time to complete, it takes time to adopt the product of research (the adoption will probably be incomplete), and the knowledge embodied in most research eventually depreciates. Pardey and Craig (1989) found that the effects of research on U.S. agricultural productivity last for at least 30 years from the time the research is begun. Similarly, the 27-year lag structure (with time weights of 9 years for each of the segments) has the best fit in the TFP decomposition equations, as measured by both the Buse R^2 suggested as a measure in estimation of generalized least squares, and by the R^2 between the actual and predicted values of the TFP index from the estimated decomposition equations. The results for this lag structure are therefore presented and discussed in detail, but the results for the alternative lag structures are also presented for comparison.

Spatial Issues

In Chapter 4, geoclimatic zones were described as a way to demarcate similar regions. That is, technology distance is low within geoclimatic zones. Technology distance between geoclimatic zones, on the other hand, is expected to be high (see Evenson [1993] for an analysis of rice productivity and technology distance). The basic problem is to define a research stock (with time weights) proportional to a real service flow with regard to technology flowing to farmers in a particular district. In practical terms, this means assigning research conducted outside the district to the district (few districts have research stations). Either a state value (that is, the value of the research in the district's state) or a geoclimatic value (that is, the value of the research in the district's geoclimatic zone) could be assigned as the value of the district-level research. The geoclimatic region assignment was chosen after testing these alternative specifications. This is consistent with the technology distance logic, which suggests that new technology produced for the geoclimatic zone is likely to be suited to all or most districts in the geoclimatic zone.

Deflation Issues

Since research on different commodity and noncommodity programs must be combined into a research variable for TFP decomposition, the question of combining weights or deflators arises. This is in part a matter of interactions in commodity technology. If a research program on one commodity does not contribute to TFP in another commodity, the TFP contribution would be expected to be related to the number of units of the commodity (in the geoclimatic zone).

Accordingly the aggregate research stock (R) can be defined as

$$R = \sum_i S_i R_i^* + R_G^* / Q, \tag{6}$$

where $S_i = Q_i / Q$ and $Q = \sum_i Q_i$, where Q_i is the output of commodity i in 1960 (in the geoclimatic zone). R_i^* is the cumulated commodity research stock (with time weights as discussed above). R_G^* is the stock of research that cannot be allocated by commodity. Q is aggregate 1960 output. This procedure implicitly deflates the research stock by commodity units. General research is deflated by all commodity units so that it is deflated by the same units as used to deflate commodity research.

Definitions of Variables

In the specification of the determinants of TFP, the TFP index was regressed on variables representing investments in research, extension, human capital, and infrastructure. The estimation was made using a fixed effects approach for the pooled cross-section time series data set for the districts, with corrections made for serial correlation and heteroskedasticity (Kmenta 1981). The total number of observations in the data set is 8,672. The equation was specified in double-log form. Table 23 gives a brief summary of the variables used in the analysis.

The independent variables used in this analysis are categorized as technology variables, infrastructure-institutional variables, and other variables. The rationale for their inclusion follows.

First, there are four technology variables: public-sector research (*RES*), public-sector extension (*EXT*), high-yielding varieties (*WHYV*), and private-sector invention (*PRIVRES*). *RES* is intended to measure research service flows to the relevant agroclimatic regions, as noted earlier. These services include research on crop varieties.

The *EXT* variable measures the services provided to farmers by extension programs. It is defined as the ratio of field staff to farmers and represents the supply of ex-

Table 23—Summary of variables in the decomposition analysis of total factor productivity

Type of variable/variable	Definition	Mean
Dependent variable		
Total factor productivity	Total factor productivity index	1.15
Independent variables		
Technology variables		
EXT	Agricultural extension staff per 1,000 farms	4.78
RES	Agricultural research stocks (billion Rs)	25.72
WHYV	Proportion of crop area in modern varieties	0.16
PRIVRES	Factor-weighted domestic invention stock (number)	0.96
Infrastructure-institutional variables		
MKTS	Number of regulated markets	9.87
NIANCA	Net irrigated area/net cultivated area	0.25
RELWAGE	Daily farm wage/annual nonfarm earnings	0.0012
LITERACY	Proportion of rural adult males literate	0.32
MCOST	Crop wholesale price/crop farm price, 1956	1.23
QMOD	Index of modern chemical (fertilizer) use	4.51
Other variables		
YEAR	Year	. . .
*AGRO*1-*AGRO*8	Agroclimatic dummy variables	. . .
YEARRAIN	Annual rainfall (mm)	1,040.60
JUNERAIN	June rainfall (mm)	137.05
JUAURAIN	July-August rainfall (mm)	535.81
*D*6676	Dummy variable, 1 for 1966–76, 0 otherwise	. . .
*D*7787	Dummy variable, 1 for 1977–87, 0 otherwise	. . .

tension services. It should be noted that this is a state variable rather than a district variable.[10]

The *WHYV* variable measures the availability of modern varieties to farmers. For individual farms, the adoption of modern varieties is determined by the characteristics of farmers. It is an endogenous variable. For districts, most of the farm characteristics are averaged out or controlled for by infrastructure-institutional variables. Thus *WHYV* is an exogenous variable. Since a research variable is included, the *WHYV* variable can be treated as an index of success or, perhaps more relevantly, as an index of the importation of varieties from other national or international programs. This is primarily the importation of parental genetic resources (see Chapter 3).

The PRIVRES variable is a measure of the services provided by the private sector to Indian agriculture. Firms in the machinery, fertilizer, seed, and chemical industries produce inventions, many of which are embodied in inputs sold to farmers. Private firms that undertake research and development to produce inventions will capture

[10] The state extension ratio is in one sense too large an aggregate for the analysis. A district ratio of extension staff to farmers would have been preferable. However, differences in extension services between states and spillovers in general information and extension management between districts in a state can be captured in the state variable.

part, but not all, of the actual productive value of their technology through higher prices. This partial capture of value means that there will be improvements in the productive quality of purchased farm inputs in addition to the improvements reflected in prices. National cumulated stocks of patentable inventions (some of which are granted to foreign firms) in farm machines, fertilizer, and farm chemicals are created to measure this contribution. These stocks are then weighted by the district's shares of machinery and fertilizer costs to reflect the district's use of invention stocks.[11]

Two of the infrastructure-institutional variables are straightforward. *MKTS* measures investment in markets and regulation of markets by the public sector. This investment should improve farm productivity. *LITERACY* reflects past investment in schooling. It is a proxy for former human capital skills and should contribute to higher productivity.

RELWAGE and *MCOST* are designed to measure market efficiency and its effect on productivity. The ratio of farm wages to nonfarm earnings opportunities measures the efficiency of labor markets. Higher values for *RELWAGE* ought to be positively associated with TFP.

The *MCOST* variable, on the other hand, is effectively a variable measuring the economic distance to farm markets. Wholesale prices are measured in wholesale markets. Farm harvest prices are measured in the district. The *MCOST* variable will thus be higher for districts more distant from wholesale markets. There are two competing hypotheses about this variable. The urban-industrial hypothesis (Schultz 1953; Nichols 1963) states that districts closer to markets will have higher productivity because the markets are more efficient. The convergence hypothesis (Barro and Sala-I-Martin 1992) is that districts that have developed more slowly in the past have a greater potential to catch up. They can, therefore, grow faster. Since TFP is indexed to equal one in all districts in 1956, the procedure used here in effect uses the *MCOST* variable to test the convergence hypothesis against the urban-industrial hypothesis.

Two input variables, *NIANCA* (net irrigated area/net cultivated area) and *QMOD*, (index of modern chemical use) are included as independent variables. Since both irrigation and fertilizer were first used as direct inputs in the computation of TFP, a justification is needed for including additional measures of the contribution of these inputs to TFP as explanatory variables. The justification for the irrigation variable is that, in the absence of water markets and water price data, and due to massive subsidies for public and private irrigation, the estimate of the share of irrigation in the input aggregate is crude. It could thus understate the contribution of irrigation water. In addition, irrigation systems are a type of public infrastructure investment and would be expected to contribute to productivity growth on these grounds. Most importantly, however, irrigation intersects with technology by making it possible to adopt high-yielding varieties and increasing their value when adopted. This interaction effect cannot be captured by computing the contribution of inputs directly.

[11] Fikkert (1994) and Basant and Fikkert (1993; 1996) discuss private sector R&D spillovers.

The justification for the inclusion of the *QMOD* index is different. Fertilizer prices were used to measure the input contributions of fertilizer. For many Indian farmers, however, fertilizer was a new input that required experimentation and testing. For such an input, the actual marginal product tends to be greater than the perceived marginal product during the diffusion period. In addition, it has been argued that government production and distribution policies indirectly rationed fertilizers over much of the study period (McGuirk and Mundlak 1991). This is an additional argument for a disparity between prices and the value of the marginal product of fertilizer. As the introduction of modern varieties generally increased the marginal product of fertilizer, an interaction between *QMOD* and *WHYV* has been provided for in the estimates. (Note that tractor use is also subject to the adoption argument, but not to the rationing argument, nor is it complementary with *WHYV.* Accordingly, it is not included in the specification.)

In addition, intercept and slope dummies are included to separate the effects of research, extension, modern varieties, and irrigation by the three time periods: 1956–65, which roughly corresponds to the time before the Green Revolution; 1966–76, which represents the early Green Revolution; and 1977–87, which represents the mature Green Revolution. The interactions between the dummy variables and research, extension, irrigation, and modern varieties (*D6676*RES*, *D7787*RES, D6676*EXT, D7787*EXT*, *D6676*NIANCA*, *D7787*NIANCA*, and *D7787*WHYV*) capture the changes seen over time in the effects of research and modern varieties on TFP growth. Note that the interaction variable between time period and modern varieties affects only the final period. The first two periods are combined since almost no modern varieties were adopted before 1965, so that the coefficient on *WHYV* measures almost entirely the effects between 1966 and 1976. Finally, dummy variables for agroclimatic zones were included in the regressions, but they are not reported here in the interest of brevity.

