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RESEARCH REPORT 87

INCENTIVES AND CONSTRAINTS IN THE TRANSFORMATION OF PUNJAB AGRICULTURE

Anya McGuirk
Yair Mundlak

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FOREWORD

The introduction of modern crop varieties in the mid-1960s caused a dramatic change, known as the "green revolution," in agricultural production in Asia, as elsewhere. However, in spite of their higher yields, the process of adoption of these varieties has taken a long time, and even today traditional varieties are still widely grown. Various reasons, such as imperfect information, uncertainty, inadequate human capital, and institutional constraints, have been given for this slow diffusion. This research report by Anya McGuirk and Yair Mundlak on the Indian Punjab experience during 1960-79 emphasizes the role of economic incentives and resource availability in determining the pace of technology adoption.

Only three years after their introduction, the modern wheat varieties accounted for 70 percent of the wheat area in Punjab. Thereafter, their spread was more gradual. From this pattern, the authors conclude that the main determinant of the pace of adoption could not have been uncertainty or lack of information. The modern varieties perform best under irrigation and heavy doses of fertilizer, and therefore their expansion was constrained by the availability of irrigated area and fertilizers. The expansion of these inputs required mobilization of resources from other activities. The improvement in yields increased the rate of returns to investment in irrigation and fertilizer production and thus generated a gradual expansion in their supply. Since total resources are scarce, such a shift is time-consuming.

This explanation illustrates what the authors see as a general and important aspect of the implementation of new technology. When the resource requirements of the new technology are different from those of the existing technology, the pace of implementation will be determined by the speed at which the resources can be shifted to the new technology. This speed depends on the difference in productivity between the new and existing techniques and on prices and overall resource availability. This identification of the process has far-reaching implications for policies directed toward agricultural growth.

This study is part of IFPRI's continuing research efforts in analyzing the nature and economic consequences of technological change and follows earlier work on the green revolution.

Just Faaland

Washington, D.C.
July 1991

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Anya McGuirk
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1

SUMMARY

Much of the rapid growth in output experienced by Punjab, India, during the period of this study was generated by agricultural growth. Most of this agricultural growth is attributed to growth in crop production resulting from improvements in the overall yields of wheat and rice and, to a lesser extent, in the yields of maize and cotton. The pattern of growth in overall yields for the various crops, particularly wheat and rice, suggests that the main improvements came as a result of a shift to modern higher-yielding varieties rather than as a result of intensifying cultivation of the existing varieties.

The extremely rapid adoption of the modern varieties (MVs) of wheat and also rice, once suitable rice varieties were introduced, indicates that factors usually associated with a slow rate of implementation of new techniques, such as imperfect information, uncertainty, institutional constraints, and inadequate human capital, did not appear to play a prominent role in the adoption process. These factors could not have changed much over the extremely short transition period and therefore could not have influenced the rate of adoption. Alternatively, the speed at which the new varieties were implemented, particularly MV wheat, suggests that the pace of transition was largely determined by the productivity of the MVs relative to the traditional varieties and by physical constraints such as, initially, the availability of seeds and, later, the availability of irrigation facilities and fertilizers. Thus, physical capital played a crucial role in the growth process.

The conceptual framework used to model the growth in Punjab agriculture is that of choice of technique. Given that much of the agricultural growth can be attributed to the implementation of new techniques of production, an understanding of the growth process requires that the factors affecting the decision to implement these techniques be identified explicitly. Analyses that aggregate techniques by crop potentially provide distorted views of the technology and therefore of the growth process. Thus, the results of this study not only have important policy implications for agricultural growth but also provide evidence of the usefulness of the choice-of-technique approach.

The techniques of production analyzed are those of the major crops in Punjab, identified by variety, season of growth, and method of production (irrigated or dry). The short-run area-allocation decisions are influenced by the expected revenues of the different techniques; the availability of fertilizers, irrigation, and cropped area; and the local environment. Overall yields by crop are determined by the composition of techniques implemented, the availability of fertilizers, and the local physical environment.

