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UNDERINVESTMENT AND THE DEMAND FOR AGRICULTURAL RESEARCH: A CASE STUDY OF THE PUNJAB

A substantial body of evidence suggests that economic forces influence the path of research conducted by public agricultural research institutions (Hayami and Ruttan, 1971). There is also evidence, however, that the level of investment in agricultural research and the allocation of that money within the agricultural research system has been less than optimal. A large number of studies that have calculated the rates of return to agricultural research indicate that in both developed and developing countries there has been an underinvestment in agricultural research (Arndt, Dalrymple, and Ruttan, 1977). However, very few studies have attempted to find the causes of the underinvestment or inefficient allocation of resources. This leaves policy makers and the general public with little guidance on how these problems can be overcome.

This paper is a case study of the development of the agricultural research system of the Punjab. It first examines available data for evidence of underinvestment in agricultural research. Second, it attempts to explain the political and economic forces that determined the size of investment and allocation of resources. The third section seeks to draw lessons from this case study that will be useful to research administrators and policy makers.

To clarify the issues, a few paragraphs will be spent showing how the issues fit into an induced innovation framework based on de Janvry and Ruttan (Chart 1). The underinvestment argument in this framework breaks down into at least two components. First, the people of the Punjab may not have realized the possible benefits of research (represented by the upper right-hand circle); thus there was little latent demand for research (represented by the circle on the lower right). If a country has had no previous payoffs from agricultural research (the payoff matrix would be empty), it is not surprising that there is little demand for research. If there were substantial payoffs to past research, however, the lack of demand for research is something of a puzzle. Thus, the

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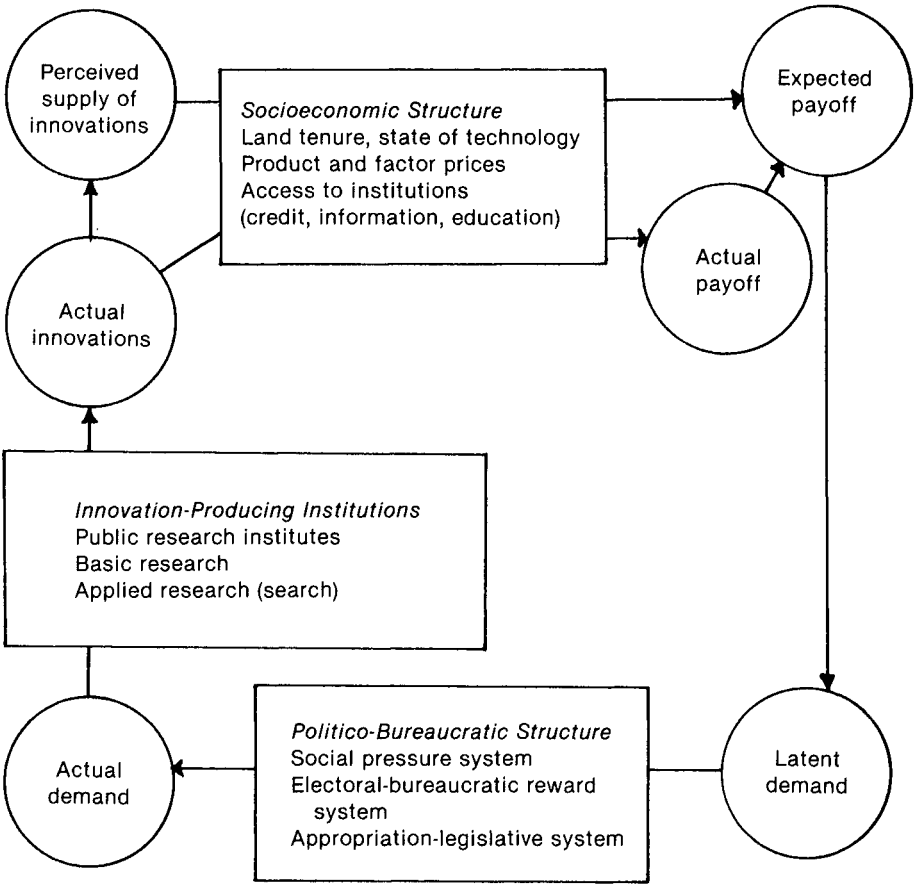
CHART 1—SUPPLY AND DEMAND FOR TECHNOLOGICAL AND INSTITUTIONAL INNOVATION



Source: Alain de Janvry, 1978. "Social Structure and Biased Technical Change in Argentine Agriculture," in Hans Binswanger and Vernon Ruttan, *Induced Innovation: Technology, Institutions and Development,* Johns Hopkins University Press, Baltimore, Maryland. 1978.

first thing that must be done in this case study is to find out the importance of the returns to research and who got these returns.

The second component of this underinvestment problem involves the government—the bottom box in Chart 1. Even if there is sufficient latent demand, the political-bureaucratic structure may not respond efficiently. The actual demand in the lower left may not accurately reflect people's preferences. Many scholars would agree that the government of British India was by its nature more responsive to the needs of the British than the needs of the Punjabis. Therefore, the paper will examine the actions of the British Indian government

and then the Pakistani government to see if the messages they passed on to the researchers in the form of budgets actually reflected the needs of the people.

THE IMPACT OF RESEARCH ON PUNJABI AGRICULTURE

The story of the Green Revolution in both the Indian and the Pakistani Punjab is well known. However, few people are aware of scientists' contribution to agricultural growth in the Punjab before 1947. The Indian nationalist literature suggests that very little progress was made in agricultural science and that the few advances that were made benefited British exporters, consumers, and plantation owners rather than Indian farmers. In fact, agricultural research made an important contribution to growth both before and after 1947, and the farmers of the Punjab received substantial benefits from the research.

Sources of Agricultural Growth

The official government data on agricultural output during both the British and the Pakistani periods have serious weaknesses that have been discussed in detail elsewhere (Pray, 1978). Independent evidence shows that both level and trend in yield-per-acre data are biased. This independent evidence has been used to establish fairly accurate benchmarks at the beginnings and ends of the British and Pakistani periods. The growth in gross value of output (GVP) was then mechanically disaggregated into the amount accounted for by the increase in yield, the amount due to the increase in acreage, and the amount due to changes in the cropping pattern. (Separate data were available for the irrigated and unirrigated areas of the Province only for the period before 1947.) The first three rows of Table 1 show the amount by which output would have increased if only the area, yield, or cropping pattern had increased and everything else were held constant. The next four rows show the total effect of changes in two or more of these variables at the same time.

Before Independence about three-quarters of the total increase in output (150 million rupees) was due to the large increase in irrigated acreage resulting from massive investments in irrigation by the British Indian government. New technology also made an important contribution to agricultural output. Adoption of higher-yielding varieties of wheat, cotton, and sugarcane led to a 12 percent increase in yields on irrigated land and a 3 percent increase on unirrigated land despite a fall in the yield of gram.[1] The change in value of output caused by shifting the cropping pattern to the production of more valuable crops accounted for about 5 percent of the total increase. This shift was almost entirely the result of the introduction of long-staple cotton varieties by the agricultural department during this period. Thus, the variables affected by new technology—yields and cropping pattern on irrigated and unirrigated land—contributed 38 million rupees or almost 20 percent of the increase in output during the British period.

The total value of output increased 47 percent between the beginning and

[1] Chickpeas (*Cicer Arietinum*).