Estimates

Total Factor Productivity Decomposition

Table 24 gives the estimated parameters from the equation that decomposes TFP for the crop sector in India using the best-fit research lag structure, nine years in all three segments (9,9,9). Tables 25–28 give the results calculated using the other lag structures. Two specifications were tested for each structure. The first excluded the *QMOD* variable. The results from both specifications show that the variables measuring public sector research and extension and private sector research (invention) are statistically significant at the 1 percent level and that the adoption of modern varieties is statistically significant at the 10 percent level. All three variables increase TFP (Table 24).

The proportion of area irrigated was included in both specifications to test whether irrigation has additional effects on productivity not accounted for by its contribution to total inputs. The estimated effect of irrigation on TFP is strongly positive, indicating that irrigation does influence productivity above and beyond its value as an input (as noted, however, this may reflect poor measures of its value as an input). The effects of relative wages and literacy are as expected, but are not statistically significant. The literacy variable may be insignificant because the definition of this variable is too crude to

Table 24—Total factor productivity decomposition for the crop sector, 1956–87, estimated parameters with lag structure (9,9,9)

Variable	Specification without the QMOD variable: Parameter estimates	*t*-ratio	Specification with the QMOD variable: Parameter estimates	*t*-ratio
INTERCEPT	–0.140**	–2.81	–0.069	–1.35
MKTS	0.021**	6.59	0.019**	5.80
NIANCA	0.144**	5.68	0.118**	4.79
D6676×NIANCA	0.092**	3.03	0.094**	3.18
D7787×NIANCA	0.111**	3.76	0.099**	3.36
RELWAGE	–0.003	–0.51	–0.002	–0.29
LITERACY	0.032	0.78	0.014	0.33
EXT	0.039**	7.28	0.043**	7.88
D6676×EXT	0.004	0.52	–0.0009	–0.11
D7787×EXT	0.006	0.65	0.002	0.19
RES	0.043**	6.85	0.036**	5.69
D6676×RES	0.007	0.86	0.010	1.36
D7787×RES	0.014	1.64	0.018*	1.97
WHYV	0.040	1.64	0.038	1.55
D7787×WHYV	–0.031	–1.03	–0.053*	–1.75
YEARRAIN	0.0001**	15.51	0.0001**	15.38
JUNERAIN	–0.00003*	–1.90	–0.00003*	–1.71
JUAURAIN	–0.00004**	–3.72	–0.00004**	–3.56
YEAR	–0.005**	–5.19	–0.006**	–6.23
MCOST	–0.035*	–2.25	–0.038**	–2.41
PRIVRES	0.014**	8.93	0.013**	7.65
QMOD	. . .	. . .	0.013**	5.42
QMOD×WHYV	. . .	. . .	0.024*	1.98
D6676	–0.081**	–4.07	–0.091**	–4.57
D7787	–0.095**	–3.55	–0.091**	–3.19

Notes: The dependent variable is the log of the total factor productivity index. All variables are specified in logarithms, except those variables defined in percentage terms, which enter linearly (*NIANCA*, *D*6676 × *NIANCA*, *D*7787 × *NIANCA*, *LITERACY*, *WHYV*, *D*7787 × *WHYV*).

The lag structure reflects lags between the time when expenditures on research (and extension) are made and when they have their full economic impact. As conceived here, the lag has three segments. The first segment comes between the first appearance of the research result and its full effect. The second refers to the number of years during which the research contributes at full strength. The third represents a sort of "decay" in the research contribution, due perhaps to biological changes or its replacement by later, superior discoveries. The numbers used here refer to the number of years in each segment.

* Significant at 5 percent.

** Significant at 1 percent.

Table 25—Total factor productivity decomposition for the crop sector, 1956–87, estimated parameters with lag structure (6,6,6)

	Specification without the QMOD variable		Specification with the QMOD variable	
Variable	Parameter estimates	*t*-ratio	Parameter estimates	*t*-ratio
INTERCEPT	−0.140**	−2.81	−0.070	−1.39
MKTS	0.021**	6.37	0.019**	5.61
NIANCA	0.142**	5.64	0.117**	4.77
D6676×NIANCA	0.090**	3.00	0.093**	3.18
D7787×NIANCA	0.115**	3.89	0.103**	3.50
RELWAGE	−0.004	−0.56	−0.002	−0.33
LITERACY	0.061	1.46	0.039	0.93
EXT	0.038**	6.92	0.041**	7.53
D6676×EXT	0.007	0.87	0.001	0.19
D7787×EXT	0.009	0.89	0.004	0.44
RES	0.041**	6.50	0.036**	5.50
D6676×RES	0.005	0.61	0.008	1.02
D7787×RES	0.007	0.73	0.010	1.02
WHYV	0.047*	1.93	0.045*	1.84
D7787×WHYV	−0.042	−1.42	−0.063*	−2.10
YEARRAIN	0.0001**	15.51	0.0001**	15.44
JUNERAIN	−0.00003*	−1.84	−0.00003*	−1.65
JUAURAIN	−0.00004**	−3.78	−0.00004**	−3.67
YEAR	−0.005**	−5.10	−0.006**	−6.09
MCOST	−0.030*	−1.89	−0.033*	−2.06
PRIVRES	0.014**	8.81	0.013**	7.56
QMOD	. . .	. . .	0.013**	5.31
*QMOD*WHYV*	. . .	. . .	0.024*	1.95
D6676	−0.078**	−3.86	−0.087**	−4.27
D7787	−0.070**	−2.68	−0.066**	−2.36

Notes: The dependent variable is the log of the total factor productivity index. All variables are specified in logarithms, except those variables defined in percentage terms, which enter linearly (*NIANCA*, *D*6676 × *NIANCA*, *D*7787 × *NIANCA*, *LITERACY*, *WHYV*, *D*7787 × *WHYV*).

The lag structure reflects lags between the time when expenditures on research (and extension) are made and when they have their full economic impact. As conceived here, the lag has three segments. The first segment comes between the first appearance of the research result and its full effect. The second refers to the number of years during which the research contributes at full strength. The third represents a sort of "decay" in the research contribution, due perhaps to biological changes or its replacement by later, superior discoveries. The numbers used here refer to the number of years in each segment.

* Significant at 5 percent.

** Significant at 1 percent.

Table 26—Total factor productivity decomposition for the crop sector 1956–87, estimated parameters with lag structure (3,6,6)

Variable	Specification without the QMOD variable		Specification with the QMOD variable	
	Parameter estimates	*t*-ratio	Parameter estimates	*t*-ratio
INTERCEPT	–0.145**	–2.92	–0.772*	–1.51
MKTS	0.020**	6.09	0.018**	5.35
NIANCA	0.141**	5.60	0.116**	4.72
D6676×NIANCA	0.093**	3.09	0.095**	3.23
D7787×NIANCA	0.115**	3.89	0.102**	3.45
RELWAGE	–0.004	–0.59	–0.002	–0.37
LITERACY	0.085*	2.05	0.061	1.46
EXT	0.038**	6.88	0.041**	7.45
D6676×EXT	0.006	0.82	0.001	0.14
D7787×EXT	0.011	1.06	0.006	0.62
RES	0.039**	6.02	0.034**	5.12
D6676×RES	0.002	0.29	0.005	0.62
D7787×RES	–0.004	–0.39	–0.0009	–0.09
WHYV	0.043*	1.78	0.040	1.64
D7787×WHYV	–0.042	–1.41	–0.063*	–2.10
YEARRAIN	0.0001**	15.52	0.0001**	15.47
JUNERAIN	–0.00003*	–1.82	–0.00003*	–1.62
JUAURAIN	–0.00004**	–3.88	–0.00004**	–3.78
YEAR	–0.004**	–4.59	–0.006**	–5.55
MCOST	–0.027*	–1.70	–0.030*	–1.87
PRIVRES	0.014**	8.72	0.013**	7.47
QMOD	. . .	. . .	0.013**	5.25
QMOD×WHYV	. . .	. . .	0.026*	2.11
D6676	–0.072**	–3.43	–0.080**	3.78
D7787	–0.047*	–1.82	–0.043	–1.56

Notes: The dependent variable is the log of the total factor productivity index. All variables are specified in logarithms, except those variables defined in percentage terms, which enter linearly (*NIANCA*, *D*6676 × *NIANCA*, *D*7787 × *NIANCA*, *LITERACY*, *WHYV*, *D*7787 × *WHYV*).

The lag structure reflects lags between the time when expenditures on research (and extension) are made and when they have their full economic impact. As conceived here, the lag has three segments. The first segment comes between the first appearance of the research result and its full effect. The second refers to the number of years during which the research contributes at full strength. The third represents a sort of "decay" in the research contribution, due perhaps to biological changes or its replacement by later, superior discoveries. The numbers used here refer to the number of years in each segment.

* Significant at 5 percent.
** Significant at 1 percent.