Because resources are scarce and therefore have to be attracted to agriculture from other uses, changes in the availability of fertilizers, irrigation, and cropped area are determined by the overall availability of resources and the differential rate of return between agriculture and nonagriculture. The relative importance of these factors depends on whether the decisions are made by the public or private sector.

Equations analyzing the investment decisions of both the private and public sectors are estimated simultaneously with the area allocation and yield equations. The data base utilized in this study consists of district-level observations over the period 1960 through 1979. The effects of the local physical environment, the initial levels of infrastructure, and the availability of human capital on choice of technique and overall level of output are detected by the inclusion of fixed district effects.

The results are summarized by deriving both short-run and long-run elasticities. The specification of the model implies that the size of both the short-run and long-run elasticities depends on the productivity of the implemented technology; the more productive the implemented technology, the greater are the elasticities (in absolute value).

The short-run output elasticities with respect to price are generally small, as the constraints are binding. The short-run aggregate output elasticity with respect to a change in all (real) prices increased from nearly zero before the onset of the "green revolution" to a high of 0.18 in 1979, when the transition to MVs of wheat and rice was largely complete. Thus, conditional on the availability of quasi-fixed inputs, total output responds little to changes in price.

The short-run elasticities of output with respect to the constraints indicate that the availability of quasi-fixed inputs played a major role in the determination of the pace of transition to MVs. The magnitude of these elasticities is large relative to their price counterparts. The availability of private irrigation and roads appears to have been particularly important in the transition process.

The results from the quasi-fixed input equations suggest that the decisions made by farmers about irrigation, and indirectly about net cropped area, were responsive to the increase in profitability spurred by the introduction of MVs. The long-run elasticities of area irrigated by private resources with respect to prices and the availability of roads and fertilizers were particularly large.

Although similar responses were not obtained in the government investment equations as specified, the observed increases in the provision of electricity and the availability of fertilizers and roads suggest that the government responded to the new opportunities.

The long-run output elasticities with respect to prices are all large relative to their short-run counterparts. These elasticities reflect the strong response of private irrigation and the somewhat more moderate response of net cropped area and fertilizers as the prices changed. The long-run aggregate supply elasticity, although negligible before the onset of the green revolution, reached a high between 1.3 and 1.5 in the late 1970s.

2

INTRODUCTION

On the whole, economic growth is driven by technical change. Therefore, an understanding of the many factors that influence technical change is key to an understanding of economic growth and the potential for that growth. The introduction of technical change has two aspects: first, it has to be generated, and second, it has to be implemented. This manuscript deals with the implementation of new techniques of production. In particular, the focus of this study is on the determinants of the level and rate of implementation of the modern wheat and rice varieties (MVs) as well as new varieties of cotton and maize introduced in Punjab, India, during what is now commonly referred to as the green revolution. The pattern of crop production growth experienced by Punjab over the period of study, 1960-79, suggests that much of this growth came as a result of the implementation of these new techniques. Further, it is the dramatic growth in crop production that is largely responsible for the rapid growth in net domestic product (NDP) experienced by Punjab.

Once a new technique of production becomes available, it usually takes some time before it is fully implemented. The transition period is characterized by coexistence of the traditional and modern techniques. Various explanations for such a transition period are provided in the literature. Some see it as a diffusion process (for example, Desai 1982). But this is not an explanation; it is merely another way to say that the process takes time. Other explanations are given in terms of the existence of imperfect information that is naturally associated with a new technique. However, when a new technique is considerably superior to the existing ones, as in the case of the MVs of wheat and rice introduced in Punjab, farmers are able to realize the gain quickly, without a long search for information. In this case, the producers' search for information cannot, by itself, explain the existence of a transition period. Furthermore, a delay in adoption due to such searching would suggest that adoption of the new techniques will initially be slow and will then pick up momentum as information on the quality of the new technique is accumulated. This type of adoption pattern is opposite to the one observed for the MVs of wheat and rice in Punjab. For example, the first year the MVs of wheat were introduced, they were sown to 30 percent of the total wheat area. This proportion had increased to 70 percent by only the third year. The experience with rice was similar, once a suitable variety was introduced. As the opportunity to adopt the more productive techniques arose, farmers implemented them rapidly.