TABLE 1—SOURCES OF AGRICULTURAL GROWTH 1907–1946
(million 1937–39 rupees)

	Irrigated		Unirrigated	
	Output change	Percent of total change	Output change	Percent of total change
Area	150.04	74.2	−5.7	−2.8
Yield	24.9	12.3	5.7	2.8
Cropping pattern	11.4	5.6	−1.4	−.7
Area and yield	15.0	7.4	−.2	−.1
Area and cropping pattern	6.8	3.4	0	0
Yield and cropping pattern	−3.0	−1.5	.5	.3
Area, yield, and cropping pattern	−1.8	−.9	0	0
Total irrigated and unirrigated	203.6	100.4	−1.0	−.5
Gross value product 1907–1911	431.0			
Gross value product 1942–1946	633.6			
Total change	202.6			

Source: Carl E. Pray, 1978, "The Economics of Agricultural Research in British Punjab and Pakistani Punjab (1905–1975)," Ph.D. dissertation, University of Pennsylvania, Philadelphia, Pennsylvania, Table 2–12, p. 58.

the end of the period, an annual growth rate of 1.08 percent. This was approximately the same rate of growth as the population of the Punjab between the 1911 and 1941 censuses and was more rapid than the growth rate of the rural population during this period (Rai, 1937).

Output growth in the period after Independence cannot be separated into irrigated and unirrigated areas (Table 2). During this period the yield effect was the most important, and the increase in acreage was a close second. The increase in yield was partially a result of new technology—the green revolution varieties of wheat, rice, and corn were introduced during this period—and of improved varieties of cotton and sugarcane. In contrast to the earlier period, chemical fertilizer played an important role in increasing yields, as did increasing use of tubewells.

The year-to-year variation in outputs and inputs was more reliably measured by the statistics than for the earlier period, however, and it was possible to estimate the determinants of yield per acre using a Cobb-Douglas function (Table 3). Tubewell irrigation, canal irrigation, salinity, and new varieties all had significant effects on yield per acre. The growth rate of output per acre during this period was 1.95 percent. The contribution of each input and that contribution expressed as a percent of total growth are shown in Table 3.

TABLE 2—SOURCES OF AGRICULTURAL GROWTH 1951–1975

	Output change (*millions of 1960 rupees*)		Percent of total change
Area	927.8		32
Yield	986.4		34
Cropping pattern	308.6		11
Area and yield	357.1		12
Area and cropping pattern	111.7		4
Yield and cropping pattern	167.1		6
Area, yield, and cropping pattern	60.5		2
Total increase in output	2,919.3		101[a]
Gross value product, 1950–55		2,554.0	
Gross value product, 1970–75		5,473.3	
Total change		2,919.3	

Source: Carl E. Pray, 1978, "The Economics of Agricultural Research in British Punjab and Pakistani Punjab (1905–1975)," Ph.D. dissertation, University of Pennsylvania, Philadelphia, Pennsylvania, p. 94.

[a]Does not equal 100 because percentages are rounded.

TABLE 3—CHANGES IN INPUTS AND CONTRIBUTION TO OUTPUT PER ACRE, 1947 TO 1975

	Changes in inputs[a] (*relative change in area*)			Growth rate	Contribution to growth in output/acre	Percent of growth rate
	Equation 1	*Equation 2*	*Equation 3*[b]			
Tubewell irrigation	.15	.07	.03	.346	.010	51
	(4.29)	(6.39)	(1.99)			
Canal irrigation	1.26	1.17	1.34	−.006	−.008	−41
	(3.33)	(2.82)	(3.56)			
Salinity	−1.43	−1.04	−1.26	−.007	.009	46
	(−4.97)	(−4.26)	(−7.30)			
Fertilizer			.002	.298	.001	3
			(.13)			
New varieties			.014	.444	.006	31
			(3.56)			
Rainfall		−.03				
		(−.988)				
Time trend	−.023					
	(−2.25)					
R^2	.95	.94	.94			

[a]T-statistics in parentheses. Dependent variable is the output per acre of 11 major crops.

[b]Multiplying the estimated coefficients in equation 3 by the growth rates of each input gives the contribution of each of these inputs to growth in value of output per acre.

Increased acreage accounted for one-third of the increase in output, and this increase was almost entirely due to the increase in irrigation facilities, as it was in the earlier period. Total acreage under cultivation increased by 7.74 million acres. Of this, 2.69 million acres was due to an increase in the area double cropped, made possible by the increase in tubewell irrigation and introduction of cotton and wheat varieties that matured more quickly. The remaining 5-million-acre increase was due to the increase in acreage irrigated by government canals and private tubewells.

This combination of increased irrigation and improved technology led to a much greater increase in output in this period than in the British period. The real value of output more than doubled, growing at an annual rate of 3.49 percent; rural output per capita increased by almost 30 percent in this period.

Specification of the Contribution of Scientists to New Technology

The Punjab Department of Agriculture from its beginning in 1905 has conducted research in a number of disciplinary areas, but quantitative evidence exists only on the contribution of plant breeders, in the form of acreage under new varieties and the effects of these new varieties on yield per acre, cost of production, and quality of the crops. Estimates of the benefits of agricultural research are therefore based on the output of the plant breeders and are biased downward because they do not include contributions of other scientists.

The success of the plant breeders in producing new varieties is shown in Table 4. It shows the number of crop varieties for which there is evidence that farmers actually used the variety, not simply that they were officially approved for cultivation by the Department of Agriculture.[2] Breeders were successful only with certain crops, especially cotton, wheat, and sugarcane, and new varieties were released periodically rather than as a continuous stream. There was also a shift in the importance of introduction of crop varieties after Independence. Not evident from Table 4 is the fact that before 1947 only wheat varieties 9-D and C-217 and gram variety C 12/34 were specifically bred for rain-fed rather than irrigated conditions. After Independence only Barani-70 and Pothwar wheat varieties and gram variety C-612 were designed for unirrigated conditions. Wheat varieties 8-A and especially C-591 were also accepted fairly widely on unirrigated land (C-591 was grown on 31 percent of the unirrigated wheat acreage in 1945/46) (Sukhatme, 1943). However, the great majority of the successful varieties could be used only in irrigated or high-rainfall areas.

Many of the new varieties increased the yield per acre, and some increased the quality of the crop and its price. The impact of the most important varieties is summarized in Table 5. There are problems with both the data on yield increases on experiment station yields and the data on farmers' fields. The differences between the yields of old varieties and yields of new varieties at experiment stations are sometimes greater than in farmers' fields because the experiment stations use more inputs than would be economical for farmers.

[2] For more details about varieties, see Appendix A.

TABLE 4—DATES OF SUCCESSFUL INTRODUCTION OF NEW VARIETIES
(number of new varieties)

	American cotton	Desi cotton	Wheat	Sugarcane	Rice	Gram	Maize	Other
1910–19	1		2					
1920–29	1	1		4		1		
1930–39	3	2	2	2	5			2
1940–49	3	1	3			1		1
1950–59	3	1	2	3		1	1	
1960–69	2		4	1	1		3	
1970–75	4		5	1	1		3	

Source: American and desi cotton 1910–1964: Abdul Hameed Khan, 1964, "Fifty Years Research and Improvement of Cotton Crop in Lyallpur Region," *Agriculture Pakistan,* XVI, No. 1, p. 48; 1970–1975: Punjab, Planning and Development Department, 1976, *Punjab Development Review and Prospects,* Government Printing, Lahore, p. 128. Wheat 1910–1960: M. A. Aziz, 1960, *Cereals and Pulses, Resume of Fifty Years Research Work at Punjab Agricultural College and Research Institute,* Lyallpur, Department of Agriculture, Lahore. 1960–75: S. A. Qureshi, "Annual Report of the Cereal Botanist, Punjab Agricultural Research Institute, Lyallpur for the Year, 1974–75," mimeo. Sugarcane 1910–1971: Punjab Agricultural Research Institute, Lyallpur, 1971, *A Guide,* Department of Agriculture, Lahore, p. 123. 1971–1975: *Punjab Development Review,* p. 128. Other crops 1910–1960: Aziz. 1960–1970: Abdur Rehman and M. Anwar Khan, 1975, "Maize and Millets, Evolution of New Varieties," *Pakistan Agriculture,* edited by Saeed Hafeez, Press Corporation of Pakistan, Karachi, p. 5. 1970–1975: *Punjab Development Review,* p. 128.