Table 27—Total factor productivity decomposition for the crop sector, 1956–87, estimated parameters with lag structure (3,3,6)

	Specification without the QMOD variable		Specification with the QMOD variable	
Variable	Parameter estimates	t-ratio	Parameter estimates	t-ratio
INTERCEPT	−0.138**	−2.78	−0.071	−1.41
MKTS	0.019**	5.84	0.017**	5.12
NIANCA	0.141**	5.62	0.116**	4.73
D6676×NIANCA	0.094**	3.12	0.096**	3.24
D7787×NIANCA	0.113**	3.80	0.100**	3.33
RELWAGE	−0.004	−0.60	−0.003	−0.39
LITERACY	0.102**	2.46	0.076*	1.82
EXT	0.038**	6.98	0.042**	7.53
D6676×EXT	0.006	0.74	0.0005	0.06
D7787×EXT	0.012	1.17	0.008	0.73
RES	0.035**	5.42	0.031**	4.59
D6676×RES	0.0002	0.03	0.003	0.32
D7787×RES	−0.009	−0.98	−0.006	−0.65
WHYV	0.039	1.61	0.036	1.46
D7787×WHYV	−0.039	−1.33	−0.062*	−2.05
YEARRAIN	0.0001**	15.55	0.0001**	15.51
JUNERAIN	−0.00003*	−1.86	−0.00003*	−1.65
JUAURAIN	−0.00004**	−4.00	−0.00004**	−3.90
YEAR	−0.004**	−4.06	−0.005**	−5.05
MCOST	−0.025	−1.53	−0.028**	−1.71
PRIVRES	0.014**	8.66	0.013**	7.41
QMOD	. . .	. . .	0.013**	5.24
QMOD×WHYV	. . .	. . .	0.027*	2.21
D6676	−0.068**	−3.43	−0.075**	−3.73
D7787	−0.041*	−1.69	−0.362	−1.39

Notes: The dependent variable is the log of the total factor productivity index. All variables are specified in logarithms, except those variables defined in percentage terms, which enter linearly (*NIANCA*, *D*6676 × *NIANCA*, *D*7787 × *NIANCA*, *LITERACY*, *WHYV*, *D*7787 × *WHYV*).

The lag structure reflects lags between the time when expenditures on research (and extension) are made and when they have their full economic impact. As conceived here, the lag has three segments. The first segment comes between the first appearance of the research result and its full effect. The second refers to the number of years during which the research contributes at full strength. The third represents a sort of "decay" in the research contribution, due perhaps to biological changes or its replacement by later, superior discoveries. The numbers used here refer to the number of years in each segment.

* Significant at 5 percent.

** Significant at 1 percent.

Table 28—Total factor productivity decomposition for the crop sector, 1956–87, estimated parameters with lag structure (3,3,3)

	Specification without the QMOD variable		Specification with the QMOD variable	
Variable	Parameter estimates	*t*-ratio	Parameter estimates	*t*-ratio
INTERCEPT	−0.131**	−2.65	−0.065	−1.28
MKTS	0.019**	5.64	0.017**	4.92
NIANCA	0.142**	5.65	0.117**	4.75
D6676×NIANCA	0.095**	3.15	0.097**	3.26
D7787×NIANCA	0.111**	3.72	0.097**	3.25
RELWAGE	−0.004	−0.58	−0.002	−0.38
LITERACY	0.113**	2.73	0.087*	2.08
EXT	0.039**	7.15	0.042**	7.69
D6676×EXT	0.005	0.64	−0.0002	−0.03
D7787×EXT	0.012	1.11	0.007	0.68
RES	0.032**	4.89	0.027**	4.08
D6676×RES	−0.003	−0.33	−0.0003	−0.03
D7787×RES	−0.010	−1.02	−0.006	−0.67
WHYV	0.038	1.56	0.035	1.41
D7787×WHYV	−0.039	−1.31	−0.062*	−2.05
YEARRAIN	0.0001**	15.56	0.0001**	15.51
JUNERAIN	−0.00003*	−1.89	−0.00003*	−1.68
JUAURAIN	−0.00005**	−4.09	−0.00004**	−3.98
YEAR	−0.004**	−3.80	−0.005**	−4.81
MCOST	−0.022*	−1.34	−0.025	−1.52
PRIVRES	0.014**	8.69	0.013**	7.42
QMOD	. . .	. . .	0.013**	5.27
QMOD×WHYV	. . .	. . .	0.028*	2.24
D6676	−0.062**	−3.30	−0.068**	−3.60
D7787	−0.043*	−1.83	−0.038	−1.51

Notes: The dependent variable is the log of the total factor productivity index. All variables are specified in logarithms, except those variables defined in percentage terms, which enter linearly (*NIANCA*, *D*6676 × *NIANCA*, *D*7787 × *NIANCA*, *LITERACY*, *WHYV*, *D*7787 × *WHYV*).

The lag structure reflects lags between the time when expenditures on research (and extension) are made and when they have their full economic impact. As conceived here, the lag has three segments. The first segment comes between the first appearance of the research result and its full effect. The second refers to the number of years during which the research contributes at full strength. The third represents a sort of "decay" in the research contribution, due perhaps to biological changes or its replacement by later, superior discoveries. The numbers used here refer to the number of years in each segment.

* Significant at 5 percent.

** Significant at 1 percent.

capture the effect of human capital on farming. Furthermore, immigration of landless labor to districts where TFP growth is high reduces the proportion of the literate in these districts, confounding the causal relationship between literacy and TFP.

The variable *MCOST* is a proxy measure of the initial stage of market and infrastructure development of each district. The convergence hypothesis, which holds that areas that are worse-off to begin with will catch up over time, predicts that *MCOST* will have a positive coefficient because high ratios of wholesale to farm prices reflect a greater potential for a district to catch up. The urban-industrial hypothesis, on the other hand, predicts that *MCOST* will have a negative coefficient. Districts nearer the central wholesale markets will perform better. The evidence presented here clearly supports the urban-industrial hypothesis. This finding is consistent with the positive effect of *MKTS*.

The time trend variable *YEAR* has a negative coefficient in both specifications. It should be noted that time trends reflect several factors. They may include negative effects from soil degradation (Antle and Pingali 1994) or cultivation intensity (Rosegrant and Pingali 1994). They can also include institutional and infrastructural factors not captured in the variables in the model, which may have either positive or negative effects. Unfortunately, the data needed to partition the negative time effects into such underlying causal factors, especially data for environmental variables, are not available.

However, other evidence indicates strongly that environmental degradation may contribute significantly to the negative trend over time. In parts of India (and elsewhere in Asia) where intensive rice monoculture has been practiced for two or three decades, there is considerable evidence that yields have been stagnant, partial factor productivities have fallen, especially for fertilizers, and that the growth rates of TFP have decreased (Cassman and Pingali 1995). A similar slowing can be seen in the trends for partial factor productivity in the rice-wheat zone in India reported by Kumar and Mruthyunjaya (1992) and Hobbs and Morris (1996). An important extension of the research reported here would be to develop the data needed to examine the underlying determinants, environmental or otherwise, of the negative time trend estimated here.

The second specification, with the variable *QMOD*, supports the rationing (and adoption) hypothesis for fertilizer. *QMOD* affects TFP positively, which indicates that in the TFP calculation fertilizer was underweighted as a direct input into production. This is given additional support by the positive interaction of *QMOD* with variables for modern varieties.[12] The estimates for extension, research, and private sector inven-

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[12] This variable picks up some of the improvement in quality of the input because the quality of fertilizer and machinery is not entirely adjusted for in the input indexes. The ratio of nutrients to total material in fertilizers produced in India went from 19 percent in 1960/61 to 41 percent in 1989/90. This change greatly reduced the cost of marketing fertilizer. The change to complex fertilizer may have increased the use of more balanced doses of fertilizer.

The fertilizer research was conducted by state corporations, cooperatives that produced fertilizer, private firms, and organizations like the Fertilizer Association of India. A large share of the research was done to develop processes that would reduce production costs and maximize the use of local materials and machinery. Another important share of "research" by the fertilizer industry was field trials. These had the dual purpose of adapting fertilizer doses to local conditions and making fertilizers more popular.

tion are all highly significant in both specifications. These activities produce TFP growth. The contribution of the private sector is particularly relevant as the profession is just beginning to take this sector into account in studies of this type.

The results show that high-yielding varieties have had an impact even controlling for the public research effect. This variable probably reflects the importance of imported high-yielding varieties (see Chapter 3).

Does the Contribution of Research, Extension, and Irrigation to TFP Fall Over Time?

The estimated parameters for the variables for the interaction between time and research and time and irrigation show that the marginal effects of research and irrigation in fact increased over time. As shown in Table 24, the marginal effect of research on TFP was slightly higher during 1966–76 than in 1956–65. During the mature Green Revolution, 1977–87, when returns could be expected to fall in regions that adopted the new varieties early, the marginal effect of research on TFP increased by approximately 50 percent.

The marginal effect of the expansion in irrigated area on TFP has also increased over time. This improvement can be attributed to the growth in private tubewell (groundwater) irrigation, which was more rapid than the growth of public canal irrigation. As noted in Chapter 2, between the late 1950s and the mid-1980s, the proportion of irrigated area under private tubewells increased from one-third to more than one-half (Figure 4). Micro studies confirm that the productivity is significantly higher in privately irrigated areas than in areas that depend on canal irrigation (Dhawan 1989).

In contrast, there is evidence of a small decline in the marginal impact of modern crop varieties on TFP during the late Green Revolution, but the decline is not statistically significant. This suggests that there may be a decline in the contribution to TFP embodied in modern crop varieties. However, since the *WHYV* variable measures the imported component, and since the research system is more productive, the estimates appear to reflect a reduced dependency on international research over time.

Results with Alternative Research Lag Structures

Tables 25–28 show the results of the two specifications underalternative lag structures. The parameters estimated for the variables other than public research change little when different lag structures are used. The one exception is literacy, which becomes statistically significant and has an increasingly positive impact on TFP as the research lag shortens. The estimated value of the coefficient of the research variable falls gradually as the research lag structure becomes shorter. The values of the dummy variables for the interaction of research and time also fall. However, as will be shown later, although the coefficient of the research variable (which is the elasticity of TFP with respect to research) declines slowly as the lag becomes shorter, the marginal internal rate of return to research increases substantially because the output from the research investment is realized more rapidly.

Accounting for the Growth of TFP

The effects of the growth-producing variables on TFP can be shown more readily through a growth-accounting exercise that relates growth in productivity to changes in the variables that produce that growth. To estimate how much each of these sources contributes to the growth of TFP, the growth-accounting exercise combines the parameters estimated for the sources of growth in the TFP decomposition equations with the rate of growth of those sources. Table 29 gives the growth rates estimated from the best-fit TFP decomposition equations presented in Table 24 for each source of growth and the explained components of TFP growth, by period, for all India.

