Staff Papers Series

Staff Paper P81-21 August 1981

Agricultural Research in British and Pakistani Punjab; An Induced Innovation Interpretation

Carl E. Pray

Department of Agricultural and Applied Economics

University of Minnesota
Institute of Agriculture, Forestry and Home Economics
St. Paul, Minnesota 55108

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A substantial body of evidence has accumulated which proves that economic forces do influence the path of research conducted by public agricultural research institutions.[1] However, there is also evidence that the level of investment in agricultural research and the allocation of that money within the agricultural research system has been less than optimal. The large number of studies that have calculated the rates of return to agricultural research indicate that both in developed and developing countries there has been an underinvestment in agricultural research.[2] Regarding the allocation of resources within the research system there is evidence to suggest that many national research programs do not allocate resources between commodities, inputs, and projects very efficiently at present. Some of the literature on the Green Revolution leaves the impression that there was little research in Asia on food crops before the Green Revolution. Colonial regimes in particular are criticized for doing research primarily on export and/or plantation crops which, it is implied, did not maximize the welfare of society as a whole. "Colonialism stunted indigenous agriculture by directing agricultural research only to export crops",[3] according to Lappe and Collins.

This paper attempts to examine these issues with a detailed case study of the Agriculture Department's research system in the British Indian province of the Punjab and then the successor institutions in Pakistani Punjab. In the case of British India many scholars have been critical of the low level of expenditure on development activities in general and the neglect of agricultural science and technology expenditure in particular. In addition some scholars have suggested that even in

the Punjab with the largest agricultural research program in British India, there was no measurable impact of technology on agricultural output.[4] The province of Punjab was originally chosen largely because I expected it to have the best data on agricultural output during the British period. The long time period from 1905 to 1975 allows me to examine the long swings in demand for research and the effect of institutional change which would otherwise be impossible.

The explanations of research resource allocation decisions and the decisions about the size of the total agricultural research budget are based on the ideas about the supply and demand of public goods found in the induced innovation literature. The demand for research comes from producers who gain increased profits or net income from certain types of technological change or from consumers who can gain from lower prices.

> "The manner in which the gains from technical change are partitioned between producers and consumers of a particular commodity depends on the slopes of the demand and supply curves for the product and on the rates at which these curves are shifting over time. In a market characterized by a highly elastic demand, or by rapid growth in demand, producers will be able to retain a relatively large share of the gains from technical change. In a market characterized by inelastic demand, or by slow growth of demand, most of the gains from technical change will be passed on to consumers in the form of lower product prices."[5]

In British Punjab, for example, the British Cotton Industry, the Indian Cotton Industry, and consumers of cotton goods and wheat hoped to benefit. They made their desires felt through petitions directly to the British monarch, through testimony before parliamentary commissions and through lobbying officials in India.

These pressures on the Indian government were translated into the development of an agricultural research system by setting up institutions,

budgeting money and hiring of scientists. This was the supply side of our market for public goods. These research institutions supplied the agricultural research services that were demanded by consumers and producers of agricultural goods. These institutions had to decide how to allocate their funds between different factors of production and between different scientific disciplines. Also, they had to decide the commodity composition of their output. The efficiency of their decision making can be judged using the tools of economics. Once these institutions started to produce useful results there was increased demand for their services. For example, when the Punjab Agriculture Department produced longer stapled cotton varieties and higher yielding wheat around World War I, farmers who grew millets, oilseeds and pulses also demanded improved varieties.

This case study is divided into three sections. The first describes the achievements of the research system and summarizes the calculations of the returns to research in the British and Pakistani period. There is also some information on the distribution of these gains between different sections of society. The second section attempts to explain the apparent underinvestment in agricultural research in terms of changes in the demand for research. The third section attempts to explain the allocation of resources within the research system and how that changed over time. Both the institution's desire for efficiency and the role of certain groups on the demand side play an important role in determining the pattern of resource allocation.

The Impact of Research on Punjabi Agriculture[6]

The story of the Green Revolution in both the Indian and Pakistani Punjab is well known. However, few people are aware of the contribution of agricultural science to growth in the Punjab before 1947. The impression one receives from reading the Indian nationalist literature is that very little progress was made in agricultural science and that any economic benefits from the few advances which were made went to 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.

Specification of the Contribution of Scientists to New Technology

The Punjab Department of Agriculture from its beginning in 1905 has been conducting research in a number of disciplinary areas. However, there is quantitative evidence only on the contribution of plant breeders. This evidence is in the form of acreage under new varieties and the effects of these new varieties on yield per acre, cost of production, and/or quality of the crops. Thus, my estimates of the benefits of agricultural research will be based on the output of the plant breeders, and my estimate will be a lower bound estimate because it does not include all of the output of other disciplines.

The success of the plant breeders in producing new varieties is shown in Table 1. It contains all of the improved crop varieties for which evidence of farmer acceptance is available. Evidence must be available showing that farmers actually used it on their fields, not simply that it was officially approved for cultivation by the Department.

The dates given are the dates the varieties went into commercial production. In parentheses after each variety is an S, H, Sy, or I, which indicates whether it was developed by selection, hybridization, as a synthetic or was introduced from outside South Asia. The other letters within the parentheses give the location of the research station where the variety was developed if it was bred in South Asia. If the variety was an introduction, the country of origin is given.

There are four patterns observable in the output of new varieties by the DAP. Three of them are evident from Table 1. First, breeders were successful only in certain crops especially cotton, wheat, and sugarcane. Second, even in these crops new varieties were released periodically rather than as a continuous stream. A third pattern is the importance of exotic varieties in certain crops after Independence. The fourth pattern, which is not immediately evident from the table, is that before 1947 only wheat varieties 9-D and C-217 and gram variety C 12/34, were specifically bred for rainfed 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% of the unirrigated wheat acreage in 1945-46).[7] However, the great majority of the successful varieties could be used only in irrigated or high rainfall areas.

The new varieties listed in Table 1 had two primary effects: first, many of them increased the yield per acre; second, some of them increased the quality of the crop which led to higher prices when farmers sold the crop. I have summarized the impact of the most important varieties in Table 2. The "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. The data on yield increases both in experiment station yields and when available on farmers' fields are presented. There are problems with both sets of data. The difference between the old variety and the new variety on experiment stations are sometimes much higher than in farmers' fields because they are not grown under conditions faced by farmers. However, they do have the advantage that they are usually comparing the different varieties under similar fertility and agroclimatic conditions. The problem with yields from the farmers' fields is that there is no control over the conditions under which the varieties are grown and so some of the yield differential may be due to factors other than simply the new variety such as fertilizer, irrigation and quality, or other inputs. The price premium over the old varieties is an average premium for several years from wholesale markets in the Punjab. I have included only representative varieties from Table 2.

There are three crops which are not included during the pre-Independence period in Table 2 in which some progress was also made. In rice and gram pure line selection and hybridization techniques were used to produce improved varieties. Rice in the Punjab varied in quality from the finest in India to some of the coarsest. In each of the four main rice categories one or two new varieties were selected and released to the farmers. The quality of these selected varieties seems to have been better and the yield of the coarse varieties was probably improved. By 1948 the West Punjab Agriculture Department claimed that 80% rice acreage was under new varieties.[8] However, there is no quantitative

evidence available about either the quality or yield improvements. In gram, botanists tried to develop higher yields and disease resistance, but again there is little quantitative evidence of the impact of the new varieties. Berseem or Egyptian clover was introduced into India in 1912, and at least one official thought it was one of the greatest achievements of the Agriculture Department. There is data on yields which indicate that this fodder yielded at least 33% more per acre than the fodders it was replacing.[9] Unfortunately, no one reported the acreage under berseem. It was simply included with the other fodders.

Table 3 gives five year averages of the area under improved varieties and the percentage of the total area of that crop which was under new varieties. American cotton after its introduction in 1913 quickly spread to about 40% of the cotton area in the early 1920's. The early American varieties could only be sown in the areas which had perennial irrigation, and within five years of their introduction, American had replaced desi (local) cotton on 90% of the cotton area in the districts that had proper irrigation. The second period of rapid spread was during the 1940's when the relative price of American increased due to the decline in desi prices. Improved desi cottons were not developed until after 1920. However, they did spread rapidly 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 1930's 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 introduced in the 1920's. They replaced local cane at a steady rate until the 1940's, when a combination of high prices and two very good new varieties pushed the acreage under new varieties over 80%.