However, experiment station data have the advantage that they usually compare the different varieties under similar irrigation, soil fertility, and agroclimatic conditions whereas yield increases on the farmers' fields may be due in part to other factors. Some of these factors can be controlled for statistically, but often they are not. The price premium over the old varieties is an average premium for several years from wholesale markets in the Punjab. Only representative varieties from Table 4 are included.

Table 6 gives five-year averages of the area under improved varieties and the percentage of the total area of that crop that was under new varieties. American cotton, after its introduction in 1913, quickly spread to about 40 percent of the cotton area in the early 1920s. The early American varieties could only be sown in areas with perennial irrigation, and within five years of their introduction, American had replaced desi (local) cotton on 90 percent of the cotton area in the districts that had proper irrigation. The second period of rapid spread was during the 1940s when the relative price of American increased as a result of the decline in desi prices. Improved desi cottons were not developed until after 1920. They spread rapidly, however, until the war cut off several important consumer nations and the price of desi slumped. Improved wheats made slow but steady progress until the middle 1930s when C-591 was introduced, producing a spurt of rapid growth. This wheat replaced other improved varieties and local varieties. Improved sugarcane varieties were first

TABLE 5—ESTIMATES OF YIELD AND QUALITY IMPROVEMENTS

	Yield increase[a] (percent)		Increase in price premium (percent)
	Experiment stations	Farmers' fields	
		British Punjab	
Desi cotton			
15-Mollisoni	16	n.a.	None
39-Mollisoni	25	n.a.	None
American cotton			28
4-F	None	None	14
289-F	None	None	34
Wheat			
P-11	10		9
8-A	20	17	3
C-591	28	38	12
Sugarcane			
Co. 205, Co. 213, Co. 223	21-159	41-74	None
Co. 312, Co. 313	100-200	80	None
		Pakistani Punjab	
Wheat			
Mexipak		77 64-82	−15
American cotton			
AC 134, AC 307	14	31	6
Rice			
IR-8		47-61	
Sugarcane			
Co. 54 and 44	26-40	0	None
Maize		15-25	None

Sources: Pre-1947: desi cotton and wheat yield from experiment stations from Punjab Department of Agriculture, 1936, *A Summary of the Important Results,* Government Printing, Lahore, p. 98. American cotton from Punjab Board of Economic Inquiry, 1948, *Agricultural Statistics of the West Punjab, 1901–02 to 1946–47,* Lahore; and British Cotton Growers Association (BCGA), unpublished records, Khanewal, Muttan District. For farmers' fields from P. V. Sukhatme, 1945, *Report on the Random Sample Survey for Estimating the Outturn of Wheat in the Punjab,* Indian Council of Agricultural Research, New Delhi, p. 46, 47; and William Roberts and Kartar Singh, 1951, *A Text Book of Punjab Agriculture,* Civil and Military Gazette, Lahore, p. 464. Prices from Punjab, 1940, *Report on the Marketing of Wheat in the Punjab,* Government Printing, Lahore, p. 69. Sugarcane yield experiment stations from Punjab Department of Agriculture, 1925, *Report*

1924–25, Government Printing, Lahore; and India, Central Marketing Department, 1943, *Report on Marketing of Sugar in India and Burma*, Government of India, New Delhi.

Post-1947: wheat yields and prices from Pakistan Ministry of Food and Agriculture, 1975, *Agricultural Statistics of Pakistan, 1975*, Islamabad; Mahmood Hasan Khan, 1975, *The Economics of the Green Revolution in Pakistan*, Praeger, New York, p. 19; Water and Power Development Authority (WAPDA), 1973, *Crop-Cutting Surveys for the Estimation of Yields of Wheat in the Mona Reclamation Experimental Project Area*, Lahore; and Jerry B. Eckert, 1979, "The Impact of Dwarf Wheats on Resource Productivity in West Pakistan's Punjab," Ph.D. dissertation, Michigan State University, East Lansing, Michigan. Farmers' cotton yields calculated from unpublished records of Punjab Agricultural Department for 1968–69 and from the *Punjab Gazette* for other years. Yields experiment station from BCGA farm records, 1975, *Prices, Pakistan*, p. 289. Rice yields from Punjab Bureau of Statistics, 1976, *1976 Statistical Pocketbook of the Punjab*, Lahore, pp. 32, 33; and Mahmood Hasan Khan, 1975, *The Economics of the Green Revolution in Pakistan*, Praeger, New York, p. 17. Sugarcane from Abdul Aziz Anwar, 1971, *Production of Sugar: Policies and Problems Board of Economic Inquiry*, Lahore, p. 64. Maize from Takumi Izuno, 1976, *Maize Production Plan 1976 Agricultural Research Council*, Islamabad, p. 7.

[a]Yield increase columns show the percentage increase in yield over the local unimproved varieties for the British period. After 1947 the increase is the percentage improvement over the varieties released in the British period.

TABLE 6—AREA UNDER IMPROVED VARIETIES
(five-year average)

	1913/14 to 1917/18	1918/19 to 1922/23	1923/24 to 1927/28	1928/29 to 1932/33	1933/34 to 1937/38	1942/43 to 1943/44
American cotton						
Acres (*thousands*)	133	464	920	831	1,151	1,712
Percent	9	30	41	38	42	70
Desi cotton						
Acres (*thousands*)		7	208	573	860	460
Percent		4	9	26	32	19
Wheat						
Acres (*thousands*)	65	600	1,329	2,477	3,752	7,686
Percent	1	7	14	26	40	75
Sugarcane						
Acres (*thousands*)		3	12	117	247	399
Percent		1	3	27	50	80

Sources: All crops before 1920 and after 1937 from Punjab Department of Agriculture, various years, *Reports*, Lahore; all crops 1920 to 1937 from ICAR, various years, *Review of Agricultural Operations*, New Delhi.

introduced in the 1920s. They replaced local cane at a steady rate until the 1940s, when a combination of high prices and two very good new varieties pushed the acreage under new varieties to more than 80 percent. In general, this table does not give much support to the idea that Indians were slow to accept new technology.

Regular reports on the acreage under new varieties are not available for the Punjab for the period when it was part of the Province of West Pakistan. All available data are presented in Table 7. Wheat and rice show rapid acceptance of the Mexican and IRRI varieties and then level off. Cotton shows a more gradual acceptance path, the result of a stream of new varieties rather than one major breakthrough. There are not enough data on sugarcane and maize to show a definite path. However, the impression from official reports is that one or two varieties had a major impact, as in wheat and rice, and that there has recently been a leveling off of the diffusion path.

TABLE 7—PERCENTAGE OF ACREAGE UNDER NEW VARIETIES AFTER 1947

Year	Wheat	Cotton	Rice	Sugarcane	Maize
1960		13			
1961					
1962				r	
1963		43			
1964					
1965	r				
1966					
1967	2		r		
1968					
1969	42	66	9	64	
1970	47		12		r
1971	53		13		
1972	58		28		
1973	58	78	18		
1974	59	92	18		
1975	65	90	14		30

Sources: Wheat for 1967 from Deputy Directors of Agriculture Reports mimeographed, 1967. Rice and wheat 1968-75 from Pakistan, 1975, Ministry of Food and Agriculture, *Agricultural Statistics of Pakistan*, Islamabad. Based on the Agricultural Department's annual crop-cutting survey. Cotton, acreage of new varieties 1960 and 1963, from A. H. Khan, 1965, "Fifty Years Research and Improvement of Cotton Crop in Lyallur Region," *Agriculture Pakistan*, XVI, No. 1, p. 50. Checked against trade figures on ginning and pressing. Cotton, new varieties 1969, 1973-75 from Agriculture Department, Statistics Cell, unpublished material, also available in the *Punjab Gazette*, Part I. Based on the Agricultural Department's annual crop-cutting survey. Sugarcane from A. A. Anwar, 1971, *Production of Sugar: Policies and Problems*, Board of Economic Inquiry, Lahore. Actual percentages of new varieties that arrived at the sugar mills in the Punjab. Maize from Izuno, 1976, *Maize Production Plan 1976*, Agricultural Research Council, Islamabad, Pakistan. The year in which new varieties were first released is designated by "r."