Table 29—Growth accounting: Indian agriculture, computed using the index for modern fertilizer use and lag structure (9,9,9)

	Annual growth in source			Economic growth accounted for			
Growth/source	**1956–65**	**1966–76**	**1977–87**	**1956–65**	**1966–76**	**1977–87**	**1956–87**
Nonconventional input sources							
WHYV	0.000	0.024	0.008	0.000 (0.000)	0.271 (0.096)	0.058 (0.008)	0.110 (0.035)
RESEARCH	0.081	0.053	0.112	0.290 (0.346)	0.244 (0.265)	0.603 (0.636)	0.379 (0.415)
PRIVRES	0.069	0.184	0.078	0.090 (0.096)	0.239 (0.257)	0.102 (0.109)	0.143 (0.154)
EXTENSION	0.210	0.052	0.155	0.903 (0.819)	0.219 (0.224)	0.634 (0.695)	0.585 (0.580)
LITERACY	0.007	0.006	0.007	0.009 (0.011)	0.009 (0.021)	0.010 (0.022)	0.010 (0.022)
MKTS	0.030	0.048	0.035	0.056 (0.061)	0.091 (0.101)	0.067 (0.074)	0.071 (0.078)
Sum of nonconventional input sources	. . .	. . .	. . .	1.348 (1.343)	1.073 (0.964)	1.474 (1.544)	1.298 (1.284)
Input sources							
NIANCA	0.003	0.006	0.005	0.035 (0.043)	0.129 (0.143)	0.107 (0.126)	0.091 (0.104)
QMOD	0.200	0.107	0.080	0.266	0.200	0.164	0.210
Measured total factor productivity growth in normal years	. . .	. . .	. . .	1.270	1.490	1.140	1.310

Notes: These figures were computed using the parameters estimated for the specification with the *QMOD* variable in Table 24. The numbers in parentheses are based on the specification without the *QMOD* variable in the same table. The measured total factor productivity growth in normal years comes from Table 20.

TFP growth in 1956–65, before the Green Revolution, was respectable. The estimates in the table credit extension with almost 70 percent of this growth. The public research system contributed about 22 percent and private research contributed roughly another 7 percent. Modern inputs also contributed significantly.

During the early Green Revolution, the contributions of high-yielding varieties (25 percent of growth), public research (23 percent), and private sector research (22 percent) became proportionally much greater, while the contribution of extension fell. The excess contributions of irrigation and modern inputs were also high during this period.

During the mature Green Revolution, the contribution of high-yielding varieties fell, largely because high-yielding varieties at this time were predominantly domestic and their contribution was included in the variables for the public research system. The contribution of extension was restored because farmers faced less obvious choices regarding technology than they had had during the early Green Revolution. The contribution of research in the private sector fell as India's trade and industrial policy turned inward and foreign technology was downplayed (see Chapter 3).

Table 29 gives the results of the estimation of the sources of the growth of Indian agriculture using both specifications.The specification that includes *QMOD* is superior, but differences between the two are minor. Nonconventional input sources almost fully account for measured TFP growth over the entire 1956–87 period of 1.31 percent. Additional growth of TFP is accounted for by the sources related to inputs, *NIANCA* and *QMOD*. However, the dummy variables for the year trend and period, *D*6676 and *D*7787, are negative. As noted in the discussion of regression parameters, these negative contributions can reflect the contributions of a number of unmeasured variables, including institutional, infrastructural, and environmental factors. The overexplanation is smaller in the first specification, without *QMOD*, than when *QMOD* is included.

Nonconventional input sources tend to underaccount for TFP growth during the early Green Revolution and to overaccount for it during the mature Green Revolution. This appears to be associated with the short time involved. Some of the differences between periods are worthy of further discussion, however.

Over the full period between 1956 and 1987, the public sector extension system was the largest source of growth. It accounted for more than 40 percent of the growth of TFP. The public sector research system accounted for more than 30 percent. When high-yielding varieties are considered—in this case they were largely imported—public sector research accounted for roughly 38 percent of TFP growth. Private industrial research (part of which was imported) contributed more than 10 percent.

The estimates show that improved markets made a significant 6 percent contribution to the growth of TFP. The excess contribution of irrigation and fertilizer in the specification with *QMOD* was also substantial. The findings show that literacy contributed little to the growth of TFP. This may be partly because literacy is a poor measure of farmers' skills.

Computation of Estimated Marginal Products, Value Marginal Products, and Internal Rates of Return

The estimated coefficients of the variables for research, extension, irrigation, and other variables not only allow us to make the growth accounting calculations, but they can be used to compute the marginal products of the capital stocks and the marginal internal rates of return to investments in research, extension, and irrigation. The estimated specification (Table 30) is

$$\ln(TFP) = a + b_r \ln(R) + b_e \ln(E) + \ldots, \tag{7}$$

where R is the research stock, E is the extension stock, and so forth. The estimated elasticity of TFP with respect to the research stock is thus

$$\partial \ln(TFP)/\partial \ln(R) = b_r. \tag{8}$$

Table 30—Estimated marginal products and estimated rates of return to investment, computed using the index for modern fertilizer use and lag structure (9,9,9)

Investment variable	Estimated elasticity of marginal total factor productivity (***EME***)	Value of output/ investment (***V/INV***)	Estimated value of marginal product (***EVMP***)	Estimated marginal internal rate of return (***EMIRR***)
				(percent)
Extension	0.039	100	3.9	45
Research (public)				
1956–65	0.036	148	5.3	58
1966–76	0.046	121	5.6	59
1977–87	0.054	97	5.2	57
1956–87	0.045	120	5.4	58
(Imported) HYVs	0.113	35	4.0	55
Private research and development	0.013	200	2.6	35
Irrigation				
1956–65	0.118	0.28	0.033	4
1966–76	0.212	0.26	0.055	6
1977–87	0.217	0.20	0.043	5
1956–87	0.184	0.25	0.044	5

Notes: These figures were computed using the parameters estimated for the specification with the *QMOD* variable in Table 24. The rates of return to irrigation, private research and development, and investments in imported high-yielding varieties (HYVs) are the returns above the direct contribution of these factors to inputs.

Before calculating value marginal products, several other variables need to be defined: V is the value of crop output associated with stock R, M_{t-i} is investment in time $t-i$, and $S = \sum_{k=0}^{i} W_{t-1+k}$ is the sum of the time weights by which the investment in time $t-i$ is added to or cumulated in the stock (these weights are the [9,9,9] time weights discussed here and in the Appendix). Since S is the cumulation factor, it is also the ratio of the stock to the investment:

$$S\,(M_{t-i}) = R_t^* \text{ or } S = R/M, \tag{9}$$

where R_t^* is the contribution of investment in time $t-i$ to the stock of research in time t. The estimated marginal product of R, the research stock, is therefore

$$EMP(R) = \partial TFP/\partial R = b_r\,(TFP/R). \tag{10}$$

The estimated value marginal product of R is

$$EVMP(R) = (\partial TFP/\partial R)V = b_r\,(V/R)\ TFP\,, \tag{11}$$

and the estimated value marginal product of M_{t-i} is

$$EVMP\,(M_{t-i}) = EVMP\,(R)\ (\partial R/\partial M_{t-i}) = EVMP\,(R)\,S = b_r\,(V/M_{t-i})TFP. \tag{12}$$

Thus the estimated value marginal product of a one-time investment in period $t-i$ is the estimated elasticity times the output to investment ratio.

It can also be seen that $EVMP\,(M_{t-i})$ has a time or benefit stream dimension. This is because it not only generates a marginal product in time t, but it generates one in all past periods going back to $t-i$. Accordingly, a benefit stream can be generated from equation (12). The investment in period $t-i+1$ will generate a benefit of (0.1) $[b_r\,(V/M_{t-i+1})]$ in period $t-i+2$, (0.2) $[b_r\,(V/M_{t-i+2})]$ and so forth, where (0.1), (0.2), and so on are the time weights. The benefit stream will thus be

$$B_k = \sum_{k=0}^{i} W_{t-i+k}\ [b_r\,(V_{t-i+k}/M_{t-i})]. \tag{13}$$

This stream can be discounted at discount rate ∂

$$PV_{t-i} = \sum_{k=0}^{i} B_k\ /\ (1+\partial)^k, \tag{14}$$

and the discount rate at which PV=1 can then be considered to be the marginal internal rate of return to investment.

Table 30 presents the relevant estimated elasticities (*EME*), output to investment ratios (*V*/*INV*), estimated value marginal products for investments (*EVMP*), and estimated marginal internal rates of return (*EMIRR*) for investments in extension, public research, high-yielding varieties, private research, and irrigation. The time weights used in computing *EMIRR*s in Table 30 follow the (9,9,9) research lag structure described above and use the specification in Table 24 that includes *QMOD.* The results using the other specification, without *QMOD,* are virtually identical. For comparison, Table 31 shows the *EMIRR*s under alternative lag structures computed using the specification of the TFP decomposition equations in Tables 25–28 that includes *QMOD.*

In interpreting the results, it is important to note that the estimates for high-yielding varieties, private research and development, and irrigation are only part of the full marginal products of these investments. For public extension and research investments, these can be considered to be the full social products. High-yielding varieties, as noted above, are predominantly imported—particularly from IRRI (see Chapter 3). Many of these high-yielding varieties have been planted widely or used as parent stock in other countries, so the contribution in India captures only part of their total values. Nevertheless, their value in India is high and, judging by its contribution in India, research on high-yielding varieties yields a high rate of return.

As Table 30 shows, the marginal rates of return to public agricultural research investment are high, nearly 60 percent in each of the three periods. The returns to public extension are also high, 45 percent.