Another explanation of the existence and pace of the transition process, which is related to the last, is scarcity of human capital. There is no question that human capital is necessary in the generation of new techniques and also in their implementation. However, it is impossible to generalize about the role of human capital in the implementation of the new techniques because it depends on the nature of the innovation. Some innovations may actually reduce the demand for some forms of human capital and so can be considered as saving human capital. Others may require only a small increase in some specific human capital that may be acquired in a short time period, building on the existing knowledge. In such cases, human capital may not be a serious constraint. This is believed to be the case for Punjab, which, given the rapid adoption of MVs, appeared to have the necessary human capital to make the transition. Because the availability of human capital could not have changed significantly over the extremely rapid transition period, changes in human capital could not have had a major effect on the pace of adoption.

What, then, were the main constraints that determined the pace of the transition to MVs in Punjab? Clearly, the MVs of wheat and rice introduced in Punjab were much more productive than the traditional varieties. However, to fully utilize their yield potential, it is necessary to apply considerably larger doses of fertilizers and water per unit of land in comparison with the quantities used for the traditional varieties. Consequently, an increase in the area planted to MVs required an expansion in the supply of fertilizers and irrigation facilities as well as an expansion in complementary inputs, such as electricity, for the operation of wells and roads needed to integrate the remote areas within the market. The speed at which the new varieties of wheat and rice were implemented suggests that the pace of transition was largely determined by the productivity of the MVs relative to the traditional varieties and the availability of physical capital.

The conceptual framework used to examine this working hypothesis is that of choice of technique, where the choice is analyzed explicitly. In other studies—Cavallo and Mundlak 1982, Coeymans and Mundlak 1987, and Mundlak, Cavallo, and Domenech 1989—this framework was applied to macro data where output is aggregated over all techniques without identifying the individual techniques. Consequently, the effect of the various determinants of the choice of technique is revealed empirically only in an implicit way. One important attribute of this study is that techniques are identified by crop variety, season of growth (*rabi* and *kharif*), and method of production (dry versus irrigated). Data on area allocated to these varieties are available and serve as a measure of their degree of implementation. It is therefore possible to measure the effect of the determinants of technique choice directly and explicitly. Thus the results of this study have broad implications for the usefulness of the choice-of-technique approach in empirical analysis as well as for policy aimed at influencing agricultural growth.

The data base for the study consists of district-level observations over the period 1960-79. The techniques of production analyzed are those of the major crops grown in the Punjab. The production decisions are formulated by assuming that, in the short-run, farmers simultaneously allocate their resources between the various techniques (intertechnique allocation) and decide on the level of intensity of technique implementation (intratechnique allocation) to maximize their value added from production. These decisions are made subject to the following constraints: cropped area, irrigation capacity by source (private tubewells and government canals), and fertilizer availability. Economic performance and, therefore, decisions are also influenced by the availability of infrastructure, such as roads, and by the local physical environment. Consequently, the area-allocation decision is a function of prices, constraints, environmental factors, and available technology. The coefficients on the price variables are allowed to depend on the implemented technology, thus average revenues per hectare are used as the measure of incentives. The premise is that a shift to the new, more-productive technique generates higher returns to land when compared with the existing varieties, so a given change in prices will have a stronger effect on area allocated to the more productive variety than to the traditional lower-yielding variety.

The yields of the various crops are determined by the composition of techniques used in planting and by the intensity of their implementation. Although the inter- and intratechnique decisions are made jointly at the beginning of the growing season, because production takes time and information sets change, the actual application of inputs during the production season may differ from the levels initially chosen. The yield equations take all these factors into account. Total crop output is determined as a product of area and yield and, as such, is affected by all the state variables that affect these two components individually.