Costs and Benefits of Agricultural Research

From the data presented in the tables and information on the shape of the supply and demand curves for these crops it is possible to calculate the economic surplus that results from agricultural research, using what is referred to in the literature as the index number approach. For the crops in which there were yield increases, the size of the shift in the supply curve is estimated on the basis of the decline in cost due to the use of the new variety, holding other factors such as irrigation and fertilizer applications constant. For crops that had changes in quality (mainly cotton) the average price is multiplied by output of the new variety. Upper and lower bounds of the benefits are estimated for all crops because of the problems of finding accurate data.[3]

The costs incurred to produce these benefits include the expenditure on research and the cost of disseminating information about the value of the new varieties. However, the budget data from the Department of Agriculture are not detailed enough to sort out the amount of expenditure on breeding and introducing improved varieties. The budget figures also include expenditure on research by other discliplines that did not help in the production of new varieties. The series on extension expenditure also includes many things that had nothing to do with the introduction of new varieties. An internal rate of return was therefore calculated under the assumptions about benefits and costs. For the British period the rates of return ranged from 34 to 49 percent with the most realistic estimate between 36 and 44 percent. For the Pakistani period estimates of the rate of return range from 17 to 45 percent because of greater variation in the measures of research and extension expenditure. A substantial portion of the extension expenditure after the mid-1950s was for plant protection, which did not have much positive impact on the spread of new varieties and so should not be counted as an expense. On the basis of the most realistic assumptions, the internal rate of return in this period was probably about 35 percent, only slightly less than the rate of return for the British period.

These results are interesting for several reasons. They do support the argument that the British were underinvesting in agricultural research, but the movement from colonialism to Independence did not greatly improve the efficiency of the allocation of government resources with respect to aggregate investment in research. The aggregate figure hides two important shifts that took place after Independence but offset each other. One was the declining productivity of the agricultural research program at least until the mid-1960s that resulted from the disruption at Independence, political interference, and perhaps diminishing returns. The other was increased research productivity, particularly in wheat, that followed scientific breakthroughs outside of Pakistan in breeding high-yielding grain varieties.

The rates of return can also be compared to the rates of interest at which funds were available. A.K. Bagchi shows that the government of India was

[3] See Appendix B.

able to borrow money in London before World War I and at certain times during the interwar period at an interest rate of less than 5 percent. In 1936, India borrowed Rs 120 million at par within India at 2¾ percent (Bagchi, 1972, pp. 42, 45, 47). Interest rates after Independence were much higher. In the 1960s the government-imposed ceiling on bank interest rates of 7 or 8 percent was below the scarcity value of capital. Foreign loans had effective interest rates of 10 to 15 percent in the 1960s according to Keith Griffin and Azizur Rahman Khan (1972a, p. 121). Thus, interest rates were clearly much higher in the Pakistani Punjab than in the British Punjab, but internal rates of return to agricultural research of over 30 percent still made it an attractive investment—particularly if foreign donors were willing to supply these funds.

Finally, it is necessary to examine the distribution of the gains from research and the cost of the program. In general the gains went to the producers of the crops in which new varieties were developed. Before Independence the prices of wheat, sugar, and desi cotton were set by the international market, and the increase in the Punjab's production due to new varieties probably did not reduce prices much. Thus few of the gains in productivity were passed on to the consumer. American cotton may have been the exception because it replaced imported cotton in Indian cotton mills. This probably decreased costs of producing finer-quality cotton materials, and this decrease in costs may well have been passed on to consumers in the form of cheaper cloth. After Independence export restrictions allowed increased productivity of wheat to reach the consumers through falling real prices. Increases in cotton and rice productivity kept these crops and cotton cloth competitive on the world market. Thus, the gains were shared by farmers and exporters depending on the level at which farm-gate prices were set.

During the British period, the costs were borne mainly by farmers, since 70 to 80 percent of the revenue in the Punjab came from land revenue and irrigation dues (Thomas, 1939). After the early 1920s cotton research was paid for by a tax on cotton pressed. After Independence the tax on cotton continued to finance cotton research, but land revenue and irrigation dues became less important sources of provincial finance. Indirect taxes took their place as the main source of revenue. In the 1960s foreign foundations and bilateral aid started to finance research. This meant a shifting of the tax burden from landowners to the rest of the rural and urban population, so that farmers received a smaller share of the benefits in the period after Independence but paid less of the costs.

THE DEMAND FOR AGRICULTURAL RESEARCH

The first section of this paper showed that the rates of return to investments in agricultural research were high relative to the normal rates of return for a development project. These rates of return indicate that both the British and the Pakistanis could have improved the welfare of the Punjab by investing more money in agricultural research. One hypothesis is that the underinvest-

ment in research was primarily due to insufficient latent demand for research by farmers, consumers, and industrialists who could have benefited from it. There are at least three possible reasons for this lack of demand: ignorance of potential benefits from research, inability to communicate demands to the government, and insufficient power to influence the government. An alternative hypothesis is that there was sufficient latent demand but that the government did not respond either because it was not concerned about the demands of the beneficiaries of research or because it did not feel that greater investment in research would yield a sufficiently high rate of return. There may have been insufficient information for even the most far-sighted official to foresee the high returns that were actually realized, or research was in fact not productive and aggregate measures of rates of return conceal a period of low returns. The purpose of this section is to sort out the various demand-side forces to see which ones were important at different times. In the next section some preliminary suggestions are made of ways in which the present research system might strengthen the demand for research.

Demand for research is considered in four periods: from 1900 until 1930; from 1930 until Independence (1947); from Independence until the Green Revolution (1960); and from the Green Revolution until 1975. The Department of Agriculture was founded in 1905 in response to All-India and British pressures. The scientists of the Punjab Department of Agriculture during the period from 1900 to 1930 were aware that there was no local demand for research, and they consciously developed a program that they hoped would build up the demand for research by the government and people of the Punjab.

The second period was one in which farmers and industrialists clearly appreciated the need for research, but growth of the budget for agriculture was inhibited by the Great Depression, World War II, and the conservative financial policy of the British government.

The first 18 years after Independence, from 1947 to 1965, was a period when supply problems rather than demand problems determined the expenditure on and output of research. A less stringent financial policy was followed, so government spending on agriculture was greatly increased. However, the Department of Agriculture had problems supplying useful innovations, the returns on investment fell, and the demand for research declined. The Green Revolution of the 1960s boosted the productivity of research, and demand for research increased, to be weakened by the actions of the People's Party in the early 1970s.

The Early Period

The establishment of the Department of Agriculture of British India in 1905 with its Provincial research, extension, and education programs was a response to at least two types of demand. The first derived from concern of the people of both India and Great Britain that something be done about the catastrophic famines that had killed and impoverished millions three times in the

last quarter of the nineteenth century. The dimensions of these tragedies became clearer as statistical services improved and famine commission reports followed each of the three major famines. In addition, some of the early Indian nationalists began to write critically about the role of the British rule in causing famine. The need for research as an important element in improving conditions in the countryside was recognized by the Famine Commission of 1901 (India, 1901, p. 113).

A second type of demand for research came from small, well-organized pressure groups that lobbied the government for agricultural research. The British cotton industry wanted to decrease its dependence on the United States for medium- and long-staple cotton, a dependence that had been emphasized at the beginning of the twentieth century when long-staple cotton was in short supply and prices were high. The British grain trade that operated in India and indirectly with the British firms wanted a more dependable supply of high-quality bread wheat at lower prices. Similarly the jute trade wanted higher-quality jute in Eastern India.