Private research and development in India (and some of the modernization of management associated with it) produce a return to the private firms investing in them (Basant and Fikkert 1996). The public benefits realized in the agricultural sector come in addition to these private gains. Clearly the social benefits realized in the agricultural sector from private research are large and sufficient by themselves to call for more investment in it. Evenson (1993) reviews the rates of return to public and private sector research and development. He notes that most studies of private sector research

Table 31—Estimated marginal internal rates of return to investment with alternative lag structures for research investments

	Estimated marginal internal rate of return			
	Lag structure (3,3,3)	Lag structure (3,3,6)	Lag structure (3,6,6)	Lag structure (6,6,6)
	(percent)			
Extension	45	44	44	44
Research (public)	91	88	84	82
(Imported) HYVs	58	57	56	54
Private research and development	35	35	35	35
Irrigation	5	5	5	5

Notes: These figures were computed using the specifications with the *QMOD* variable in Tables 25–28. The rates of return to irrigation, private research and development, and investments in imported high-yielding varieties (HYVs) are the returns above the direct contribution of these factors to inputs.

and development find that a large proportion of the benefits from such research are public goods, not captured by the firms making the investments.

Similarly, some returns to investment in irrigation are captured by the private firms and government agencies that made the investment. (These returns are reflected in the TFP measures by treating the value of irrigation investment as an input into production. The returns reported for irrigation in Table 30 are additional, technology-related benefits. These gains can be interpreted as associated with an expansion of production environments favorable to newly developed technology.

A comparison of Table 31 with Table 30 shows that the marginal rates of return to private research and development and irrigation are identical for all the alternative research lag structures. However, the rates of return to research and high-yielding varieties increase steadily as the lag structure on the research variable shortens.

Conclusion

This chapter provides evidence that the growth of TFP in Indian crop agriculture is associated predominantly with improved technology. Before the Green Revolution, the largest source of this growth was the extension service. Extension facilitated the adoption of modern inputs and the improvement of farm efficiency, even though India had not yet produced much improved technology.

With the advent of the Green Revolution, access to high-yielding varieties and the associated public research system became the major sources for growth in TFP. The ease with which farmers could identify superior varieties reduced the role of extension. Private-sector research and modern inputs were important during this period.

After the Green Revolution, the public-sector research and extension systems came back into prominence as major sources of TFP growth. Improved varieties came mostly from domestic programs, and farmers were faced with decisions about adopting second and third generations of high-yielding varieties. Extension systems were more important to these decisions than to the adoption of first generation high-yielding varieties.

The returns estimated for public agricultural research are high and consistent with evidence from other studies. Table 32 shows *EMIRR*s for South Asian agriculture from previous studies. This study confirms the findings of previous studies for the investments considered. The returns to investment in public-sector agricultural research and extension programs are high—far higher than the average returns from public-sector investment in India.

Table 32—Estimated marginal internal rates of return to agricultural research and extension in South Asia

Category/study	Year	Country/ crop	Period	Type[a]	Estimated marginal internal rate of return (*EMIRR*)
					(percent)
Aggregate program estimates (research)					
Evenson and Jha	1973	India	1953–71	EM	40
Kahlon et al.	1977	India	1960–73	EM	63
Pray	1978	Pakistan	1906–56	ES	34–44
			1948–63	ES	23–37
Nagy	1985	Pakistan	1959–79	D	64
Khan and Akbari	1986	Pakistan	1955–81	EM	36
Evenson and McKinsey	1991	India	1958–83	D	65
Dey and Evenson	1991	Bangladesh	1973–89	D	143
Azam, Bloom, and Evenson	1991	Pakistan	1956–85	D	58
Rosegrant and Evenson	1992	India	1956–87	D	62
This study	1998	India	1956–87	D	58
			1966–76	D	59
			1977–87	D	57
Aggregate program estimates (extension)					
Rosegrant and Evenson	1992	India	1956–87	D	52
This study	1998	India	1956–87	D	55
Private research and development in agriculture					
Rosegrant and Evenson	1992	India	1956–87	D	50
This study	1998	India	1956–87	D	35
Commodity research					
Evenson and McKinsey	1991	India			
		Rice	1954–84	D	155
		Wheat	1954–84	D	51
		Jowar	1954–84	D	117
		Bajra	1954–84	D	107
		Maize	1954–84	D	94
Nagy	1985	Pakistan			
		Maize	1967–81	ES	19
		Wheat	1967–81	ES	58
Morris, Dubin, and Pokhrel	1992	Nepal			
		Wheat	1966–90	ES	37–54
Byerlee	1993	Pakistan			
		Punjab			
		Wheat	1978–87	ES	22

(continued)

Table 32—Continued

Category/study	Year	Country/ crop	Period	Type[a]	Estimated marginal internal rate of return (*EMIRR*)
					(percent)
Azam, Bloom, and Evenson	1991	Pakistan			
		Wheat	1956–85	D	76
		Rice	1956–85	D	84
		Maize	1956–85	D	45
		Pearl millet	1956–85	D	42
		Sorghum	1956–85	D	48
		Cotton	1956–85	D	102

[a] The types of study are: EM = aggregate production function
ES = economic surplus
D = total factor productivity decomposition.

CHAPTER 6

Conclusions and Policy Implications

Several key conclusions can be derived from the analysis in this report. First, India has made significant investments in public-sector agricultural extension and research. Today, the Indian agricultural research system is one of the largest in the world. Indian research programs—with considerable support from IARCs (especially ICRISAT, IRRI, and CIMMYT)—have produced significantly improved crop technology. This has been embodied in several generations of improved crop varieties and patented agricultural inventions.

The private sector in India has also made large investments in research and development relevant to agriculture. This investment has increased rapidly over time. The amount of agricultural research and development in the private sector is now approximately half the amount in the public sector. A considerable body of research and development of foreign origin has influenced agriculture in India.

India's agriculture has made substantial gains in productivity, as measured by indexes of TFP. These gains have varied by period (they were highest during the early Green Revolution) and by region (they were highest in regions that produce wheat or rice), but TFP has increased in virtually every district in India. The rate of change in TFP has been high. Growth in TFP has contributed 1.1–1.3 percent per year to crop production growth in India (the precise figure depends on the method used to compute growth rates). Conventional inputs have contributed about 1.1 percent per year since 1956. TFP and conventional inputs have thus contributed roughly 2.3 percent per year to the growth of crop production. They have enabled India to increase food production per capita despite high population growth rates and limited land resources.

Analysis shows that several types of investments are associated with and contribute to TFP growth. Public agricultural research explains nearly 30 percent of TFP growth between 1956 and 1987 and almost half of it since the Green Revolution. This study is one of the first to investigate the contributions of private sector research and development to the growth of productivity in India. It shows that research and development by agribusiness firms in the farm machinery and farm chemical industries have contributed significantly to TFP growth. The private sector contribution is associated with the modernization of agriculture through adoption of improved inputs and improvements in farm management practices. Investment in agricultural extension programs has had substantial effects on the growth of TFP. Improved rural markets, irrigation investment, and modern inputs have also contributed to TFP growth. Irrigation investment and modern inputs generate growth over and above the contribution that they make as conventional inputs. The additional contribution from irrigation comes largely because it improves the environment for crop technology.

The report examined the hypothesis that the contributions of public research and other investments to TFP growth decreased over time. The effects of these factors were disaggregated into three periods: before the Green Revolution (1956–65), the early Green Revolution (1966–76), and the mature Green Revolution (1977–87). The marginal effects of public research on TFP were moderately higher during 1966–76 than in 1956–65. More importantly, during 1977–87, when returns could be expected to fall in regions such as the Punjab that had been quick to adopt modern varieties, research had an impact on TFP, shown by the estimated marginal elasticity of TFP, which was 50 percent higher than before the Green Revolution and 17 percent higher than in the early Green Revolution. The marginal impact of the expansion of irrigated area on TFP also increased over time. This improvement can be attributed to the rapid growth of private tubewell (groundwater) irrigation.

Modern crop varieties contributed to TFP growth during the early Green Revolution, and, at a reduced rate, during the mature Green Revolution. This decline in the contribution of modern varieties, at a time when the public-sector research and the irrigation contribution actually increased, appears to reflect both a shift from an early reliance on modern varieties of foreign origin to modern varieties originating in India and a broadening of the mechanism through which research contributes to TFP. The contributions of Indian public research are captured in the latter period mainly through their effects on research rather than their embodiment in modern crop varieties.

It is thus clear that from the perspective of growth accounting, India has achieved significant growth in TFP and that this growth has made it possible to increase food production per capita since Independence. This occurred even though the growth rates of India's population have been the highest in its history and even though India began the period with high population densities and only a limited potential to use cropland expansion as a source of output growth. It is also clear that this growth in TFP was produced by investments in research, primarily, but also in extension, markets, and irrigation.

The rates of return to investment were computed from the parameters estimated in the TFP decomposition analysis presented in Chapter 5. The perspective gained from looking at investment differs from the perspective gained from looking at growth accounting in one important aspect. The investment perspective attempts to measure the stream of benefits associated with increases in investment in research, extension, and irrigation. The growth accounting perspective, in contrast, takes into account the growth in investment in these activities and measures the associated growth in TFP.

It is important to note that the evaluation of the sources of TFP is based on the research and extension programs implemented over the past three to four decades. This does not imply that the management and design of these programs was ideal. There was almost certainly room for improvement, as many management reviews indicated. The methods (and data) used here do not lend themselves easily to an examination of the qualitative dimensions of these programs. An assessment of these issues would require additional data on such things as research quality and the skills of extension staff. Further study using such data is merited—although policymakers should not expect too much qualitative guidance from these types of ex-post studies. Experience alone can be evaluated with studies of the type undertaken here. This type of analysis does not end the need for careful and continuous ex-ante evaluations of research and extension programs using other methods.