Regular reports on the acreage under new varieties are not available for the Punjab during the period when it was part of the Province of West Pakistan. However, I have gathered all of the available data in Table 4. The r in each column marks the year when the new varieties were officially released by the government. In the wheat and rice we find a very rapid acceptance and then leveling off of the Mexican and IRRI varieties. Cotton shows a more gradual acceptance path which is the result of a stream of new varieties rather than one major breakthrough. There is not enough data on sugarcane and maize to be sure what the path is. 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.

On the basis of the data present in Tables 4 through 6 and information on the shape of the supply and demand curves for these crops I have been able to calculate the economic surplus due to agricultural research. I have used what is referred to in the literature as the index number approach.[10] For the crops in which there was yield increases I have estimated the size of the shift in the supply curve on the basis of the decline in cost due to the use of the new variety. For those crops which had changes in quality (mainly cotton) I have basically multiplied the average price premium times the output of the new variety. For all crops I have made an upper and lower bound estimate of the benefits because of the problems of finding accurate data.

The costs incurred to produce these benefits include the expenditure on research and the cost of spreading the information about the value of these new varieties. However, the budget data from the Department of Agriculture is not detailed enough to sort out the amount of expenditure

on breeding improved varieties and the expenditure on spreading these varieties. The budget figures also include expenditure on research by other disciplines which did not help in the production of new varieties. More important, the series on extension expenditure includes many things that had nothing to do with the spread of new varieties. Thus, I have tried several different expenditure series. I then calculated an internal rate of return under the different assumptions about benefits and costs. For the British period the rates of return ranged from 34 to 49 percent with the most realistic estimates between 36 and 44 percent.[11] For the Pakistani period my estimates of the rate of return range from 17 to 45 percent. The greater range is due to greater variation in the various measures of research and extension expenditure. On the basis of the most realistic assumptions the internal rate of return in this period was probably about 30 to 37 percent which is only slightly less than the rate of return for the British period.[12]

These results do support the argument that the British were underinvesting in agricultural research. However, the movement from colonialism to Independence has not greatly improved the efficiency of the allocation of government resources with respect to aggregate investment in research. These aggregate figures hide two important shifts which took place since Independence but which offset each other. One shift is the declining productivity of the agricultural research program at least until the mid-1960's due to the disruption at Independence, political interference and perhaps diminishing returns. The other shift is increased research productivity, particularly in wheat, due to the scientific breakthroughs in breeding high yielding grain varieties in Mexico and elsewhere outside of Pakistan.

The rate of return can be compared to the rates of interest at which funds were available. Bagchi shows that the Government of India was able to borrow money in London in the pre-World War I and at certain times during the inter-war periods for less than a 5 percent interest rate.[13] In 1936 it was able to borrow Rs. 120 million at par within India at 2-3/4 percent.[14] After Independence interest rates are clearly much higher. In the 1960's the government imposed ceiling on bank interest rate of 7 or 8 percent clearly was below the scarcity value of capital. Foreign loans according to Griffin and Rahman had effective rates of interest of 10 to 15 in the 1960's.[15] Thus, the Pakistani interest rates were clearly higher 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 anxious 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 Punjabi consumer. American cotton may have been the exception because it was used to replace 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 the ban on exporting wheat isolated the Punjab market from the international market. In this environment technical

change would have reduced wheat prices and much of the benefits would have gone to consumers. However, at the same time the government was processing wheat, which set a floor on wheat prices. This procurement price ensured that farmers received some of the gains from research. Also, due to the increased supply the government imported less grain than it would have, which saved foreign exchange. The benefits from cotton research went to the farmers because it was an export crop, but the farmer's gains would have been far greater in the absence of implicit or explicit export duties which held down cotton prices. In the coarse rice and coarse grain market there was little exporting or importing and so much of the benefits were passed along to consumers. Without a more detailed analysis about all that we can say is that both producers and consumers shared in the benefits from new varieties and that the division of benefits was largely determined by government price and export policies.

The Demand for Agricultural Research

The first section of this paper showed that the rates of return to investments in agricultural research were very 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. The purpose of this section of the paper is to explain the underinvestment in research by examining the demand for research. This section will deal with the problem of the demand for research in three periods. First, there is the period from about 1900 until the Royal Commission on Agriculture to India arrived in 1927. The second period is from 1927 until Independence and the final period is from Independence until 1975.

The first period started with a department of agriculture which was the institutional response to all-India and British pressures. The scientists of the department during this period consciously developed a program which they hoped would justify their existence to the government and people of the Punjab and increase the size of their budget. They were notably successful at this. It was an educational period when the Punjab learned that research could give practical results.

The second period I would characterize as one in which the farmers and government clearly appreciated the need for research but the depression, World War II, the Independence movement, and more importantly, the conservative financial policy of the British government slowed the growth of the budget for agriculture. This, in turn, meant little increase in agricultural research spending and underinvestment in agricultural research.

After Independence a far less stringent financial policy was followed, and so development spending was greatly increased. However, in this period the possible contribution of agricultural research relative to other types of investment in agriculture was probably underestimated. This led to a much smaller percentage of the agriculture department's budget being devoted to research while the department's total budget has increased greatly.

There had been a Department of Land Records and Agriculture in the Punjab since 1880. This was the provincial branch of the British Indian department which was set up as the result of the recommendations of the Indian Famine Commission of 1880. The main job of this department was the collection of agricultural statistics, and it did almost no agricultural research and development work. An agricultural experiment farm was first set up in Lyallpur in 1901 and some trials of wheat and cotton varieties were started there. However, research was not carried out on a regular basis until a separate Department of Agriculture was set up in 1905.

The establishment of the Department of Agriculture of British India with its Provincial research, extension, and education programs was a response to at least three sets of pressures. The first was the demand by both the people of India and the British people and government that something be done about the catastropic famines that had killed and impoverished millions three times in the last quarter of the 19th century. These famines became increasingly visible as the dimensions of these tragedies became clearer through the improved statistical services and the famine commission reports that followed each of the three major famines. In addition some of the early Indian nationalists were beginning

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 stated by the Famine Commission of 1901.[16]

In addition to the demand for relief from famine, at least three smaller pressure groups supported government agricultural research. The first was the British cotton industry which had long dreamed of ending its dependence on the United States for medium and long staple cotton. This dependence had been emphasized at the beginning of the twentieth century by the short supply and high prices of long stapled cotton which the industry faced. The demand for long stapled cotton was communicated by the Lancashire cotton industry directly to the King of England, and from him, through the bureaucracy, to the Indian Department of Land Records and Agriculture. The second group was the British grain trade which operated in India and indirectly the British consumers who wanted lower bread prices. During the first decade of the Twentieth Century about 16 percent of British wheat and flour imports came from India (and most of that from the Pumjab). In the Punjab soon after the Department of Agriculture was set up officials were in close contact with the grain trade. As a former director of agriculture put it before the Royal Commission: "Large firms exporting wheat and cotton have generally branches in them (the irrigated areas) and it is more easy to get into touch with them to find out what is wanted."[17] What these firms wanted was higher quality wheat and a more dependable supply. A third group was the jute trade and industry which wanted improved varieties of jute from Eastern India.

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 Privincial government for three quarts 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. A review of the strategy of working on irrigated crops in early period provides evidence of the Department's success during this period. This is part of the testimony of Mr. Milne, the Director of Agriculture, Punjab and the first economic botanist of the department, before the Royal Commission in 1927. The questioner was Mr. Barron a member of the Commission and a member of the Indian Civil Service.

> Barron: 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 it was of no use whatever.
>
> Barron: ...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.
>
> Barron: ...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.
>
> Barron: 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?
>
> Milne: Yes; the position is that in the canal irrigated land we have conditions which are far more constant than in the barani area, where, for example, in some years there is no rain while in other years there is a lot of rain. The dates of the precipitation are not the same, &c. You can show something definite on the irrigated land in a few years, while you cannot do so in the barani areas; it was the proper way to start the work in this province.[18]

There were major structural changes after World War I which probably changed the relative importance of the different groups which 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 any direct influence on 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 the increased power of the legislative councils and the widening of the electorate. This increased the influence on the department of large landlords of the Province. At the same time there was a decrease in influence of the wheat and cotton trading companies.