The influence of these groups shows up in Punjab in the initial concentration of research on wheat and cotton. The first Economic Botanist of Punjab was told explicitly by his superiors in the government that "cottons and wheats are the main crops in the Punjab and that it was my duty, whatever my tastes were to improve these crops in preference to others" (India, 1919, p. 165). This decision was made at the All-India level. The special crop programs that were considered at the first and second meetings of the Indian Board of Agriculture in 1905 and 1906 were cotton, jute, wheat, and tobacco. These meetings led to the appointment of a wheat specialist and a cotton specialist as the first All-India crop specialists.

Official reports of the meetings of the Board of Agriculture provide evidence of the direct connection between Britain's commercial interests and research priorities. One report stated, "The improvement of Indian wheat was considered largely from the point of view of the export trade. This has recently reached very large proportions, India having supplied more wheat to the United Kingdom in 1904-5 than any other country" (Butler, 1906). The link between British needs and interests in cotton research was equally direct. The first Board of Agriculture meeting considered a memorial from the British Cotton Growers Association dated 30 December 1904. The memorial refers to "the serious importance of the shortage which has occurred in recent years in the supply of raw cotton (in Great Britain)" (Punjab, 1904), a shortage caused by decline in American production due to boll weevil attacks.

The initial demand for agricultural research was thus a recognition by the central government and some specific interest groups of the possible benefits of agricultural research. The Punjab Department of Agriculture, however, depended on the Provincial government for three-quarters of its financial support before 1920, and so they had to convince the people with power in the Punjab that their work could be useful; they had to create a demand for research. A review of the strategy of concentrating on irrigated crops in this early period provides evidence of the Department's strategy and success. Mr. D. Milne,

Director of Agriculture, testified before the Royal Commission in 1927 (Great Britain, 1927, p. 283):

> *Question:* In the beginning was there very much belief as to how much good Department of Agriculture could do?
> *Milne:* Absolutely none; there was strong belief that is was of no use whatever.
> *Question:* . . . that was the feeling of the outside public opinion. First of all I take it that you could prove the value of your work more quickly on irrigated land than on barani (rainfed), could you not?
> *Milne:* Yes.
> *Question:* . . . Do you think if you had devoted a greater part of your time and energy to work on barani lands, on gram and so forth, you would have been able to prove the value of your department, quickly enough to get these increased grants (Rs 300,000 in 1911-12 to 3,850,000 in 1926-27) from the Government?
> *Milne:* No, emphatically not.
> *Question:* So that there has been some method in the principle adopted by the department, of course with the approval of Government, to devote most of your time and energy to nahri (canal irrigated) lands as yielding quicker return?

New groups wanted research to improve their commodities and old beneficiaries wanted more research on their problems. The success of cotton variety 4-F and wheat varieties 8-A and P-11 made farmers and officials in the government aware of potential benefits from the research program. At the hearings of the Royal Commission on Agriculture in the Punjab in 1927, several Punjab officials who represented farmers in unirrigated districts of the Punjab criticized the fact that the researchers were working only on irrigated wheat and cotton (Great Britain, 1927, p. 210). The Commission asked researchers about this bias, and in their report recommended that the provincial agricultural departments spend more of their time on crops like gram, bajra, and jowar.[4]

There was also strong demand for information about fruit (Great Britain, 1928, p. 97, 210):

> In July, 1926, Government appointed a Fruit Specialist temporarily, but as soon as it was known that a Fruit Specialist had been appointed there was an overwhelming demand from farmers in all parts of the Province for help and advice, and Government has given administrative approval for the inclusion of a post of a second Fruit Specialist in the next years' budget.

There were only 39,000 acres of orchard in the Punjab in 1926 (Roberts and Singh, 1951, p. 337), but because many of the orchard owners were well-off

[4] *Bajra* is pearl millet; *jowar* is sorghum.

landowners and some of them were European, they had much more influence than the value of their crop or their numbers suggests.

The Period from 1930 to 1947

By 1929 the pressure to produce new wheat varieties had decreased somewhat because it was no longer exported from India, and the British government and private British trading companies were no longer interested. Big wheat farmers who were active in Provincial politics were by now aware that the Department of Agriculture had something to offer, but their influence was insufficient to offset demand for work on other crops. Wheat's share of research resources dropped sharply although the absolute amount did not.

Cotton research continued to receive the most support because of the organization of the Indian Central Cotton Committee. Although the influence of the British cotton industry on Indian policy declined rapidly after 1900 (Dewey, 1978), its influence on research policy was replaced by that of the Indian Central Cotton Committee. In 1917/18 an Indian cotton committee investigated the prospects for increasing the cultivation of cotton in India, especially American cotton, and the Indian Central Cotton Committee was founded in 1921 to represent all sections of the cotton industry (India, 1919). The committee was headed by a government official and had representatives of the provincial agricultural departments, the Indian states, cotton growers, cotton ginners, spinners, and merchants. It was funded through tax or cess on all cotton ginned or exported. One of its main activities was to fund cotton research. From 1925 onward, this committee and its successor, the Pakistan Central Cotton Committee, provided most of the funds for the agriculture department's research on cotton. It provided an articulation between major beneficiaries of research and research scientists that few other Indian crops had.

Major structural changes after World War I probably changed the relative importance of the groups that supported agricultural research. The first was the devolution of power in 1919, which gave the provinces complete autonomy over agricultural and some other government activities. This meant that the central government no longer had direct control of the Punjab's decisions about the agriculture department and that the budget for that department no longer had to be approved in Delhi. The second change was increased power of the legislative councils and widening of the electorate. This increased the influence on the department of large landlords of the Province and decreased the influence of the foreign wheat and cotton trading companies.

In the Punjab there was considerable demand for research, but it was not translated into rapid growth in governmental research expenditure (Table 8). Fiscal conservatism seems to have been the most important constraint on growth. Research expenditure during the last part of the British period grew in both nominal and real terms. Perhaps more revealing is the fact that research expenditure increased as a percentage of the agriculture department's budget and as a percentage of the total budget of the Punjab. When overall fiscal constraints were lifted just a bit in the late 1930s and after World War II, expenditure on agriculture increased greatly.

TABLE 8—GROWTH OF AGRICULTURAL RESEARCH BUDGET

	1930	1940	1950	1960	1972	1975
Research expenditure (*100,000 current Rs*)	3.0	6.9	11.0	25.5	67.0	160.0
Research expenditure (*100,000 1960 Rs*)	30.4	35.0	21.9	25.5	52.0	60.0
Scientific Man-Years	18	22	23	36	55	
Expenditure as percent of agriculture budget	15.6	24.6	19.6		8.2	6.0
Expenditure as percent of total budget	0.34	0.56	0.59		0.50	0.45
Expenditure as percent of value of agricultural output		0.07	0.086		0.095	

Sources: Expenditure for 1930 to 1955 and SMY for 1951 from Punjab, various years, *Detailed Estimates of Revenue and Expenditure*, Superintendent Government Printing, Lahore; expenditure and SMY for 1960 from "Agricultural Research—A Retrospect," in *Fifty Years of Agricultural Education and Research at Punjab Agricultural College and Research Institute, Lyallpur*, 1960, Ripon Press, Lahore; Expenditure for 1966 to 1975 from unpublished data from Extension Branch, Punjab Agricultural Research Institute and the Agricultural University, Lyallpur; SMY for 1929 from DAP, 1929, *Reports*, Government Printing, Lahore; SMY for 1939 and 1946 from Punjab, 1939 and 1946, Civil Secretariat, *Civil Lists*, Government Printing, Lahore; SMY for 1971 from Punjab Agricultural Research Institute, Lyallpur, 1971, *A Guide*, Department of Agriculture, Lahore; value from Carl Pray, 1978, "The Economics of Agricultural Research in British Punjab and Pakistani Punjab (1905-1975)," Ph.D. dissertation, University of Pennsylvania, Philadelphia, Pennsylvania. Research expenditures were not shown as a separate item in the Punjab budget before 1930.