Several broad policy conclusions can be drawn from this evidence. The most obvious is that India has realized high returns to investment in TFP. By inference, it could have realized greater gains in TFP with more investment. The signals clearly call for expanding research and extension programs. Such an expansion should be based on careful review of projects and programs and of system design.

The results also indicate the need to continue support for IARCs and to strengthen the links between the IARCs and the Indian system. The role of the IARCs has changed over time, so that the IARCs are now predominantly suppliers of germplasm to be further adapted by Indian institutions, rather than suppliers of varieties for immediate release to farmers. And within the Indian system, many strong institutions supply germplasm to other institutions. But all institutions in the Indian system should be aware that they are receivers of germplasm as well.

Those who make policy affecting research and extension clearly need to be aware that the role of private-sector research and development in India is expanding, as is the role of foreign suppliers of technology. This was shown in both qualitative and quantitative analyses. Indian public policy toward private-sector research and development has not fully recognized this. Industrial and technology policies, including policies toward intellectual property rights, should be evaluated carefully in order to encourage private investment in agriculture. Barriers to technology transfers should be removed.

The Indian experience provides opportunities for social science research on the sources of growth of agricultural productivity. India is a large country with a broad range of environments for agricultural production. Because research and extension programs are supported largely by state governments, there are important differences across India in the amounts invested.

This study and others preceding it have by no means exhausted the opportunities to study productivity afforded by the Indian experience. More recent data can be exploited further. Models of inventions and the process of research discovery can be used to impose more structure on the TFP decomposition equations. The adoption and diffusion of modern varieties of major crops can be treated as endogenous to the production model. The determinants of TFP can be disaggregated by agroclimatic zone, to explore, for example, the determinants of TFP and rates of return to research in favorable and unfavorable environments. One of the most important extensions of this work would be research on the effects of changes in the environment on TFP.

This study is one of the first to recognize the role of private-sector research and development in agricultural productivity. It implicitly recognizes spillovers from international research and development as well. Additional studies can do more to explore these dimensions. The agricultural sector has been important to broader economic developments in India. Further work documenting these contributions will add to the understanding of the process of economic growth and to the ability to develop policies and make investments that can facilitate this process.

APPENDIX

Variables in the Data Set

This appendix describes the variables in the data set: their definitions, units, sources, any transformations they underwent, and any special treatment that they required. The variables are presented in five groups: coverage, outputs, variable inputs, and other inputs.

Coverage

The data set covers nearly all districts—a total of 271—within 13 of the states of India: Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, and West Bengal. These 13 states include the 3 primary states producing northern wheat and northern rice (Haryana, Punjab, and Uttar Pradesh), 2 states producing northwestern pearl millet (Gujarat and Rajasthan), 3 eastern states (Bihar, Orissa and West Bengal), and all of the states specified by ICRISAT as being in the semi-arid tropics. The major agricultural states not included in the data set are Kerala, at the southern tip of the subcontinent, and the eastern state of Assam. Also absent, but less important agriculturally, are the minor states and union territories in the northeast and the far-northern states of Himachal Pradesh, Jammu, and Kashmir.

During the period covered by the data set, numerous adjustments were made in the boundaries (and even existence!) of some of the districts. Such changes occurred, for example, when the Punjab was divided into Punjab, Haryana, and Himachal Pradesh, when some districts were divided into two or more smaller districts (this was especially important in Bihar), or when parts of one district were transferred to another. The data set preserves the original district boundaries where possible. Where districts were broken up, the values for the resultant districts were summed to yield values appropriate to a shadow consolidated district.[13] The data set treats Haryana's districts as though they always belonged to a state named Haryana even though they were part of the original Punjab before 1966. Some districts that now exist do not appear in the

[13] This means that the actual number of modern-day districts covered is considerably larger than 271 because many current districts have been consolidated into the larger districts from which they had emerged.

data set, therefore, because they have been combined with other districts to create aggregations that approximate historical boundaries. Other districts may not appear for other reasons, the most common of which would be a dearth of agricultural activity (examples are Bombay, a few Himalayan districts of northwestern Uttar Pradesh, and a few desert districts of Rajasthan). Occasionally, however, they are not included because there is little data available for them.

Each district is assigned a unique identification code. This is composed of a two-digit state code (in the variable *STATE*) and a two-digit district code (in the variable *DISTRICT*). In addition, the variable *STNAME* contains the name of each state or its abbreviation. The data set contains observations for each of the variables for the agricultural years 1956/57 through 1987/88. The agricultural year 1956/57 is denoted by 1956 in the variable *YEAR* in the data set, the agricultural year 1983/84 is denoted by 1983, and so forth. With the exception of three of the rainfall variables (which are clearly identified to refer only to a few specified months during the given year), all variables are expressed as annual flows, average annual stocks, or average annual levels.

Outputs

The data set contains data for 5 major and 13 minor crops. The major crops are represented by the variables pearl millet (*BAJRA*), sorghum (*JOWAR*), *MAIZE*, *RICE*, and *WHEAT*. The minor crops are barley (*BAR*), cotton (*COTN*), groundnuts (*GNUT*), gram (*GRAM*), jute (*JUTE*), other pulses (*OPULS*), potatoes (*POTAT*), rapeseed and mustard (*RMSEED*), sesamum (*SESA*), soybeans (*SOY*), sugar (*SUGAR*), sunflowers (*SUNFL*), and tobacco (*TOBAC*).

For each of the minor crops the data set includes area planted (1,000 hectares; A followed by the crop code), production (1,000 metric tons; Q followed by the crop code), and the farm harvest price (rupees per quintal; P followed by the crop code). For the five major crops, the data include the three variables listed above plus the area irrigated under the crop (1,000 hectares; I followed by the crop code) and the area planted with high-yielding varieties of each crop (1,000 hectares; H followed by an abbreviated crop code).

The primary sources for the data on area and production include: India, Directorate of Economics and Statistics, *Area and Production of Principal Crops in India* (New Delhi, various years); crop and seasonal reports of the various states; statistical abstracts of the various states; and India, *Agricultural Situation in India*, various years.

From 1954 until the late 1960s, the Directorate of Economics and Statistics published *Area and Production of Principal Crops in India* in two parts. Part I contained data for all-India and the states, while Part II contained data for the districts. Typically, each issue of Part I would cover three years or so, while Part II would appear less frequently and cover a longer time. But no Part II has been published for 20 years. Therefore, the most convenient source for more recent data on area and production has been the monthly *Agricultural Situation* report.

The estimates of area and production for districts presented in *Agricultural Situation* are called “final” estimates and are usually the first estimates to be published. But these so-called final estimates are still subject to change, to be superseded by what are called "revised" estimates. No such changes are reported in *Agricultural Situation*, so there is no way to know whether revisions have even been made without consulting other sources. The revisions are seldom large, however, so this data set relies heavily for much of the 1970s and 1980s on estimates from *Agricultural Situation.*

Whenever it was possible to gain access to statistical abstracts or crop and season reports of any state for any of the years covered by the data, those sources were used for estimates of area and production. Those sources were especially valuable in providing data on area irrigated and area planted with high-yielding varieties for each of the major crops, although *Agricultural Situation* has begun to include those data as well.

Farm harvest prices by district are easily available from *Farm Harvest Prices of Principal Crops in India*, published every four years or so by the Directorate of Economics and Statistics. The prices are reported in rupees per quintal. Both wholesale and retail prices for all crops are also available, published regularly in *Bulletin on Food Statistics, Agricultural Prices in India*, and elsewhere. Retail prices would be appropriate, for example, in a study on consumption behavior or poverty. Wholesale prices would be of interest, for example, in studying a government's grain procurement policies or interstate food movements. For this report, however, farm harvest prices are of greater interest. It is on the basis of those prices, or farmers' expectations of their future values, that farmers determine their behavior. But the data set also includes the wholesale prices of most crops, and a weighted and aggregated average variable for relative prices (*RELPRICE*), whose weights are the share of the crop in total area in the district. *RELPRICE* is computed as the farm harvest price divided by the wholesale price. It is one of the institutional variables in the data set.

Variable Inputs

The data set includes three categories of variable inputs: labor, fertilizer, and power.

There are seven variables for labor. Rural population (*RURPOP*) is the total population of a district, male and female, residing in areas classified as rural. Agricultural labor (*AGLABOR*) is the number of rural males whose primary job classification is agricultural labor. Cultivators (*CULTIVAT*) is the number of rural males whose primary job classification is cultivator. Total farm labor (*QLABOR*) is a weighted sum of *AGLABOR* and *CULTIVAT.* Wages (WAGE) is the weighted annual cost of labor. Factory earnings (*FACTEARN*) is the weighted annual earnings in a rural factory.

The first three variables are obtained from the decennial population census. This gives many population totals and the job classifications of all persons enumerated. Population censuses have been conducted in India for more than a century and are widely regarded as highly accurate. Census results are published in an extensive series of volumes for each state; the values of the rural population and job classifications in districts are reported in the *Primary Census Abstract*. They are reprinted frequently in *Statistical Abstracts* and in many other sources. The data set is based on values for the census years 1951, 1961, 1971, and 1981. The values of *RURPOP, AGLABOR,* and *CULTIVAT* for the other years in the data set are linear interpolations (1956 through

1960, 1962 through 1970, and 1972 through 1980) and linear extrapolations (1982 through 1987) of the reported data. Interpolating population values is probably benign: such variables change regularly and consistently. The numbers of agricultural laborers and cultivators often change substantially within a decade, so that linear interpolations between census years may mask more volatile behavior. Unfortunately, however, the values of the population variables are not measured between censuses, so no better data exist.