By the time of the arrival of the Royal Commission of Agriculture in India the groups supporting agricultural research in India had changed considerably. Cotton research was financed by the Indian Central Cotton Committee (ICCC) which was funded by a special cess on the cotton that was exported or consumed in India. This organization contained representatives of all groups who were interested in Indian cotton, and, the Indian cotton industry had more influence than the British industry. The fact that the Indian cotton had never been able to substitute for cotton from the United States in Great Britain probably led to a decline in the British industry's interest. The grain trade with Britain was unimportant after World War I because the increase in Indian population increased local demand for grain. The Punjab's surplus went to other parts of India rather than Britain. As a result another pressure group -- the British grain merchants and consumers --

lost interest in Indian research. However, the benefits of research quantified in Part I had by this time started to flow to Punjabi farmers and they now demanded more results. At about the same time devolution of power and increasing democratization of the government provided farmers with more instruments for applying pressure. In testimony before the Royal Commission they pressed the department to work on rainfed crops. Farmers who had orchards started coming to the department for advice in large numbers. The findings of the Royal Commission that research had been successful in the Punjab and elsewhere in British India and that research should be increased undoubtedly helped convince government officials in Britain and in Punjab of the value of agricultural research.

In the Punjab there seems to have been considerable enthusiasm for research, but the fiscal conservatism of the colonial government seems to have been the most important constraint to growth. Table 5 shows the growth of the research budget from the time that it was listed as a separate item in the Punjab budget. Research expenditure during the last part of the British period was growing in both nominal and real terms. Perhaps more revealing is the fact that it was increasing as a percentage of the Agriculture Department's budget and as a percentage of the total budget of the Punjab which was the Punjab governments response to rising demand. However, the overall constraint to increased spending on development remained. The 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, which included agriculture.[19] There was a general reluctance of 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 against paying land revenue and other groups to resist taxes in many parts of India. In addition the Provincial governments had not been given complete freedom to borrow in 1919 and finance development in that manner. 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..."[20] After World War I the criteria for borrowing loosened up somewhat for railroads and irrigation, but there still was no borrowing for other types of development projects.

Since Independence there were two trends which are apparent in Table 5. First, there has been a steady increase in the nominal and real expenditure on research and the expenditure as a percentage of the value of agricultural output in the Punjab has increased. Second, research has steadily declined as a percentage of the total agricultural department's budget and of the total Punjab government's budget. My hypothesis is that the government's budget constraint was lifted by the departure of the British and the availability of foreign aid and so real expenditure on research went up as the total expenditure on agriculture increased. However, the government's expected payoff to investment in agricultural research was low relative to the investments in extension, chemical plant protection, price supports for grain, subsidies on inputs like fertilizer, mechanization and irrigation water. This expectation of relatively low returns to research was due to three factors -- first, the small output from research during the first 15 years after Independence; second, the high, perhaps exaggerated, expected economic returns to some of the other investments; and finally, the immediate payoffs to certain groups when subsidies are given led to

stronger political support for those policies. In the following paragraphs I will concentrate 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, Alavi, Herring and others.[21]

In the first section of this paper it was noted that the cotton crop was the only one in which there was a stream of new varieties that continued through the 1950s and early 1960s. In sugarcane two important selections were made from the old Coimbatore material, but in the other crops Punjab had to wait until the introduction of new genetic material from Mexico and the Philippines before research had any impact. The reason for this decline of productivity is clear -- Independence had disastrous effects on the agricultural research program. Most of the scientific personnel except those in the cotton program were Hindus or Sikhs. In 1947 they all left for India. They took with them all of the genetic material that they could carry and the rest was mixed or destroyed. The library and other facilities were partially destroyed. The source of sugarcane genetic materials in Southern India was cut off soon after Independence, and so it was much more difficult to breed sugarcane.

These difficulties were compounded by the policies of the government which made recruitment difficult and provided few incentives for practical research. The primary interest of the first Pakistani governments was in development through industrialization. Hence, agriculture department jobs were low status positions, and the pay scales and opportunities for advancement for officials in the agriculture departments were less than in other branches of government.[22] This meant that the agriculture department

could not recruit the best scientists. A second problem was that some of the people who had to be promoted quickly at Independence had not been particularly effective researchers. Thus, once they were in power they emphasized seniority, which strengthened them, rather than scientific output, which might have increased productivity, as the means for advancement. Third, real research expenditure per scientist declined considerably after Independence. Finally, politics seems to have played a more important role in appointments and promotion than it had under the British. This impression may simply be due to the fact that I was able to talk to 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 politicized.

Whatever the reasons agricultural research did not produce much other than cotton varieties until the mid-1960s. In the process they seem to have lost the support among farmers and officials which they had built up before 1947. In the previous section I have mentioned that the availability of high yielding varieties of wheat and rice at a time when the Pakistani government was particularly aware of their dependence on foreign grain, led to a shifting of priorities toward grain research in the 1960s. It was these same pressures and the rapid spread of the Mexican varieties in the late 1960s which led to the doubling of real expenditure on research between 1960 and 1972. The high yielding varieties also enabled researchers to regain the respect of farmers as a source of productivity increasing varieties. However, it is not clear that the government appreciated the contribution that local research made. Table 5 shows that the percentage of the agricultural budget which was spent on research declined in the

first few years of the Bhutto regime (1972). The government seemed to think that it could continue to import new agricultural technology from abroad with very little input from local research. In 1975 wheat breeders discussed with me their on-going battle to convince the government that it was not necessary to import more Mexican wheat varieties and seed because the local research and seed production program could provide the same quality seed at a lower cost. This is just one indication of the lack of confidence the government had in its own researchers and seed multiplication program.

In conclusion, the underinvestment in research was due to two factors. During the last half of the British period although the demand for research was strong, the government's budget constraint tightened by the depression and the generally conservative fiscal policy prevented the Punjab from investing more in agricultural research. During the Pakistani period the fiscal policy became more liberal and the budget constraint was released in part by foreign aid. The demand for research was weak before the Green Revolution varieties arrived because of the absence of concrete payoffs. After the Green Revolution farmer support for research seems to have grown rapidly but government interest in local research has been deflected by the apparent availability of technology from foreign institutions and greater short run political payoff to other agricultural programs.

Efficiency of Resource Allocation Within the Agricultural Research Program

There is a series of decisions which scientists, administrators, and politicians have to make about allocating resources within the agricultural research system. The one which has prompted the most discussion is the decision about the commodity priorities of the research system. The preceding section has confirmed the observation by economic historians that the benefits from research were concentrated in a few crops during the British period. However, these crops included the main food crop of the Punjab - wheat. In addition the Punjab government after Independence continued to have most of its success in the same commodities. Therefore, there is no clear evidence that colonialism adversely affected the allocation of resources between the different crops.

In addition to the allocation of resources between commodities, policy-maker's decisions include the choice of whether to work on the problems of irrigated or unirrigated agriculture; the choice of working to develop land-saving or labor-saving techniques; choices about working on quality or yield improvement; the mix of scientific manpower, physical capital, information flows and other inputs; and within disciplines the decisions about which scientific techniques to use. The case for irrigated versus unirrigated crops was presented by Milne on page This section of the paper will test the efficiency of the allocation of resources between commodities, disciplines, and land-saving versus labor-saving biases. Although none of these decisions can be tested very rigorously, it is possible to have some idea about the efficiency of the allocation of resources and to find some of the sources of inefficiency.

Boyce and Evenson[23] have suggested a rough rule of economic efficiency in allocating research resources to different commodities which they have termed congruence. It is that the percentage of resources going to a commodity should be the same as its percentage of the value of total agricultural production. Empirically, they have shown that as research systems mature they move in this direction and that the older, more developed, research systems follow this rule more closely than less developed systems. However, it makes three important assumptions which may not hold for decision-makers at a specific point in time. The first is that the resources required to improve any commodity are roughly equal. The second is that the price elasticities of demand and growth of future demand for the commodities are roughly equal. The third is that innovations will spread equally fast in all commodities. If the assumptions do not hold, then it is possible that decisions which do not follow this rule are still economically efficient. Another possibility is that economically inefficient decisions* were politically efficient in that they were responding the demands of certain politically powerful special interest groups. Finally, it is possible that researchers made poor decisions because there was no incentive to try to be efficient. Therefore, I will first use this rule to highlight possible economic inefficiencies, and then I will examine some of the apparent inefficiencies to find out whether were inefficient or not. If they are, I will try to find out why they took place.

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* However, these decisions may have been efficient in maximizing political support for the research institutions which in turn led to larger aggregate investments in research and thus aggregate expenditures closer to an efficient level.

The number of scientific-man-years found in Table 6 is the best quantitative data that is available on the distribution of resources between commodities. It does have problems because some of the crops like cotton may have gotten more resources in the form of farms and equipment than is indicated by the number of scientists. However, in general this distortion is not great, and the few cases where it is a problem will be discussed below.