Changes in the constraints require investment. As resources are scarce, they have to be attracted from other sectors. A distinction is made between investment decisions taken privately by farmers and those taken by the government. It is postulated that the private sector chooses levels of investment that maximize the present value of the future stream of value added. As technical change occurs, the flow of value added increases and investment becomes more profitable. Therefore, agriculture's share in total investment should increase. The government's decision to invest is more complicated and is not captured in this study. However, the government also mobilized resources as the profitability of agriculture increased. The supply of fertilizers, electricity, roads, and to a lesser extent, public irrigation all increased over the period of study.

Background information on Punjab is provided in Chapter 3, discussing in detail the growth in Punjab agriculture during 1960-79. Chapter 4 outlines the conceptual framework that is used as the point of departure for this study. Chapter 5 is devoted to the empirical results of the short-run area-allocation and yield responses conditional on the constraints or quasi-fixed inputs. Based on these results, a comprehensive and consistent picture of the transition of Punjab agriculture is detailed. Chapter 6 discusses the changes in the availability of the quasi-fixed inputs in response to the changing profitability of crop production and the long-run elasticities. Finally, conclusions are drawn in Chapter 7. See Appendixes 1 and 2 for detailed discussions of the major data issues.

3

AN OVERVIEW OF AGRICULTURAL DEVELOPMENT IN PUNJAB

A summary description of the development in Punjab agriculture is provided to assist in placing the subsequent analysis in an appropriate perspective. Because much has been written about Punjab elsewhere, only a brief discussion of the relevant background and historical information is provided.[1] The primary focus of the summary is the performance of present-day Punjab during the period of study (1960-79).

Background Information

Punjab is the fourth smallest state of India, accounting for approximately 1.6 percent of the total area (Mehra 1983). According to the 1981 census (India 1981a, 1981b), 17.7 million people, or 2.4 percent of the Indian population, live in Punjab. Punjab is largely a rural state; 72 percent of the population live in rural areas. Since its annexation by the British in 1849, the former Punjab has undergone several geographical changes, the most significant being the partition in 1947. The many internal and external boundary changes make it difficult to assess the growth record of present-day Punjab. This is particularly true for analyses at the district level, because most district-level data have not been adjusted for these changes. Appropriate adjustments have been made to the published data for the analysis and discussion of the performance at the district level.[2]

Sectoral Output

By many conventional measures, Punjab is well advanced relative to much of the rest of India.[3] In 1981, per capita NDP in Punjab was 1.8 times that of all India and 3.2 times that of Bihar, the poorest state in the country. Of all Indian states, Punjab has the lowest percentage of people below the poverty line, and it has the highest average life expectancy.

During the 1960s and 1970s, the real NDP of Punjab grew at a compound rate of 4.9 percent a year (Figure 1). This growth was largely generated by the growth