The values for *RURPOP* appear in the data set exactly as they were recorded. The values for *AGLABOR* and *CULTIVAT,* however, measure stocks: the number of people who claim those activities as their primary job. The appropriate variable is a flow: the amount of labor performed during the year by such workers. The data for this variable are given below:

State	Number of Days Worked by Farm Workers
Andhra Pradesh	230
Bihar	210
Gujarat	215
Haryana	244
Karnataka	217
Madhya Pradesh	239
Maharashtra	240
Orissa	210
Punjab	244
Rajasthan	215
Tamil Nadu	293
Uttar Pradesh	210
West Bengal	210

To get these figures, the number of agricultural laborers and cultivators were added and their sum was multiplied by the average number of days worked in the state by farm workers. This made it possible to compute the appropriate flow for the labor services variable (*QLABOR*). The data come from various farm management surveys.

Agricultural wages are obtained from *Agricultural Wages in India*, published by the Directorate of Economics and Statistics every two or three years. It reports daily wages and normal daily working hours in each month for different farming activities. The data are collected at reporting centers in most districts. Wages for some activities are reported separately for men, women, and children. Whenever possible, the wages of a male plowman were recorded; if a district did not record such a wage, the wages of a male field laborer or a male in the category “Other Agricultural Labor" were selected instead. An average annual wage was constructed from the monthly wages, weighting June and August more heavily than other months because of the intensity of fieldwork during those months in most cropping patterns and most states.

The variable for factory earnings measures the average annual earnings of an unskilled laborer working in a rural factory, which could employ as few as two people. This variable not only measures the opportunity cost of working on one's own farm, it also captures some of the supply conditions of the local rural labor market. A relative wage is computed simply by dividing annual farm earnings by average annual factory earnings.

The variables for fertilizer include the quantities of nitrogen, phosphorous, and potassium fertilizers (in metric tons: denoted by *NITRO_TQ*, *P*205_*TQ* and *K*20_*TQ*) and the prices of the three fertilizers (in rupees per metric ton of nutrients: *NITRO_TP*, *P*205_*TP*, *K*20_*TP*). The source for fertilizer data is *Fertilizer Statistics*, published annually by the Fertilizer Association of India. The quantities of fertilizer are given by district, by nutrient, and often by season; only annual data are included in the set. The prices of fertilizers are strictly controlled by the central government, so the only cross-section price variations stem from differences in the cost of transportation from the railhead to the field. The prices of the nutrients in the data set, therefore, show no cross-section variation, but are based on the reported maximum sale prices of common fertilizer compounds, adjusted for the proportion of the nutrient present in each compound. Prices are not reported for all nutrients for all years; prices for intervening years are estimated based on movements of the fertilizer wholesale price index.

Farm (draft) power comes primarily from two sources: bullocks and tractors. The quantities of both are given in the quinquennial livestock census. As with the population census, the results of each livestock census are published in two parts, with the data for all India and the states in Part I and district data in Part II. Part II has been published for the censuses of 1956, 1961, 1966, 1972, and 1977 (the census scheduled for 1971 had to be postponed to 1972), but the data for districts were not yet available for the census of 1982 for this study. The publication backlog seems to be increasing, and since the district data from the 1977 census were not released until December 1987, it is unlikely that the district data from the 1982 census will be available soon.

Bullocks (*QBULLOCK*), as recorded for the data set, refer to castrated (male) cattle more than three years old, which are used in rural areas only for work. Tractors (*QTRACTOR*) are four-wheel machines, that is, they are neither tracked machines nor walk-behind two-wheel tractors.

The numbers of bullocks and tractors are estimated for the years between censuses (1957–60, 1962–65, 1967–71, and 1973–76) by linear interpolation. For the years after 1977, for which no data had yet been published for the districts at the time of this study, the data set contains estimates computed by extrapolating the 1982 observations at a rate equal to the percentage change in the 1977 to 1982 values for the states.

Tractor prices do not vary across India: therefore, a single tractor price is used for all districts in any given year. The tractor price is constructed as follows: the price index for agricultural machinery and transport equipment from 1954 through 1985 was compared to the prices of Eicher 24-horsepower tractors in selected months from 1978 to 1987. (The Eicher prices were collected by P. C. Bansil of the Techno-Economic Research Centre, New Delhi.) Movements in the price index mirrored movements in the Eicher tractor prices almost perfectly, so the Eicher price series was extended back to 1956 on the basis of proportional changes in the price index for agricultural machinery and transport equipment. Eicher commands more than half of the market for tractors in the 1 to 25 horsepower range, which is the largest segment of the tractor market in India. Larger tractors command a higher price, however, so the Eicher 24-horsepower tractor's share is smaller in the value of all tractors than in the number. Thus the average price of a tractor would be higher than the price of an Eicher 24-horsepower tractor. To adjust for that, the estimated Eicher price series was multiplied by 1.66. This number is derived from data that show the difference in prices for Escort tractors of various horsepower ratings in the early 1970s. The result is a series for tractor prices that is consistent with both movements of the price index and independent data on the prices of actual tractors. This tractor price series was multiplied by one-fourth to derive an annual tractor cost variable (*PTRACTOR*). This multiplier—one-fourth, or 25 percent—represents both depreciation and debt service on the investment. It includes the rate of return required if tractors are to be bought in the first place. Thus the variable for the annual cost of tractors represents a sort of shadow rental cost of a tractor, in the appropriate flow form.

The data set contains three series of bullock prices, reflecting the physical differences in bullocks in different parts of India. Each series is based on retail price indexes reported in various issues of *Agricultural Prices in India,* published by the Directorate of Economics and Statistics. Bullocks are identified by state in this publication, for example, Bihar, Gujarat, Haryana, and Uttar Pradesh. The Haryana price was applied to bullocks in Haryana and Punjab, the Gujarat price was applied to bullocks in Gujarat, and the more prevalent Uttar Pradesh price was applied to bullocks in all other states. Rental fees for bullocks are difficult to obtain. The annual bullock cost variable (*PBULLOCK*) was obtained by multiplying each bullock price by 0.50. This takes into account both the expenses of breeding, raising, and feeding bullocks and the necessary rate of return on their ownership.

In closing the discussion of the variable inputs, it should be noted that the values of these prices and quantities are realistic in the sense that they imply input cost shares that are consistent with the range of cost shares obtained in earlier research.

Other Inputs

The data set contains additional inputs that are not subject to the control of farmers in the short run. Some of these inputs, such as rainfall, are beyond the influence of any human agency. And some, such as certain forms of irrigation and perhaps literacy, can be influenced by farmers' decisions and behavior only over a long period of time. Still others, such as research and extension, are partly the result of governmental decisions, possibly in response to diffuse and highly lagged demand from farmers, which is as much political as economic. Though they are not variable in the traditional sense, these other inputs do significantly influence agricultural output and productivity. They can be classified into two subgroups, agroclimatic inputs and public inputs.

Agroclimatic Inputs

The inputs classified as agroclimatic include the most basic agricultural inputs: soil and water. Two of the variables measure the use of land: gross cropped area (*GCA*) and net cropped area (*NCA*). The latter is the total geographic area on which a crop has been planted at least once during the year. Gross cropped area is the total area planted with crops during all the growing seasons of the year. If any land has been double-cropped, it will appear only once in the data for net cropped area, but twice in the data for gross cropped area. Both *GCA* and *NCA* are measured in units of 1,000 hectares.[14]

Water is supplied in two ways: naturally, as rainfall, and artificially, as irrigation. Data on irrigation are reported as area irrigated by source (for example, by canal, tank, or tubewell) and by total area irrigated.

The data set includes three variables to show irrigation by source. The quinquennial *Livestock Census*, discussed above, gives the stocks of farm implements, including irrigation equipment. The variables for rural electric pumps (*RELCPUMP*), rural oil pumps (*ROILPUMP*) and rural Persian wheels (*RPERWHL*) are interpolated and extrapolated in the same fashion as the tractor and bullock variables. These three variables represent numbers of wells—both modern tubewells and more traditional pit wells serviced by Persian wheels. They do not measure the area covered by the water pumped from those wells.

The data set also includes two variables to show total area irrigated. Net irrigated area (*NIA*) measures the total geographic area that was irrigated by any source during the year. Gross irrigated area (*GIA*) measures the total area under crops that was irrigated during the growing seasons of the year. As with *NCA* and *GCA*, if any irrigated land was double-cropped, it would appear only once in the data for net irrigated area, but twice in the data for gross irrigated area. Once again, the variables are measured in units of 1,000 hectares.[15]

Estimates of gross and net cropped area and gross and net irrigated area are available from the annual *Indian Agricultural Statistics*. This is published in two volumes. Data for all of India and the states appear in Volume I ; district data appear in Volume II. These data are also available in most states' crop and season reports and statistical abstracts. They have also been published in the *Agricultural Situation in India* since the early 1980s. Data on irrigated area for specific crops are also given in *Fertilizer Statistics*.

Two additional variables were computed to convert the data for *NCA* and *NIA* into acres, rather than in units of 1,000 hectares. They are, respectively, *QLAND* and *QIRR.*

The data set includes two land price variables: the price of all arable land (*PNCA*) and the price of irrigated land (*PNIA*). The prices are given in rupees per acre, which is what made it necessary to create *QLAND* and *QIRR.* Both *PNCA* and *PNIA* are based

[14] Another variable computed measures the intensity of double-cropping. This is *GCANCA,* which is *GCA* divided by *NCA.* It ranges upward from a value of one, at which no double-cropping occurs.

[15] As before, a variable was computed that measures the intensity of irrigation. This is *NIANCA,* which is *NIA* divided by *NCA.* It ranges upward from a value of zero, at which no irrigation occurs.

on estimates of land prices as of June 1971, reported by R. P. Pathak in *The Journal of Income and Wealth* (1981). The 1971 values were extended to earlier and later years on the basis of changes in the index number of prices of all agricultural outputs. They were converted into an annual flow variable, which can be interpreted as a rental rate.