In the early days of the Department the research work was concentrated on wheat and cotton. The first Economic Botanist, Mr. Milne was asked about this by the Royal Commission, which in 1926 was explicitly thinking about the congruence rule.

> Commission: Do you think that the work done on crops in the Punjab bears due proportion to the value of the crops of the Punjab? Wheat, for instance, is about 43 percent, and cotton is 10 percent. Would you say you put four times as much work into wheat as into cotton?
>
> Milne: I do not think we went into spending time in proportion to the value of the crop. Wheats and cottons are two valuable crops, and we do what we can for both of them with the staff that we have available.[24]

Table 7 shows the distribution of scientists and the value of crops in later periods. The year 1960 is the only one in which I have a breakdown of the budget by crop. It suggests that SMY's are not a good measure only in the oilseed and cotton cases. There are a few generalizations that can be made with some confidence. First, wheat did not receive its share of resources after the mid-1920's. However, this situation improved somewhat after 1971 with the establishment of the rainfed wheat institute. Second, the large share of resources in cotton, mentioned above by the Royal Commission, continued until 1971 when its share of resources fell below its share of value. Third, the oilseeds seem to have received more than their share of resources even

if we do not use the percentage of expenditure rather than SYM's. Fourth, the millets were roughly in line with congruence except in the first period when the combined share of resources of millets and maize was higher than the share of value. Fifth, maize apparently received too many resources throughout this period. Sixth, sugarcane was roughly congruent. Finally, there seems to have been an overemphasis on cash crops as a group until 1971 and the shift from a colonial to an independent government in 1947 had little effect on this situation.

This initial decision to concentrate on wheat and cotton was not made by the researchers. When Milne took up his post, he 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."[25] In fact the decision seems to have been made at the all-India level. The special crop programs 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 before any other all-India crop specialist. The wheat specialist was particularly active in the Punjab before Mr. Milne was appointed. He made the first systematic collection of wheat varieties in the Punjab and selected the first improved variety.

The enthusiasm of the British for cotton and wheat clearly was not simply the product of the governments' desire to serve the needs of the Indian people. An official report of the second meeting of the Board of Agriculture 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

U.K. in 1904-5 than any other country.[26] The link between British needs and interest in cotton research was equally direct. The first Board of Agriculture meeting considered a memorial from the British Cotton Growing Association dated 30th 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) ... during the last two years." This shortage was caused by the decline in American production due to the boll weevil attack at this time. The memorial went on to say: "we do not necessarily advocate that further larger attempts should be made to introduce exotic varieties. Much good will be done if careful selection is carried on with native varieties only. At the same time, we would strongly recommend that further experiments should be made with American, Egyptian, Brazilian and other varieties, as it is quite possible that in some parts of India foreign varieties may prove more successful than native ones."[27] The fact that this memorial was quoted in full in the Punjab Department of Revenue proceedings indicates that the Provincial government was fully aware of the British Cotton Growers Association's position.

To neglect the crops which made up the other 47 percent of the value of crops in 1926 would seem to be inefficient. However, the neglect of the other crops before 1928 is somewhat exaggerated by Table 6. Research on sugarcane was conducted by the agricultural chemist, and so it does not show up in the table. All sugarcane breeding had to be conducted in South India, because it does not flower in the Punjab. The subordinate staff of the Punjab Agriculture Department conducted trials of the varieties which were bred in South India, and this program was very successful. In most other crops some exploratory work was done -- a

small collection of local varieties was collected, and these were grown to see if there was any striking variability in the crop. However, no important breeding work was started until the late 1920's.

After the initial successes in wheat and cotton the Department's decision about moving into work on other crops seems to have been left to the researchers within the department. In the early 1920's there still were only a handful of scientists, and so they were forced to choose fairly carefully which crops to work on. The basis of their decision not to spend much time on the pulses, oilseeds, and millets as indicated by their testimony before the Royal Commission and in written papers seems to have been a combination of the low probability of producing important economic gains and the cost of producing those gains.

Gram was the third most valuable crop in the Punjab in 1925[28] and in acreage it was second only to wheat. When the Commission asked Milne if any work had been done on gram, he replied:

> Very little. I made a collection of all the types of gram I could find in the Province, and I have sown these pure types along side one another with a view of seeing which is the best from a farmer's point of view in an acreage season. But gram is a very tricky crop to grow because the results are so variable; it is not nearly as steady a crop as wheat is. You will find the outturns fluctuating up and down annually, with the result that it is not easy to get down to anything definite with gram.[29]

Later tests in Lyallpur confirmed that on the same soil under similar weather conditions the variance of gram yields was much greater than the variance of wheat yields. This made it harder for breeders who were not using statistical techniques to pick out the improved varieties.

The millets, maize, and oilseeds made up 4 percent of the value of the main field crops in 1929. However, they received little attention before 1926. This neglect was attributed to the cost of improving these

crops, all of which were highly cross-pollinated. Developing a pure line (or inbred line) or cross-pollinated crop required that each plant be self-pollinated by hand each segregating generation in contrast to wheat or cotton which are largely self-fertilized and thus require no such artificial self-pollination. The comments of Sir Albert Howard, the Economic Botanist for British India, on the oilseeds also hold for bajra and maize. In his 1924 book on Indian agriculture, he said:

> In the case of sarson, rai, and toria -- the rape and mustard seed of commerce -- gingelly, safflower, and castor, the amount of natural cross-fertilization is so great that the labor involved in isolating high-yielding unit species and in maintaining them in pure culture is greater than the means of the present Agricultural Department allow.... Form-separation, within rather wide limits, which would allow of crossing between the types, is perhaps the utmost the plant breeder can accomplish. [30]

This assessment of the expense of pure-line breeding along with his pessimism about mass-selection (which he calls form-separation) was widespread among scientists in the Provinces at least until the 1930's. They also recognized that once in the farmers' fields, any advantage the pure-line had would be lost in a year or two because of cross-pollination with the local varieties unless farmers bought new seed from the Department each year.

The expansion of the departmental research that took place in the late 1920's into gram, cross-pollinated crops, and fruits was largely due to forces outside the scientists' control. The position of these crops changed from neglect to one of too much attention. Table 7 indicates that in 1929 millets, gram (legumes), and oilseeds, which made up about 28 percent of the value of the main field crops, were receiving 42 percent of the scientific manpower. Fruits (not included in Table 7 for lack of output data) which were at most 5 percent of the total value of crops were being worked on by two horticulturalists while wheat and

barley which were 44 percent of the value of crops had only one senior scientist.

The cause of this movement away from congruence was a shift in demand for breeders' output. The success of cotton variety 4-F and wheat varieties 8-A and P-11 made farmers and officials in the government aware of the potential benefits from the research program. By 1927 when the Royal Commission on Agriculture visited the Punjab, several Punjab officials who were not in the agriculture department criticized the fact that the researchers were working only on wheat and cotton.[31] The Commission asked researchers about this bias, and in their report they recommended that the provincial agricultural departments spend more of their time on crops like gram, bajra, and jowar.[32] This demand pressure undoubtedly shaped the way in which the new funds were spent.

There was also strong demand for information on fruit:

> 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.[33]

The demand for research on this crop was narrowly based (there were only 39,000 acres of orchard in the Punjab in 1926)[34] but because most of the orchard owners were well-off landowners and many of them were European they had much more influence than the value of their crop as their numbers suggest.

By 1929 the pressure to produce new wheat varieties decreased somewhat because it was no longer exported out of India, and so the British government and private British trading companies were no longer interested. Some of the slack was taken up by big wheat farmers who were active in Provincial politics and were by now aware that the Depart-

ment of Agriculture had something to offer. However, it was insufficient to balance demands for work on other crops and so wheats share of research resources dropped sharply. Cotton continued to be the most researched crop because of the organization of the Indian Central Cotton Committee. In 1917-18 the Indian Cotton Committee had investigated the prospects for increasing the cultivation of cotton, especially American cotton in India. As a result of their recommendations the Indian Central Cotton Committee was founded in 1921. This committee was supposed to represent all sections of the cotton industry. It was headed by a government official and had representatives of the provincial agricultural departments, the Indian states, the cotton growers, cotton ginners, spinners, and merchants. It was funded through a small tax or cess on all cotton ginned or exported. One of its main activities was to fund cotton research and from 1925 onwards, this committee and its successor, the Pakistan Central Cotton Committee, provided most of the funds for the agriculture departments research work on cotton.