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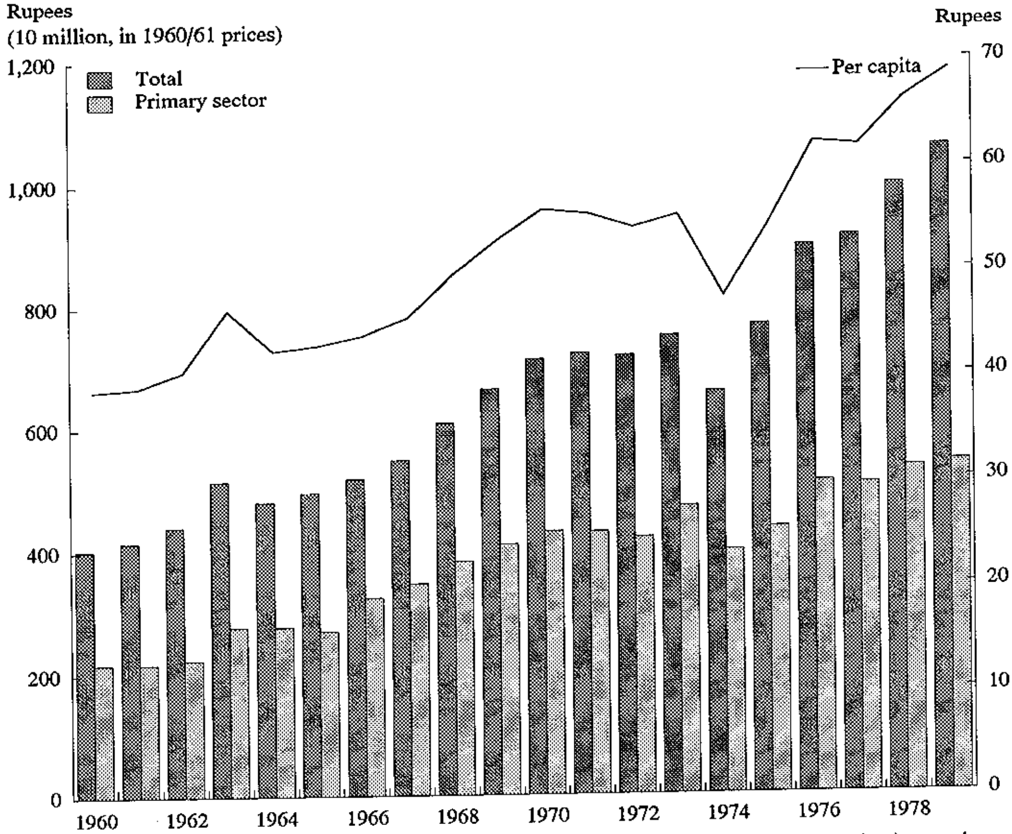
[1]In addition to the specific references cited throughout this chapter, other important references on Punjab include Sims 1988, Chaudhri 1979, Bhalla et al. 1990.

[2]The adjustments made to the district-level data are detailed in Appendix 1. A "consistent" series has been constructed using data from 11 out of the 12 districts of present-day Punjab.

[3]This section draws on Westley 1986 and Singh 1983.

Figure 1—Net domestic product, 1960-79



Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

of agriculture. Value added by the primary sector, which is largely agriculture, grew at a rate of 4.4 percent annually between 1960 and 1980. This performance is impressive when compared with that of all India and of other countries (Table 1). It is more than double that of India, almost twice that of low-income countries (excluding China and India), and significantly greater than that of the middle-income countries. Agricultural growth has induced growth in the economy at large, with the secondary sector (industry) growing at a 6.2 percent annual rate over 1960-79, and more strikingly, at a 16 percent rate during the last five years of the 1970s. The annual growth rate of the tertiary sector (services) during these two recent decades was 4.7 percent, but between 1975 and 1979 the sector grew at a spectacular rate of 36 percent a year.[4] The differences in growth rates by sector

[4]Because a complete time series of value added was not provided in Westley 1986 (Table 1), real NDP (Figure 1) is used to summarize the performance of the various sectors over different periods within this sample.

Table 1—Average annual real growth rate in value added, by sector, 1960-80

Sector	Punjab	India	Low-Income Countries	Middle-Income Countries
		(percent)		
Primary	4.4	1.9	2.3	3.1
Secondary	7.0	4.5	5.1	7.2
(Manufacturing)[a]	(7.5)	(4.7)	(5.0)	(6.0)
Tertiary	5.6	5.0	4.4	5.7

Source: Based on data from John R. Westley, *Agriculture and Equitable Growth: The Case of Punjab-Haryana* (Boulder, Colo., U.S.A.: Westview, 1986).
[a]Manufacturing is a part of the secondary sector and is therefore shown in parentheses.

largely reflect differences in income elasticities and the relative importance of the various sectors.The sectoral composition of Punjab's economy in 1980 is presented in Table 2.