Critics of British fiscal policy during the 1930s and 1940s have emphasized the conservatism of the government as the reason for the low expenditure on the development departments, including agriculture (Thomas, 1939, p. 433). There was in fact a general reluctance by the government to impose new taxes with which to fund expanded development projects. This was particularly true during the latter part of the British period when the Congress Party was organizing farmers and other groups to resist land taxes in many parts of India. In addition the Provincial governments had not been given complete freedom to finance development by borrowing. Thomas reports, "borrowed funds have generally been spent only on railways and irrigation works which were expected to yield a normal return on the capital invested . . ." (1939, p. 433). After World War I the criteria for borrowing loosened up somewhat for railroads and irrigation, but no borrowing was permitted for other types of development projects.

Independence to 1965

Since Independence, two trends have been apparent (Table 8). First was a steady increase in the nominal and real expenditure on research and in expenditure as a percentage of the total value of agricultural output. Second, expenditure on research has steadily declined as a percentage of the agricultural department's total budget and of the Punjab Government's budget. It appears that when the government's budget constraint was lifted by the departure of the British and the availability of foreign aid, total expenditure on agriculture increased, and real expenditure on research was pulled along.

Productivity of agriculture was greatly reduced in the first 15 years after Independence. Except for some cotton varieties, few new varieties were released successfully and those had been developed during the British period (Table 4). The expected payoff to investment in agricultural research fell in the late 1950s and 1960s relative to the investments in extension, chemical plant protection, price supports for grain, and subsidies on inputs like fertilizer, machinery, and irrigation water, and the rate of return from research predicted by even the most far-sighted planners was undoubtedly very low. This expectation of relatively low returns to research was due to the small output from research during the first 15 years after Independence, the high, perhaps exaggerated, economic returns expected from some of the other investments, and the immediate payoffs to certain groups from subsidies. The following discussion concentrates on the first of these factors. The second and third factors, which may be equally important, both require more research, although the third has received some attention in the writings of Burki (1976), Alavi (1976), Herring and Kennedy (1979), and others.

Independence had disastrous effects on the productivity of agricultural research. Most of the scientific personnel except those in the cotton program were Hindus or Sikhs. In 1947 they all left for India, taking with them all of the genetic material that they could carry; the rest was mixed or destroyed. The library and other research facilities were partially destroyed. The southern Indian source of sugarcane genetic materials was cut off soon after Independence, and sugarcane breeding became more difficult.

These difficulties were compounded by governmental policies that made recruitment difficult and provided few incentives for practical research. The primary interest of the first Pakistani governments was in development through industrialization. Agriculture department jobs were regarded as low-status positions, and the pay scales and opportunities for advancement for officials in the agriculture departments were far less than in other branches of government (Pakistan, 1960). At the same time, real research expenditure per scientist declined. This meant that the agriculture department could not recruit the best scientists. Furthermore, some people who were promoted quickly at Independence were not particularly effective researchers, and once in power emphasized seniority in advancement, which strengthened their position, rather than scientific output, which might have increased productivity. Finally, politics seems to have played a more important role in appointments and pro-

motions than it had under the British. This impression may simply be due to the fact that it was possible to interview dissatisfied researchers of the Pakistani period but not of the British period. However, there does seem to be evidence that in the first few years after Independence every decision became political.

Whatever the reasons, agricultural research did not produce much until the mid-1960s. Because it did not produce, research seems to have lost the farmer support that had been built up before 1947. The needs of two other groups that have demanded agricultural research in some countries—urban consumers who want cheap food and the champions of industrial growth—were met by large shipments of PL 480 grain in the late 1950s and 1960s. The reduction of PL 480 might well have increased the demand for agricultural research, although other policies might also have been chosen to hold down food prices and conserve foreign exchange.

The Green Revolution to 1975

The developments in Mexico in wheat research greatly increased the productivity of the Pakistani research system and actual rates of return to research investment. The results of some local scientists' work, the efforts of the Ford Foundation, and visits by Dr. Borlaug himself convinced local government officials that the expected rates of return to high-yield wheat varieties and wheat research were very high. At the same time the Ford Foundation and later the United States Agency for International Development (USAID) provided resources for agricultural research. This lifted the budget constraint on the government. Other events also led to renewed interest in investing in agricultural development. The cutoff of United States food aid during and after the Indo-Pakistan war of 1965 and two years of drought at the same time made President Ayub Khan realize his vulnerability to changes in American policy and fluctuations of weather, and self-sufficiency in food grains became a high-priority item (Aresvik, 1967).

Demand for research by farmers became important after the spectacular success of Mexican wheat and led to criticism in scholarly journals and the popular press of research that helped only the big farmers in irrigated areas who grew wheat and rice. Bajra and jowar received increasing attention from the maize research people after the late 1960s. A separate section for work on gram was set up in 1971 and has developed a collection of varieties and begun to do some breeding. A separate program for the development of rain-fed wheat was also set up. These programs appear to have resulted from the demands of farmers in the rain-fed areas of the province who had not benefited from the Green Revolution crop varieties, much as demand in the 1920s for research on rain-fed crops grew in response to earlier successes with cotton and wheat.

Another constituency for research that developed in response to the Green Revolution was made up of merchants and industrialists who supplied farmers with the modern inputs needed to produce high-yielding varieties (HYVs). High-yielding seeds were provided by the government and multiplied by the

farmers. Fertilizers and pesticides were produced and partially distributed by the private sector. At least one of the fertilizer companies and several of the pesticide companies worked with government scientists and provided financial and political support to research. Mechanization was not as closely tied to the HYVs and may not have been a particular object of research.

Much of this demand for research was cut off by actions of the government in the early 1970s. Javed Burki (1980) claims that the end of the Basic Democracies[5] marked a decline in power for middle-sized farmers who had benefited most from the Green Revolution. Nationalization of some fertilizer producers and government control of fertilizer distribution at this time also decreased this industry's support of research. Pesticide distribution, most of the processing industries, and the cotton and rice export trade were nationalized. The management of nationalized industries had its hands full simply to keep going and had little time to worry about agricultural research. Finally, the other potential supporter—the urban consumer—was not pressing for research because the government continued to keep prices low by means of export controls, food aid, and ration shops. The only groups who really pushed research expenditure at this time were scientists, some officials, and the donor community—the Ford Foundation and USAID in particular.

POLICY IMPLICATIONS

The first section of this paper provides quantitative information on the impact of new technology on the economy of the Punjab. The rates of return to research expenditure were greater than 30 percent in both the British and the Pakistani periods. The main improvements were of the wheat, cotton, and sugarcane crops with some improvements of rice, gram, and fodders. After Independence the benefits of technology continued to be concentrated in wheat, cotton, and sugarcane production, although rice registered great improvements and there was measurable improvement in maize. The main beneficiaries of the research program during both periods were the farmers of the Punjab. Indian and Pakistani consumers of cloth and other cotton products gained some of the benefits of improved cotton varieties. Indian and Pakistani consumers may also have received benefits through somewhat lower grain prices. The groups that did not benefit were British industrialists and consumers. Contrary to the assumption of some authors, agricultural research made substantial contributions to the growth of the Punjab's income and much of that contribution was increased production of food grains even before the Green Revolution.