There were few major changes in the distribution of scientific manpower during the rest of the British period. One scientist was added to the oilseeds program in the 1940's, a vegetable specialist was added, and the millets were shifted into the cereals section. Within the different crop research programs there was some shifting of priorities which showed that researchers were responsive to the changing needs of farmers. When World War II cut off the Japanese demand for short staple cotton, the cotton research people shifted all of their efforts into the longer-staple American cotton. They developed the main cotton varieties which were released in both the Indian and the Pakistani Punjab between 1947 and 1960. The research work on gram varieties concentrated

on producing varieties that were resistant to the blight and wilt diseases that attacked gram in the late 1930's and 1940's.

A simplistic view of the shift from colonialism to Independence would suggest that the replacement of Britain by Pakistan as the sovereign power should have eliminated the demand pressure applied by British manufacturers, British consumers, and British farmers and merchants residing in India. This would allow the people of Pakistan more influence and their demand would shift the research emphasis away from export crops to the basic food crops. However, no substantial shift took place. The output from the research system continued to be concentrated in wheat and cotton. New technology in sugarcane was somewhat less important after Independence and benefits in rice and maize eventually were quite significant. Tables 6 and 7 show that the actual allocation of researchers between different commodities had changed very little by 1950, three years after Independence.

There are several reasons why the expected changes did not take place at Independence. First, the importance of the British consumer and the British manufacturers in the making of policy in British India had been declining long before Independence. At the Provincial level this influence on agricultural policy had been declining since World War I. Provincial autonomy and the development of democratic institutions plus low payoffs for British cotton and wheat interests combined to decrease British interest and influence. Second, the influence of Manchester cotton interests on the British government had been declining since the turn of the century.[35] Third, the institutional financing of research on the main export crop, cotton, was basically set by the size of the cotton crop and the decision of the government about the size of cess on the cotton trade. This meant that in contrast to other

crops there was a steady supply of money to finance cotton research which was not as vulnerable to changing governments. Fourth, the government after Independence continued to be interested in export crops. They were seen as a source of foreign exchange with which industrial development could be financed.

By 1960 all crops were receiving more attention by breeders, but there seems to have been little change in the allocation of resources to different crops. The main change was the increase in the number of breeders working on oilseeds. There was one botanist for each of the six most important oilseeds. This greatly exaggerates the actual expenditure on oilseeds. If actual expenditure is used the share of resources going to cotton and oilseeds is reversed -- cotton received almost 40 percent while oilseeds got 10 percent. The shift from being an exporter of wheat to being an importer, which took place in 1952, does not seem to have generated much pressure for more wheat research. Beringer and Irshad, writing in the early 1960's, have suggested that the availability of PL-480 wheat generally decreased the pressure on government to invest in agriculture:

> ..."there is a danger that the relatively stable urban food-price situation which has been maintained with the help of PL-480 imports is beginning to blur the government's vision of the seriousness of the agricultural supply situation in Pakistan."[36]

An examination of the price of wheat relative to the price of cotton from 1947 to 1975 shows no important shift upward of wheat prices. This indicates that government import and price policies kept the food situation from putting pressure on food prices.

The one grain which did receive increasing attention was maize. The inspiration apparently was the recent success of hybrids in the

U.S. With technical assistance from the U.S. a hybrid corn research program was started. Hybrids were released but little acreage was covered because a hybrid seed industry did not develop.

In the 1960's the shift toward more work on food grains and thus increased efficiency finally took place. Table 8 shows that in 1960 food grains and pulses had about 35 percent of the scientists. In 1971 this increased to about 53 percent. This change was due to a big increase in scientists working on rice and maize. These changes were caused by important changes in both the supply and demand for technology in these commodities. Because of the poor record of grain research described above in Section II, there continued to be little public demand for new technology in food grains. However, the cut-off of United States food grain aid during and after the Indo-Pakistan war of 1965 and two years of drought made President Ayub Khan realize his vulnerability to changes in U.S. policy and fluctuations in the weather. This led to a shifting of priorities and a determination to become self-sufficient in food grains as soon as possible.[37] At the same time the President became aware of the availability of Mexican wheat and its potential for increasing yields in Pakistan. This awareness was due to a considerable amount of groundwork by Pakistan scientists aided by CIMMYT and the Ford Foundation. When wheat production took off very quickly in the last few years of the 1960's, the enthusiasm of the government for other crops like rice and maize in which high yielding varieties had been developed in the international centers for agricultural research was very high. Therefore, large programs in these crops were started.

Demand for research by farmers became an important influence on decision makers again after the spectacular success of Mexican wheat and IRRI rice. Three changes have taken place in the research system which reflect this demand pressure (although they do not show up in Table 7). Bajra and jowar have been getting an increasing amount of attention from the maize research people since the late 1960's. A separate section for work on gram was set up in 1971. It is developing a collection of varieties and beginning to do some breeding. Also a separate program for the development of rainfed wheat has been set up. These programs are clearly in response to the demands of farmers in the rainfed areas of the province who have benefitted little from Green Revolution crop varieties. Whether they are economically efficient remains to be seen.

In general most of the diversions from the congruency rule seem to have been movements away from economic efficiency. This was the case with the relatively large amount of resources spent on millets, maize, oilseeds, and fruit in 1929, probably maize research in the 1960's. The continuing flow of resources to cotton research can be only partially justified on economic grounds as the Punjab's main export good and an important source of foreign exchange. The differences in the elasticities of demand for cotton and other crops were not sufficiently large to outweigh the difference in the value of the crop. The expost analysis in my thesis confirms this.[38] In contrast, the neglect of pulses, oilseeds, millets, and maize in the first 20 years of the Department's existence appears to have been an efficient decision given the lack of staff and breeding technology of that period.

The major shifts in the allocation of resources were largely due to the realization of farmers or individuals within the government that research could play an important role in agricultural development. In the 1920's new cotton and wheat varieties had proven themselves in irrigated areas and so farmers and officials in other areas wanted research done on their crops and problems. In a similar manner the Green Revolution varieties of wheat and to a lesser extent rice proved the value of research in the 1960's leading to enthusiasm for research on other crops. Throughout the period cotton was supported by industry through a central cotton committee.

The second set of choices to be examined is the choice of discipline which also at least partially determines whether research is applied or basic. After the initial selection of three disciplines -- agricultural chemistry, economic botany and agronomy -- the staffing decisions of the Department of Agriculture had three main characteristics. First, the disciplines were chosen on the basis of how much they could contribute to the solution of practical problems. This leads to the second characteristic which is that the disciplines which contributed the most grew most rapidly and to the third characteristic that new disciplines were added when a specific need arose.

The growth of the research staff in different disciplines is shown in Table 9. An agricultural chemist, economic botanist and agronomist were appointed to each provincial department of agriculture in British India around 1907. In the Punjab an agricultural engineer was also appointed, but he did not do any research except for a period of about 10 years starting in the 1920's. In 1905 it was clear that the British expected the best results would come from the agricultural chemist. In the Punjab the chemist immediately started work on salinity and water-

logging problems of the canal irrigated areas of the Province. However, he did not come up with any practical techniques for solving this problem before this topic was taken over by the Irrigation Department in 1925. At that time this discipline shifted into research on animal nutrition in which they did some basic research and some work with fertilizers although most of the fertilizer experiments were conducted by the agronomist.

The agronomist carried out a number of experiments on cultural practices such as fertilizer application, planting crops in rows, replacing local plows with iron plows, green manures, different rotations and introducing new fodders. Most of these were not widely used in the early days. Some of his findings were negative. He showed that the application of chemical fertilizer on wheat and cotton was not economical during the teens and 1920's. Later he tried steam plows and tractors with the agricultural engineer and found that they were not economical in the Punjab before World War II.[39] Thus, the impact of the agronomist does not seem to have been great and what impact he had was not easily measurable.

In contrast to the other scientist the results of the Economic Botanist's research were quick, economically important and very visible. Five years after his appointment in 1907 he had released new wheat and cotton varieties. By 1920 the wheat varieties were being grown on 600,000 acres and the cotton varieties on almost 500,000 acres (Table 3). As shown in the first section of this paper there continued to be a stream of new varieties from the botanists both before the after Independence. The results of this success for the disciplinary mix is obvious from Table 8. The research staff became predominantly botanists by 1928 and has remained that way to the present.