Rainfall is measured every month in most districts in India at observatories established by the India Meteorological Department. The district data are aggregated into approximately three dozen subdivisions. These range from parts of a state (such as Coastal Karnataka, North Interior Karnataka, and South Interior Karnataka to an entire state (such as Orissa or Punjab). The monthly data for these subdivisions are then published in a number of sources, including *Agricultural Situation in India.* Annual data for the subdivisions are printed in many sources, most conveniently in *Fertilizer Statistics.* District data (that is, nonaggregated data) are also published in some states' crop and season reports and statistical abstracts. They also appear in some specialized meteorological publications such as the occasional *Climatological Tables of Observatories in India*. A number of states augment the India Meteorological Department's data collection (and publication) with data collected by their own means.

The data set contains five rainfall variables. Four of these measure actual precipitation during parts or all of the agricultural year. The first, *YEARRAIN*, is the total rainfall in the given year; it is the sum of the rainfall in each of the 12 months. The other three variables measure rainfall in only one or a few months, at periods crucial to crop production. *JUNERAIN* measures rainfall in June, at the beginning of the monsoon. *JLAGRAIN* measures it in July and August, the remainder of the monsoon in most parts of India. *AUTMRAIN* measures rainfall in September through December. The fifth rainfall variable is a dummy variable (*DROUGHT*) that gives a value of one to those districts designated as "drought-prone" by ICAR. It has no time-series variation, and does not measure whether a drought, by whatever definition, occurred in any given year. Instead, it simply denotes those districts with low and highly variable rainfall.

Public Sector Inputs

The public sector provides physical infrastructure that facilitates agricultural production. Some of the infrastructure helps to transport inputs (and information) to the farm and outputs to market. The variable *ROADS* takes the length of paved roads (sometimes classified as "surfaced" or "metalled") in the district and divides it by the district's gross cropped area. It is thus a measure of the accessibility of the district's farms. Road lengths are reported in a number of publications; the Ministry of Shipping and Transport's *Basic Road Statistics* and the various state statistical abstracts are often the most convenient sources of data for districts, but state-wide data are easily available in many sources.

The government has established (and continues to oversee) a number of regulated markets throughout India. These offer several advantages, including standardized weights and measures, freedom from the potentially monopolistic behavior of local traders, and easier access to modern inputs. The variable *MARKETS* measures the number of regulated markets in each district. State-wide data are published in the *Bul-*

letin on Food Statistics; data for districts were obtained by researchers in the Economics Group of the Resource Management Program at ICRISAT from unpublished data available from the Directorate of Marketing for 13 years between 1959/60 and 1984/85. Estimates for districts in other years were computed on the basis of changes in the corresponding state-wide series.

One of the most important inputs into agriculture provided by the public sector is the results of agricultural research. These come in the form of new seeds, improved design of tools and implements, improved management practices, or any number of other forms. Research activities are undertaken by all of the states as well as by numerous schemes and projects of the center. They focus on practically every crop grown in India, on many inputs, and all of the basic agricultural sciences. The specification of a valid and appropriate research variable is difficult, for a number of familiar reasons. Budget data are seldom available that make it possible to separate the accounts of research units from those of their parent organizations. Even the budget data that exist are flawed in that it is seldom obvious how to separate current from capital expenses or researchers from the other staff. Even if one could confidently measure staff and expenditures, it is difficult to measure research output, especially if one recognizes the problems posed by differences in quality, the stochastic nature, and the lags in realizing benefits from research.

In constructing the research variables for this data set, therefore, special efforts have been made to address those problems as fully as possible. The research variables are based on three sets of data. First is the series for indigenous state agricultural research expenditures, covering the years 1953 through 1971, reported in Mohan, Jha, and Evenson (1973). Second is a data set that contains articles reporting research results that were abstracted in *Indian Science Abstracts* from 1950 through 1979. This data set provides crop-specific data for wheat, rice, maize, sorghum, pearl millet, cotton, sugar, and "other" crops and data for general agricultural research. It also contains data for the states (including Delhi) that measure the output of the research activity. The editorial authority exercised by the abstractors in imposing and enforcing quality thresholds for inclusion in the *Indian Science Abstracts* makes this set particularly useful. Third is information published in state budgets on research spending at the state agricultural universities and elsewhere from the late 1970s through the 1980s. These three sets of data were combined to create data series for expenditures for each of the states, by commodity, from 1950 through 1983. These series were created by taking the ratio of the number of publications abstracted for that commodity in that state to the total number of publications on a commodity (that is, not general publications) in the state and multiplying it by each year's research expenditures. In addition, a data series on general expenditures in each state was created by multiplying the year's research expenditures by the ratio of general abstracts to the total publications. (This procedure uses the proportion of abstracted publications on each crop to allocate the total research effort, as measured by expenditures, among the various commodities.)

For each state and each commodity, a variable for the stock of research was then defined by combining past research activity using several patterns of time-shape "inverted V" weights, as used in Evenson (1968). The inverted Vs have three regions. The first, sloping upward, refers to the number of years between the first appearance of a research result and its full effect. During this time the research outcome has an increasing impact. In this region of the V, recent results are multiplied by smaller fractions, while more distant results are multiplied by larger fractions, until at the top of the upward-sloping region, the weights become one. The second region, a horizontal plateau, refers to the number of years the research output can continue to make its full contribution. The weights remain equal to one. The third region, sloping downward, represents a sort of decay of the contribution of the research. This can come about because of biological changes, or the research might merely be supplanted by later, superior discoveries. In this region, earlier research contributions are multiplied by weights that become successively smaller as time passes.

The data set contains five measures of public research. These differ in the time pattern of the three sets of weights. The table below lists the five crop research variables for the states, followed by the number of years specified in their upward-sloping, horizontal, and downward-sloping regions, respectively:

In order not to lose early observations because of the lengthy lag structure, research activity in years before 1950 was set equal to half the activity in 1950.

Variable	Years in Region of V-curve
*STRES*1:	3,3,3
*STRES*2:	3,3,6
*STRES*3:	3,6,6
*STRES*4:	6,6,6
*STRES*5:	9,9,9

The research stock variable, *STRES*, for a district was constructed using two sets of weights. First, for the state, the size of the research stock was estimated for each crop. This stock was first weighted by the gross cropped area planted with that crop in each state to reflect differences in the production environments associated with the state research program. This can be considered a measure of research intensity. Second, the district variable was constructed as the crop-share weighted sum of the state research variables of the state commodity research intensity. This stock "deflation" was undertaken to account for different patterns of production in each district. This means that the research important to a district is research on the crops produced in the district.

The data set also includes a variable measuring private research activity (*PRIVRES*), which has increased markedly in importance during the past two decades. This variable is based on data collected by Carl Pray that measures research spending by private firms in the seed, fertilizer, and machinery industries. Three variables for the stock of research were constructed from this expenditure data, one for each input. This was done using a linear five-year lag structure with no decay. The stock was defined as one-fifth of the spending in the previous year plus two-fifths of the spending two years before plus three-fifths of the spending three years before plus four-fifths of the spending four years before plus the sum of all spending five years before and earlier. The lag structure reflects the time required for a research program to produce economically meaningful results, from the time spending began, to invention, innovation, manufacture, marketing, and, finally, full diffusion.

The variable *PRIVRES* was created from the three input-specific variables for private research stocks. *PRIVRES* measures the local contribution (or potential) of privately created research knowledge within each district. This is done by taking the year's stock of seed research multiplied by the factor share of land in the district, plus the year's stock of fertilizer research multiplied by the district's factor share of fertilizer, plus the year's stock of machinery research multiplied by the district's factor share of bullocks and tractors.

The extension variable (*EXT*) is based on three sets of data. The first measures the size of the extension service staff in 1975, 1980, 1983, and 1986 in each state. It is based on surveys by the World Bank. The second is the number of villages in each state. The third is data from 1955 through 1972 published in the annual reports of the Department of Community Development of the Ministry of Agriculture (during some years the Ministry of Food, Agriculture, Community Development and Cooperation). These reports give the number of Community Development Blocks in each state that were classified as Stage I, Stage II or Stage III (strictly speaking, these were called "post-Stage II" blocks). A Stage III block was the most advanced. It would have not only more contemporary extension activity but also show benefits from past and current extension activity. The expectation was that a block would remain in Stage I for about five years and Stage II for another five years. So to some extent the variability in stages reflects the staggered onset of extension activity in the blocks. By the middle 1970s practically all blocks had progressed beyond Stage II.

The data on staffing were interpolated to obtain estimates for the years 1976 through 1979, 1981, and 1982. The staffing estimates were then divided by the number of villages (in units of hundreds) to obtain an indicator of extension presence. This variable was then extended backward, from 1975 to 1956, as follows. First, the stage data were combined into a single weighted variable by multiplying the number of Stage I blocks by two-fifths, adding the number of Stage II blocks multiplied by four-fifths, adding the number of Stage III blocks, and dividing the final sum by the total number of blocks. The coefficients 0.4 and 0.8 are admittedly arbitrary; they were chosen to reflect the lower intensity of extension activity in the earlier stages. The resulting quotient is necessarily a positive fraction that can be interpreted as the degree to which the extension effort in a state reached the norm.

Under the assumption that a state's extension effort reached the norm by 1975, the weighted stage variable would equal one for 1975. Because it is assumed that all blocks have reached Stage III, the number of staff in 1975 can be taken to represent the "normal" number of staff. (The numerator contains only one term, the number of Stage III blocks, and the denominator equals the numerator, since all the blocks are in Stage III.) For the years before 1975, the estimated extension variable is computed as the product of the number of staff in 1975 times the weighted stage coefficient. This is interpreted as the number of staff that would be in place for a particular amount of below-norm extension activity disclosed by the pattern of stages.

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Robert E. Evenson is professor of economics at Yale University's Economic Growth Center. Carl E. Pray is professor of agricultural economics and marketing at Rutgers, the state university of New Jersey. Mark W. Rosegrant is a research fellow in the Environment and Production Technology Division at the International Food Policy Research Institute.