The history of underinvestment in agricultural research and the allocation of resources within the research system is outlined in Chart 1. The categories shown in the circles in Chart 1 and listed in the first column of Table 9 represent the perceptions or actions of people in institutions represented by the boxes in Chart 1. The historical development of the agricultural research

[5] A form of decentralized government created by the government of Ayub Khan.

system can be traced by using the elements of Table 9 to follow Chart 1 in a clockwise direction. For example, row 1 of column 1 of Table 9 states that the British cotton industry in 1900 thought that it could lower the costs of its inputs if the Indian agricultural departments developed long-staple cotton. The perceived supply of innovations was long-staple cotton varieties, and the expected payoff was increased profit for the British cotton industry. British cotton interests put political pressure on the government (the latent demand for innovation), and the government responded by appointing economic botanists and instructing them to spend a major part of their time on cotton (actual demand). This led to new, longer-staple cotton varieties (actual innovations). However, the benefits went to the Indian cotton industry and the Punjabi farmers instead of the British industry and consumers as had been expected.

Rates of return in excess of 30 percent reflect a continuing underinvestment in agricultural research in the Punjab. The actual reasons for this underinvestment seem to have been different for different periods. Before the 1920s there was no public pressure or demand for expenditure on agricultural research. Only the British grain trade and cotton industry saw any payoff to agricultural research in the Punjab. Farmers in general did not appreciate the potential benefits of applying science to agriculture. They had not seen any practical benefits of research. After the success of the first cotton and wheat varieties (round 2 in Table 9) farmers wanted to continue to receive improved crop varieties, and the Bombay cotton industry wanted improved cotton. Both put pressure on the legislative councils for more research expenditure, and the cotton trade and industry joined with the farmers to form the Indian Central Cotton Committee to fund research. The provincial legislative council responded by increasing research expenditures. However, the conservative fiscal policies of the colonial government and inability to raise revenue constrained the growth of research. This probably was the most obvious negative effect of British control.

Underinvestment after Independence has also gone through two periods. In the first (round 3) farmers still expected that agricultural research could produce useful results in the form of new varieties. However, disruption of the research institutions at Independence and lack of interest in agriculture by the early Pakistani governments caused the supply of innovations to almost stop. Thus, the actual payoff matrix includes entries only for cotton farmers, and the expected payoff matrix in the next round probably included only cotton farmers and manufacturers. Therefore, in the fourth round there was little popular demand for agricultural research. The government was able to increase the supply of innovations in the 1960s, however, because Mexican genetic material was available and several local scientists had selected varieties for Pakistani markets and agro-climatic conditions. This led to the well-publicized "Green Revolution," which in turn increased the demand for research not only on wheat and rice but also on the millets, pulses, and oilseeds.

For scientists and research administrators to develop greater support for agricultural research, they must influence both private and public beneficiaries

TABLE 9—SIMPLIFIED HISTORY OF INDUCED AGRICULTURAL RESEARCH IN PUNJAB

	Round 1 1900-1925	Round 2 1925-1947
Perceived supply of innovations	Long-staple cotton Increase production of good-quality wheat	Improved varieties, all crops
Expected payoff	British cotton industry British bread consumers	Increased income for Punjabi farmers of all crops Indian cotton industry
Latent demand	Political pressure on government for research on cotton and wheat	Testimony at Royal commission, political pressure in legislative council
Actual demand	Research budget and Instructions to work on cotton and wheat	Funding for crop specialists in millets, oilseeds, pulses, fruits
Actual innovations	Improved wheat, cotton, and sugarcane varieties	More wheat, cotton, sugarcane, rice varieties
Actual payoff	Increased income for wheat, cotton, sugarcane farmers Indian cotton industry cut costs Consumers of Indian wheat and quality cloth benefited	Increased income for wheat, cotton, sugarcane, rice farmers, and for Indian cotton mills Slightly lower prices for consumers

Round 3 1947-1959	Round 4 1959-1970	Round 5 1970-1976
Improved varieties, all crops	Improved varieties, all crops	Improved varieties, all crops
Income for farmers Foreign exchange for industrialization	Increased income from cotton varieties	Large increases in income for farmers of all crops Lower food prices
Political pressure for agricultural improvement	Support for cotton	Pressure for work on neglected food crops and regions
Small increase in funds for all crops	Money for foodgrain, cotton, sugarcane research	Research expenditure for other crops and unirrigated regions
Cotton varieties	Green Revolution wheat and rice varieties; also some cotton, sugarcane, maize varieties	–
Increased income for cotton farmers only	Increased income for farmers and lower food prices for consumers	–

of research: The first category consists of farmers, consumers, suppliers of inputs, and traders and processers of agricultural output; the second consists of the politicians and bureaucrats who obtain some political or economic benefit from meeting the needs of the first group.

To get the first group to actively demand research, scientists must convince them of the benefits of research. The best way to do that is to have some well-publicized successes like the Green Revolution. However, scientists clearly must go beyond this. They must spend some of their time and resources on publicizing their role in developing these innovations. In some cases they can help develop institutions for informing beneficiaries of research results and articulating the demands of beneficiaries back to scientists. The development before Independence of the Indian Central Cotton Committee and similar committees for other cash crops are examples of one type of institution that played this role. Developing cooperative research and demonstration programs with private fertilizer producers might be another example. Institutions that extend into the villages, such as the Basic Democracies and religious organizations, might be used to inform farmers of the benefits of research and find out what farmers need. This can be done by placing representatives of these groups on advisory boards for the research system and by making information and training available to the leaders of these groups. The extension system has official responsibility to provide information to farmers and provide feedback to research, but in Pakistan it has been only partially successful in providing information and even less successful in providing feedback.

The second category—politicians and bureaucrats—will be most impressed by well-organized pressure groups from the first category. Therefore, there is undoubtedly a payoff to involving groups that are already organized or encouraging the organization of commodity groups that will support research. The other important thing that researchers can do is educate politicians and bureaucrats about both the technical possibilities and the economic and political payoffs of successful government research programs. This educational process needs to include not only casual discussion of past results but also careful analytical papers that quantify the economic and social benefits of local agricultural research. It is this type of analysis that will convince planners and technocrats of the need for investment in research.

Pakistani scientists are clearly aware of the benefits of a breakthrough like HYV wheat and rice. However, they do not appear to have put much effort into educating politicians and bureaucrats and have put less time into developing a clientele outside the government. There are no studies calculating the rates of return to Pakistani agricultural research other than this one. More effort is required to convince some policy makers that local research contributed to the Green Revolution. Many officials still believe that the research of the International Agricultural Research Centers was entirely responsible for the Green Revolution.

The research system could get more support for its program from farmers, consumers, the private sector, and agribusiness by spending more resources to

develop a clientele. It has done little to develop such a clientele so far. In addition, the breakdown of the Basic Democracies and then the electoral system has left many progressive farmers who would normally support research with no effective means of influencing decisions. Recent actions by the government have encouraged the private sector to supply inputs and process agricultural output. Government scientists should work to make the input markets more productive and should not try to hinder their growth (as has sometimes happened in the past). Also, the research system must encourage progressive farmers to help set research priorities and bring their problems to the research system.

These are simply general suggestions about the type of activities that need to be encouraged. Some research stations like the Pakistan Central Cotton Committee Research Institute in Multan and the the Tobacco Research Center near Mardhan are already working closely with farming and industry and have built up demand for research. However, many of the other stations need to do more.

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APPENDIX A
DETAIL OF CROP INTRODUCTIONS

American cotton: 1910 to 1919—4-F (S-Ly); 1920 to 1929—289F (S-Ly); 1930 to 1939—289F/K25 (S-Kh), L.S.S. (S-Ly), 289F/43 (S-Ly); 1940 to 1949—124F (S-Mul), 216F (S-Ha), 199F (S-Mul); 1950 to 1959—362F (S-Ly), AC-134 (H-Mont), Lasani 11 (H-Mul); 1960 to 1969—AC-307 (H-Ly), BS 1 or 13/26 (H-Ba); 1970 to 1979—MS 39/MS 40 (H-Mul), 149F (H-Mul), Delta Pine (I-U.S.), B557 (H-Ly).