Many of the additions to the other disciplines can be explained as the reaction to specific problems which faced the farmers. For example, the outbreak of "tirak" disease in cotton which caused premature opening of the bolls at first led to some part-time work by department scientists. Then it was decided to appoint a full-time plant physiologist to work on this problem. He does not show up on Table 8 because he was hired only for five years in the 1930's. Similarly the serious blight and wilt disease attacks in the gram crop led the department to hire a second mycologist in the late 1930's. The increase in agronomists in the 1960's is a function of the payoffs to better management of the HYVs of wheat and rice.

The above decisions about disciplines appear to be justified on economic grounds. There were other decisions that do not look as efficient. The increase in entomologists in the 1940's may represent only a small increase in research since many of them were involved in monitoring pest attack rather than actually conducting research. Thus, this imbalance may have been more apparent than real. The decline in entomological research in the 1960's is harder to understand considering the pest management problems in cotton, sugarcane and the new rice varieties, which had probably been made worse by the widespread, spraying of insecticide in the 1960's. Another possible distortion (although many scientists might argue this was a source of efficiency) was the absence of agricultural economists in the agricultural research institutions.

The department's allocation of resources to research which would increase the efficiency of input use appears to have been quite rational. Although there was no explicit policy on land-saving versus labor-saving research, the department's research clearly reflects the relative

scarcity of land. The resources which the department put into developing mechanical technology have been small. Most of the time there was no agricultural engineer and the agronomist devoted little time to it. The biological sciences which aimed at increasing the quantity or value of output per acre received most of the research resources (the numbers of biological scientists dominate Table 8). This continued to the present despite the increase in mechanized farming in the Punjab in recent years. In addition the research of the agricultural chemist in the early days was largely to improve yields or bring back into cultivation irrigated land that was affected by waterlogging and salinity.

Research on the use of chemical fertilizer and the breeding of fertilizer responsive varieties was responsive to changes in the availability and price of fertilizer. The early trials by the agronomist indicated that chemical fertilizers were not economical, and so they were not recommended nor was fertilizer responsiveness a major goal of the breeding programs. Instead they attempted to improve the quality and the yield per acre under low fertility conditions. In the 1920's the ratio of price of nitrogen to price of wheat ranged from 7.3 to 15.6.[40] However, with the introduction of imported fertilizer in the 1950's and then the local production of fertilizer, prices were greatly reduced. In 1960 the ratio of fertilizer to wheat price was 2.3 and in 1970 it was 1.73.[41/] Fertilizer responsiveness became one of their goals and fertilizer trials became an important part of the agronomy research program. The dwarf wheat and rice varieties from the international centers enabled the breeders to fulfill their goals. In sum, the Punjab research program has shown itself to be responsive to the relative scarcity of the various inputs of the agricultural production process.

To conclude this section on the allocation of resources within the agricultural research program, on the supply side the pressure for economic efficiency within the institutions runs through the decisions that we examined. However, this pressure for economic efficiency was at times successfully countered by demand side pressures. The commodity allocation was pulled away from efficiency by influential small groups such as the fruit growers, by well organized institutions such as the Central Cotton Committees, and by farmers in certain agro-climatic zones like the rainfed areas. Regarding the decision about the disciplines, the research institute played the main role and so these decisions were made on a fairly rational basis. Scientists could have put too much emphasis on academic rather than practical disciplines if there were no pressure from the political structure for practical results. In the Punjab there was pressure for practical results and the decisions about disciplines seems to have been quite efficient. Finally, the direction of research with regard to the inputs which should be saved seems to have been efficient. This is probably due to a consensus of the research and the political system during most of the period considered here, that land was the scarce input. Even toward the end of the period when tractors become more important, the political system did not turn to the research system for new mechanical technology.

Conclusion

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 on research expenditure were above 30 percent in both the British and Pakistani periods. The main improvements were in the wheat, cotton, and sugarcane crops with some improvements in rice, gram and fodders. After Independence the benefits of technology continued to be concentrated in wheat, cotton and sugarcane. Rice registered large improvements and there was measurable improvement in maize. The main beneficiaries of the research program were the farmers of the Punjab during both periods. Indian and Pakistani consumers of cloth and cotton industries 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 which did not benefit were British industrialists or consumers. These findings indicate that contrary to the assumption of some authors, research did make substantial contributions to the growth of the Punjab's income and much of that contribution was in food grain before the Green Revolution.

To summarize the issues of underinvestment in agricultural research and the efficiency of the allocation of resources within the research system I have used the induced innovation framework which is presented diagramatically in Figure 1. The categories listed in the first column of Table 9 correspond to the circles in Figure 1. They represent the perceptions or actions of the people in the institutions represented by the boxes in Figure 1. With this table I can trace the historical development of the agricultural research system by following Figure 1 in a clockwise direction. For example, in column 2 of Table 9 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. They 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-stapled cotton varieties (actual supply). However, the benefits went to the Indian cotton industry and the Punjabi farmers instead of the British industry and consumers as had been expected. There is no need to go through the entire table here. However, I will use it to illustrate my conclusions about the major issues posed at the beginning of the paper.

The rates of return in excess of 30 percent indicate that there was a continuing underinvestment in agricultural research in the Punjab. The suggested reason for this underinvestment in the first period -- that colonial governments underinvest because they are colonialists and only interested in exploiting the colony -- is too simple. The continued underinvestment in agricultural research by the Independent governments of Pakistan, India and other Asian countries indicates that Independence was not sufficient to improve the situation. The actual reasons for this underinvestment seem to have been different for different periods. Before the 1920's the public pressure or demand for expenditure on agricultural research simply was not there. Only the British grain trade and cotton industry saw any payoff to agricultural research. Farmers in general could not read and so did not appreciate the possibilities 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 Bombay wanted improved cotton, and so they put pressure on the legislative councils for more research expenditure or in the case of cotton for institutional innovation which would ensure funding for research expenditure. The provincial legislative council responded by increasing its expenditure on research. However, the conservative fiscal policies of the colonial government and the inability to raise revenue constrained the growth of research. This probably was the most obvious negative effect of British control.

The underinvestment in the Pakistani period also went through two periods. In the first (round 3) farmers still had expectations that agricultural research could produce new varieties. However, the disruption of the research institutions at Independence and the lack of interest in agriculture by the early Pakistani governments meant no big increases in expenditure and that very few new varieties of crops other than cotton were produced. Thus, the actual payoff matrix includes entries only for the cotton farmers and the expected payoff matrix in the next round probably only included cotton farmers and manufacturers. Therefore, in the 4th round there was little popular demand for agricultural research. However, the government decided in the late 1960's to boost the actual demand for research as indicated by the increase in research expenditure. This government decision was due to the realization that the country's food supply was very vulnerable to U.S. policies on food aid and second, the realization that Mexican wheat varieties could make food grain self-sufficiency possible. This led to the payoffs of the Green Revolution varieties.

The second issue is the efficiency of resource allocation within the research sector. Research resources were not distributed according to their economic value of the different commodities produced in the Punjab. Much of this is due to the political influence of the groups which expected payoffs from research. Therefore, this also fits quite well into Table 9 with the expected payoff matrix driving the system. Cotton and wheat received an equal amount of attention and of the other crops only sugarcane had a sustained research program. The wheat and sugarcane research indicates that accusations of nationalists that no work was done on food crops by colonialist governments is not true. However, there is support for the argument that there was too much emphasis on export crops particularly cotton. This was because only the British cotton and wheat interest expected payoffs from research while farmers did not. The counterfactual that an Independent government would have done much better in allocating resources is not supported by the facts. Pakistani Punjab did not change the allocation of resources towards food grains until the late 1960's.

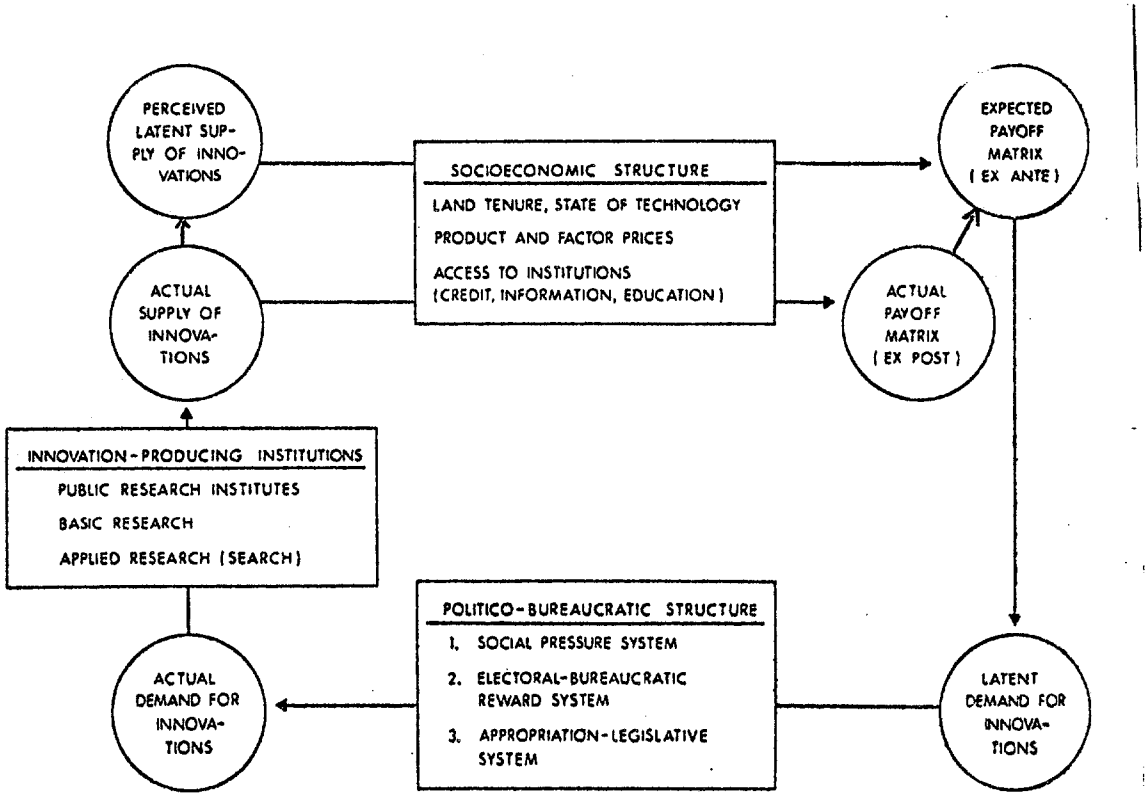
In the second period farmers who wanted improved varieties of all crops and the Bombay cotton industry replaced British cotton and wheat interests in the expected payoff matrix. They were able to shift research resources into the pulses, oilseeds, and millets and to keep funding of cotton research at a high level. This meant more was spent on cotton, oilseeds and millet than was warranted by their potential for improvement and that wheat was relatively neglected. This pattern continued until the late 1960's when top level Pakistani officials under pressure of two poor crop years and the cutoff of food aid shifted resources into food grain research. The resultant payoffs of the Green Revolution led

to the expectation of payoffs by farmers in all crops and the shift of funds into oilseeds, grain and millets.

What is not evident in Table 9 is the actions of the research institution itself. It had very little to do with setting the broad outlines of the commodity allocation of agricultural research although they were able to delay some inefficiencies such as investment in oilseeds and millets in the early period. However, they had a large role in the decisions about the disciplines and the type of research done within the commodity groups. In this they seem to have been guided by efficiency considerations. Finally, regarding the decision about which inputs should be saved there was little doubt among the British in the research institutions and the rest of the government that land and water were the scarce resources and research was guided by this consideration. There was some question about the possible role of chemical fertilizer and tractors. Druing the British period tests were conducted which indicated that neither of these were economical. After Independence little research was conducted on mechanization which seems efficient, but perhaps too little work was done on fertilizer.

FIGURE 1

Supply and Demand for technological and institutional innovations.



Source:

Vernon W. Ruttan based on de Janury "Institutional Factors Affecting the Generation and Diffusion of Agricultural Technology: Issues Concepts, Analysis" World Employment Programe Research Working Papers. (I.L.O. Geneva, Oct. 1980) p. 37.

TABLE 1

Successful New Varieties - All Crops

Year	American Cotton	Desi Cotton	Wheat	Sugarcane	Rice	Other
1910	4-F (S-Ly)		P-11 (S-Ly)			
1915			S-A (S-Ly)			
1920	289F (S-Ly)	Mollisoni (S-Ly)		Co 205 (H-Co) Co 213 (H-Co) Co 223 (H-Co) Co 285 (H-Co)		Gram T-7 (S-Ly)
1925						
1930	289F/K25 (S-Kh) L.S.S. (S-Ly) 289F/43 (S-Ly)	15-Mollinsoni (S-Ly) 39-Mollisoni (S-Ly)	9-D (S-Ly) C-518, C-591 (H-Ly)		349 Jhona, 370-B Basmati, 41 Mushkan 246 Palman (All Selections Kala Shah Kaku)	Barley T-4,T-5 (S-Ly) Rape Selection A (S-Ly)
1935				Co 312 (H-Co) Co 313 (H-Co)		
1940		119-Sanguineum (S-Mul)	C-228 (H-Ly) C-217 (H-Ly) C-250 (H-Ly)			Jowar, J-8 (S-Ly) Gram C 12/34 (H-Ly)
1945	124F (S-Mul) 216F (S-Ha) 199F (S-Mul)					

S - Selection; H - Hybrid; I - Introductions; Sy - Synthetic.

Ly - Lyallpur; Co - Coimbatore, Madras; Kh - Khanewal; Mul - Multan; Ha - Hansi; Mont. - Montgomery; Y - Yousefwala; Ba - Bahawalpur.

TABLE 1 (cont'd)

Year	American Cotton	Desi Cotton	Wheat	Sugarcane	Rice and Gram	Maize
1947						
1950				Co. L. 29 (I-Co) Co. L. 38 (I-Co) Co. L. 44 (I-Co)	Gram C612 (H-Ly)	
1955	362F (S-Ly) AC-134 (H-Mont) Lasani-11 (H-Mul)	231 R(S-Ha)	C-271 (H-Ly) C-273 (H-Ly)			DC 59(H-Ly)
1960	AC-307 (H-Ly)					
	BS 1 or 13/26 (H-Ba)		Dirk (I-Aus) Lerma Roja (I-Mex)	Co. L. 54 (I-Co)		
1965			Penjamo-65 (I-Mex) Mexipak (I-Mex)		Rice IR-8 (I-PH)	DC 697 (H-Ly) J-1 (I-Mex) Synthetic 200 (Sy-Y)
1970	MS 39/MS 40 (H-Mul) 149F (H-Mul) Delta Pine (I-U.S.)		Chenab-70 (H-Ly) Barani-70 (H-Ly) Sa-42 Blue-Silver (H-Ly) Ly-73, Sandal (I-Mex)	B.L. 19 (I-Bar)	IR-6 (I-PH)	Neelum (I-Mex) Agaiti-72 (Sy-Y) Akbar (Sy-Y)
1975	B557 (H-Ly)		Pari-73, Pothwar (H-Ly)(I-Mex)			

S - Selection; H - Hybrid; I - Introductions; Sy - Synthetic.

Ly - Lyallpur; Co - Coimbatore, Madras; Kh - Khanewal; Mul - Multan; Ha - Hansi; Mont. - Montgomery; Y - Yousefwala; Ba - Bahawalpur.

TABLE 1

Sources: American and desi cotton 1910-1964: Abdul Hameed Khan, "Fifty Years Research and Improvement of Cotton Crop in Lyallpur Region," Agriculture Pakistan, XVI, No. 1 (1964), p. 48. 1970-1975: Punjab, Planning and Development Department, Punjab Development Review and Prospects (Lahore; Government Printing, 1976), p. 128.

Wheat 1910-1960: M.A. Aziz, Cereals and Pulses, Resume of Fifty Years Research Work at Punjab Agricultural College and Research Institute, Lyallpur (Lahore, Department of Agriculture, 1960). 1960-75: S.A. Qureshi, "Annual Report of the Cereal Botanist, Punjab Agricultural Research Institute, Lyallpur for the Year, 1974-75," mimeographed.

Sugarcane 1910-71: Punjab Agricultural Research Institute, Lyallpur, A Guide (Lahore, Department of Agriculture, 1971), p. 123. 1971-75: Punjab Development Review, p. 128

Other Crops 1910-1960: Aziz. 1960-70: Abdur Rehman and M. Anwar Khan, "Maize and Millets, Evolution of New Varietues," Pakistan Agriculture (ed.) Saeed Hafeez (Karachi, Press Corporation of Pakistan, 1975), p. 5. 1970-75: Punjab Development Review p. 128.