Desi cotton: 1920 to 1929—Mollisoni (S-Ly); 1930 to 1939—15-Mollisoni (S-Ly), 39-Mollisoni (S-Ly); 1940 to 1949—119-Sanguineum (S-Mul); 1950 to 1959—231 R (S-Ha).

Wheat: 1910 to 1919—P-11 (S-Ly), S-A (S-Ly); 1930 to 1939—9-D (S-Ly), C-518, C-591 (H-Ly); 1940 to 1949—C-228 (H-Ly), C-217 (H-Ly), C-250 (H-Ly); 1950 to 1959—C-271 (H-Ly), C-273 (H-Ly); 1960 to 1969—Dirk (I-Aus), Lerma Roja (I—Mex), Penjamo-65 (I-Mex), Mexipak (I-Mex); 1970 to 1979—Chenab-70 (H-Ly), Barani-70 (H-Ly), Sa-42, Blue-Silver (H-Ly), Ly-73, Sandal (I-Mex), Pari-73, Pothwar (H-Ly) (I-Mex).

Sugarcane: 1920 to 1929—Co 205 (H-Co), Co 213 (H-Co), Co 223 (H-Co), Co 285 (H-Co); 1930 to 1939—Co 312 (H-Co), Co 313 (H-Co); 1950 to 1959—Co. L. 29 (I-Co), Co. L. 38 (I-Co), Co. L. 44 (I-Co); 1960 to 1969—Co. L. 54 (I-Co); 1970 to 1979—B. L. 19 (I-Ba).

Rice: 1930 to 1939—349 Jhona, 370-B Basmati, 41 Mushkan, 246 Palman (All selections Kala Shah Kaku); 1960 to 1969—IR-8 (I-PH); 1970 to 1979—IR-6 (I-PH).

Gram: 1920 to 1929—T-7 (S-Ly); 1940 to 1949—C 12/34 (H-Ly); 1950 to 1959—C 612 (H-Ly).

Maize: 1950 to 1959—DC 59 (H-Ly); 1960 to 1969—DC 697 (H-Ly), J-1 (I-Mex), Synthetic 200 (Sy-Y); 1970 to 1979—Neelum (I-Mex), Agaiti-72 (Sy-Y), Akbar (Sy-Y).

Other: 1930 to 1939—Barley T-4, T-5 (S-Ly), Rape Selection A (S-Ly); 1940 to 1949—Jowar, J-8 (S-Ly).

Sources: American and desi cotton 1910–1964: Abdul Hameed Khan, 1964, "Fifty Years Research and Improvement of Cotton Crop in Lyallpur Region," *Agricultural Pakistan,* XVI, No. 1, p. 48; 1970–1975: Punjab, Planning and Development Department, 1976, *Punjab Development Review and Prospects,* Government Printing, Lahore, p. 128. Wheat 1910–1960: M. A. Aziz, 1960, *Cereals and Pulses, Resume of Fifty Years Research Work at Punjab Agricultural College and Research Institute,* Lyallpur, Department of Agriculture, Lahore. 1960–1975: S. A. Qureshi, "Annual Report of the Cereal Botanist, Punjab Agricultural Research Institute, Lyallpur for the Year, 1974–75," mimeo. Sugarcane 1910–1971: Punjab Agricultural Research Institute, Lyallpur, 1971, *A Guide,* Department of Agriculture, Lahore, p. 123. 1971–1975: *Punjab Development Review,* p. 128. Other crops 1910–1960: Aziz. 1960–1970: Abdur Rehman and M. Anwar Khan, 1975, "Maize and Millets, Evolution of New Varieties," *Pakistan Agriculture,* edited by Saeed Hafeez, Press Corporation of Pakistan, Karachi, p. 5. 1970–1975: *Punjab Development Review,* p. 128.

S—selection; H—hybrid; I—introduction; Sy—synthetic. Research stations where varieties were developed: Ly—Lyallpur; Co—Coimbatore, Madras; Kh—Khanewal; Mul—Multan; Ha—Hansi; Mont—Montgomery; Y—Yousefwala; Ba—Bahawalpur. If the variety is an introduction, the country of origin is given.

APPENDIX B
ESTIMATION OF NET BENEFITS

Most of the commodities that experienced technological changes faced very elastic demand curves. Before 1947 British India was basically an open economy and the Punjab had a small portion of the total world market. After Independence, during the 1960s and 1970s, the government had a fairly large procurement program for wheat, under which it purchased everything available at a fixed floor price. The government purchased more than half of the rice that was produced and fixed the price at which sugarcane was purchased

by sugar mills. Cotton prices were determined by the world market and government policies on exchange rates during the 1950s and 1960s, and were set by the Cotton Export Corporation after 1972.

The increase in producer surplus has been estimated assuming a parallel shift in the supply curve due to yield-increasing new varieties, adjusted for changes in value that result from changes in quality. The most crucial parameter of estimated producer surplus is the shift of the supply curve. The wheat crop presents an example of how this parameter was estimated. The basic function used to estimate the producer surplus is:

$$PS = khPQ \tag{1}$$

where P equals the price of the crop; Q equals the total quantity of the crop; and kh is the shift in the supply curve, which can be decomposed into k, the related change in productivity, and h, output of improved variety as a percentage of total output.

The change in productivity is calculated for equation 2:

$$k = (a_n - a_o)/a_n \tag{2}$$

where a_n is the total factor productivity of the new variety and a_o is the total factor productivity of the old variety. For wheat Surajit Sidhu has estimated the increase in productivity to be 23 percent with one method and 45 percent with the other (Sidhu, 1974a, p. 220; 1974b, p. 744). This means that the reduction in productivity if these varieties were not available would be 19 percent ($23/123 \times 100$) or 31 percent ($45/145 \times 100$). The commodity then has to be adjusted for quality changes due to research. Wheat is changed into one quality, in this case the lower-quality Mexican wheat, using the average wholesale market price differential for the period 1970 to 1975, when one kilogram of the new wheat was worth 1.15 kilograms of the old. Thus, equation 2 becomes:

$$k = (a_n - 1.15a_n)/a_n \tag{3}$$

and the estimates of k are 5.7 as a lower-bound estimate and 20.7 as an upper-bound estimate. Table B.1 provides the k's used in this paper.

The improvements in quality that are reflected in market prices also were used to calculate the benefits from research. There was a steady increase in the quality of cotton and wheat before 1947, and much of the increased output was exported elsewhere in India. The increase in producers' surplus was therefore calculated as the increase in price times the quantity of the new variety produced. This is a very rough-and-ready method of adjusting for the quality changes, but unlike most other studies of technological change it does take these changes into account.

TABLE B.1—PRODUCTIVITY CHANGE

	Productivity increase (*percent*)		Quality adjustment (P_n/P_o)[a]	k	
	Minimum	Maximum		Minimum	Maximum
Pre-1947					
Desi cotton					
Mollisoni	11	17		11.0	17.0
American cotton			1.28		
Sugarcane					
Early Coimbatore	50	80		33.0	40.0
Late Coimbatore	80	100		44.0	50.0
Wheat					
P-11 and 8-A	9.4	19.0	1.06	9.4	16.0
C-591 and C-518	13.75	22.0	1.18	13.75	22.0
After 1947					
Wheat	21	45	$\frac{P_o}{P_n} = 1.15$	5.7	20.7
Cotton	14	31	1.06	17.4	28.0
Rice	25	50		20	33
Sugarcane	0	10		0	9
Maize	15	25		13	20

Source: Carl E. Pray, 1978, "The Economics of Agricultural Research in British Punjab and Pakistani Punjab (1905-1975)," Ph.D. dissertation, University of Pennsylvania, Philadelphia, Pennsylvania.

[a] P_n = price of new variety and P_o = price of old variety.