TABLE 2

ESTIMATES OF YIELD AND QUALITY IMPROVEMENTS

Crop and Variety	Yield (%) Increase		Price Premium (% Increase)
	Experiment Stations	Farmers' Fields	
BRITISH PUNJAB			
Desi Cotton:			
15-Mollisoni	16	NA	None
39-Mollisoni	25	NA	None
American Cotton			28[1]
4-F	None		14[2]
289F	None		34[2]
Wheat			
P-11	10	17	9
8-A	20		3
C-591	28	38	12
Sugarcane			
Co.205, Co.213, Co.223	21-159	41-74	None
Co.312, Co313	100-200	80	None
PAKISTANI PUNJAB			
Wheat			
Mexipak		77[3]	-15
		64-82[4]	
American Cotton			
AC 134, AC307	14	31	6
Rice			
IR-8	47-61		
Sugarcane			
CoL 54 and 44	26-40	0	None
Maize		15-25[5]	None

TABLE 2 (cont'd)

Source: Chapter IV of Pray 1978

Notes:
1. Average premium of all American varieties over desi varieties before 1947.
2. Khanewal market data only.
3. From Punjab offical data.
4. From three microstudies.
5. Scientist's Estimates

TABLE 3

Area Under Improved Varieties

Year	American Cotton (1000 acres)	%	Desi Cotton (1000 acres)	%	Wheat (1000 acres)	%	Sugarcane (1000 acres)	%
1913-14 / 17-18	133	9			65	1		
1918-19 / 22-23	464	30	7	4	600	7	3	1
1923-22 / 27-28	920	41	208	9	1329	14	12	3
1928-29 / 32-33	831	38	573	26	2477	26	117	27
1933-34 / 37-38	1151	42	860	32	3752	40	247	50
1942-43 / 43-44	1712	70	460	19	7686	75	399	80

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

TABLE 4

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

* r is year in which new varieties were first released.

TABLE 4 (cont'd)

Sources: Wheat: 1967: Deputy Directors of Agriculture Reports mimeographed, 1967.

Wheat: 1968-75: Pakistan, Ministry of Food and Agriculture, Agricultural Statistics of Pakistan, 1975 (Islamabad, 1975).

Cotton, acreage of new varieties 1960 and 1963: A. H. Khan, "Fifty Years Research and Improvement of Cotton Crop in Lyallpur Region," Agriculture Pakistan, XVI, No. 1 (1965), p. 50.

Cotton, new varieties 1969, 1973-75: Agriculture Department, Statistics Cell, unpublished material, also available in the Punjab Gazette, Part I.

Rice: Agricultural Statistics of Pakistan.

Sugarcane: A. A. Anwar, Production of Sugar: Policies and Problems (Lahore; Board of Economic Inquiry, 1971).

Maize: Izuno, Maize Production Plan 1976 (Islamabad, Agricultural Research Council, 1976).

TABLE 5

GROWTH OF AGRICULTURAL RESEARCH BUDGET

	Research Expenditure* (Current Rs.)	Research Expenditure* (1960 Rs.)	S.M.Y.	Expenditure as % of Ag. Budget	Exp. as % of Total Punjab Budget	Exp. as % of Value of Ag. Output
1930	3.0	30.4	18	15.6	0.34	
1940	6.9	35.0	22	24.6	0.56	0.07
1950	11.0	21.9	23	19.6	0.59	0.086
1960	25.5	25.5	36			
1972	67.0	52.0	55	8.2	0.50	0.095
1975	160.0	60.0		6.0	0.45	

Source: Expenditure from Tables 3-1 and 3-2, p. 114-115 in Pray 1978; SMY from Table 8

* 100,000 Rupees

TABLE 6

DAP Botanists and Horticulturalists by Crop Specialty

	1920	1928	1939	1946	1951	1960	1971**
Cereals (Wheat, Barley)	½*	1	1	2*	2*	3*	9*
Millets		1	1*			1	1
Maize						1	10
Rice		1	1	1	1	1	9
Cotton	½	2	2	2	2	3	9
Sugarcane			1		1	1	7
Legumes		1*				1	
Oilseeds and Tobacco			1	2	3	7	10
Fodder		1	1	1	1	1	1
Fruit		2	4	2	2	3	5
Vegetables			1	1	1	2	

Sources: 1920, 1927: DAP Reports (Lahore, Government Printing, 1921, 1929).

1939, 1946: Punjab, Civil Secretariat, Civil Lists (Lahore, Government Printing, 1939, 1946).

1951: Punjab, Detailed Estimates of Revenue and Expenditure (Lahore, Government Printing, 1951).

1960: "Agricultural Research--A Retrospect," in Fifty Years of Agricultural Education and Research at Punjab Agricultural College and Research Institute Lyallpur (Lahore, Ripon Press, 1960).

1971: Punjab Agricultural Research Institute, Lyallpur, A Guide (Lahore, Department of Agriculture, 1971).

*Gram included in this category.

TABLE 7

VALUE OF CROP AND DISTRIBUTION OF RESEARCH RESOURCES

	1929				1960					1971			
	Value*	% of Value	SMY**	% of SMY	Value*	% of Value	SMY	% of SMY	% of Research Expenditure	Value*	% of Value	SMY	% of SMY
Cereals:													
Wheat	36.0				128.8					238.1			
Barley	2.1	44.	1	14	2.4	48.8	3	17.6	17	1.8	40.5	9	16.4
				(Gram)	20.4					21.2			
Rice	4.1	5	1	14	40.2	12.9	1	5.9	4	77.8	12.1	9	16.4
Millets:													
Bajra	3.6				7.6					10.1			
Jowar	1.0	9	1	14	3.6	3.6	1	5.9	4	5.8	2.5	1	1.8
Maize	3.3												
Maize					8.1	2.6	1	5.9	14	19.3	3.0	10	18.2
Legumes (gram)	11.7	14	1	14									
Total Foodgrains and Pulses		72		56		67.9		35.3	39		58.1		52.8
Cotton	19.7	23	2	29	44.6	14.3	3	17.6	37	165.6	25.7	9	16.4
Oilseeds	4.3	5	1	14	8.3	4.34	7	41.2	9	16.6	4.4	10	18.2
Tobacco					5.2					11.4			
Sugarcane			½		42.1	13.5	1	5.9	13	76.7	11.9	7	12.7
Total Cash Crops		28.0		43		32.1		64.7	59		42.0		47.3

Source: SMY, Table 7 and Value, Pray 1978, p. 279.
*: Millions of current Rupees.
**: Scientific Man Years

TABLE 8

DAP Research Staff by Discipline

	1920	1928	1939	1946	1951	1960	1971
Agricultural Chemists	1	3	3	5	3	3	3
Agronomists	1	1	2	1	1	1	6
Bacteriologists		1	1	1	1		
Mycologists			1	2			
Plant Pathologists					2	4	4
Botanists and Horticulturalists	1	9	12	11	13	24	40
Entomologists		2	3	8	3	4	2

Sources: Same as Table 7

TABLE 9

Simplified History of Induced Agricultural Research in Punjab

	Round 1 1900-1925	Round 2 1925-1947	Round 3 1947-1959
Perceived Supply of Innovations	Long Staple cotton Increase Production of good quality wheat	Improved varieties of all crops	Improved varieties all crops
Expected Payoff	British Cotton Industry British Bread Consumers	Increased income for Punjabi farmers of all crops Indian cotton industry	Income for farmers Foreign exchange for Industrialization
Latent Demand	Political pressure on government for research on cotton and wheat.	Testimony at Royal Commission, political pressure in legistive council	Political pressure for agricultural improvement
Actual Demand	Research budget and instructions to work on cotton and wheat	Funding for crop specialists in millets, oilseeds pulses, fruits	Same as round 2.
Actual Innovations	Improved wheat cotton and sugarcane varieties	More wheat, cotton, sugarcane rice varieties.	Cotton varieties
Actual Payoff	Increased income for wheat, cotton, sugarcane farmers. Indian cotton industry cuts costs. Indian wheat and quality cloth consumers.	Increased income for wheat, cotton, sugarcane rice farmers, and for Indian cotton mills. Slightly lower prices for consumers	Increased income for cotton farmers only

TABLE 9 (cont'd.)

	Round 4 1959-1970	Round 5 1970-1976
Perceived Supply of Innovations	Improved Varieties all crops	Improved varieties all crops
Expected Payoff	Increased income from cotton varieties	Large increases in income for farmers of all crops Lower food prices
Latent Demand	Support for cotton	Pressure for work on neglected food crops and regions
Actual Demand	Money for Foodgrain cotton, sugarcane research	Research expenditure for other crops and unirrigated regions
Actual Innovations	Green Revolution wheat and rice varieties also some cotton, sugarcane maize varieties	---
Actual Payoff	Increased income for farmers and lower food prices	---

FOOTNOTES

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11. Pray, p. 289.

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