Importance of Agriculture

Agriculture is the single most important component of the primary sector. In 1980 it accounted for 73 percent of the NDP of the primary sector, and according to the 1981 census, nearly 60 percent of Punjab's total labor force is employed in agriculture. This is slightly higher than the 56 percent figure reported in 1961, but lower than the 63 percent for 1971.

Over the two decades under discussion, crop production has continued to dominate agriculture. However, its growth rate lagged behind that of livestock, which increased its share in agriculture's NDP from 13 percent in 1960 to about 29 percent in 1980. Again the differential growth rate can be attributed to a higher income elasticity for livestock products, which fits the picture of overall growth. However, it remains true that much of the success of Punjab agriculture can be attributed to the expansion in crop production that accompanied the adoption of MVs during the period of time now commonly referred to as the green revolution.

Table 2—Sectoral shares in value added, 1980

Sector	Punjab	India	Low-Income Countries	Middle-Income Countries
		(percent)		
Primary	50	38	45	15
Secondary	21	25	17	37
(Manufacturing)[a]	(13)	(17)	(10)	(23)
Tertiary	29	37	38	48

Source: Based on data from John R. Westley, *Agriculture and Equitable Growth: The Case of Punjab-Haryana* (Boulder, Colo., U.S.A.: Westview, 1986).
[a]Manufacturing is a part of the secondary sector and is therefore shown in parentheses.

Trends in Crop Production

Crop production across Punjab is diverse, but for the period under study, the five major crops analyzed here (American and Desi cotton, wheat, rice, maize, and gram) accounted for 67-80 percent of the gross cropped area.[5] During 1960-80, the cultivated area for these crops in Punjab increased only from 4.5 million to 4.6 million hectares, while real value (in 1960/61 rupees) of production rose from Rs 1,253 million to Rs 3,996 million. This translates into an annual growth rate in the real value of production per hectare of 4 percent over the 20-year period.

Agricultural output depends on (among other factors) the physical environment, which includes factors such as soil quality and climate. For descriptive purposes, Punjab can be divided into three geographical regions: the northern submontane (hilly) strip, the central plains, and the southwestern region (Figure 2). The submontane strip in the north contains major portions of the districts of Gurdaspur, Hoshiarpur, and Rupnagar. Maize and wheat tend to be the major crops in the hilly region, although significant amounts of gram, *bajra* (pearl millet), rice, mustard, lentils, and potatoes are also grown (Mehra 1983). Despite an average annual rainfall for this area of about 87 centimeters, agricultural productivity of the submontane strip is low relative to that of the other two regions in Punjab (Bhalla and Khan 1979).

The central plains comprise the districts of Amritsar, Kapurthala, Jullundur, Ludhiana, and Patiala, and most of Sangrur. High-value crops such as wheat and gram are grown during the winter, and rice, maize, cotton, sugarcane, and pulses are grown during the summer. The average annual rainfall for the region is 57 centimeters, of which 46 centimeters are received during the summer monsoons (Bhalla and Khan 1979). The alluvial soils along with the given rainfall make this region the most productive in Punjab.

The southwestern region contains the districts of Ferozepore, Bhatinda, Faridkot, and part of Sangrur.[6] The average annual rainfall in the area is a meager 27 centimeters, of which 23 are received during the monsoons. Wheat, gram, and cotton are grown in the irrigated parts of this region; *jowar* (sorghum), *bajra,* and rapeseed/mustard are grown in the less-irrigated parts (Mehra 1983).

The climatic conditions of Punjab allow the possibility of double cropping. The two main harvests are the *rabi* or spring harvest and the *kharif* or autumn harvest. *Rabi* season crops are sown in October and November after the monsoons and harvested from mid-March to mid-May. The main *rabi* crops include wheat and gram as well as barley and green fodder. *Kharif* season crops are sown from June to August and harvested from early September to late December. The main *kharif* crops include rice, maize, *bajra,* and *jowar.* Cotton is also considered a *kharif* crop,

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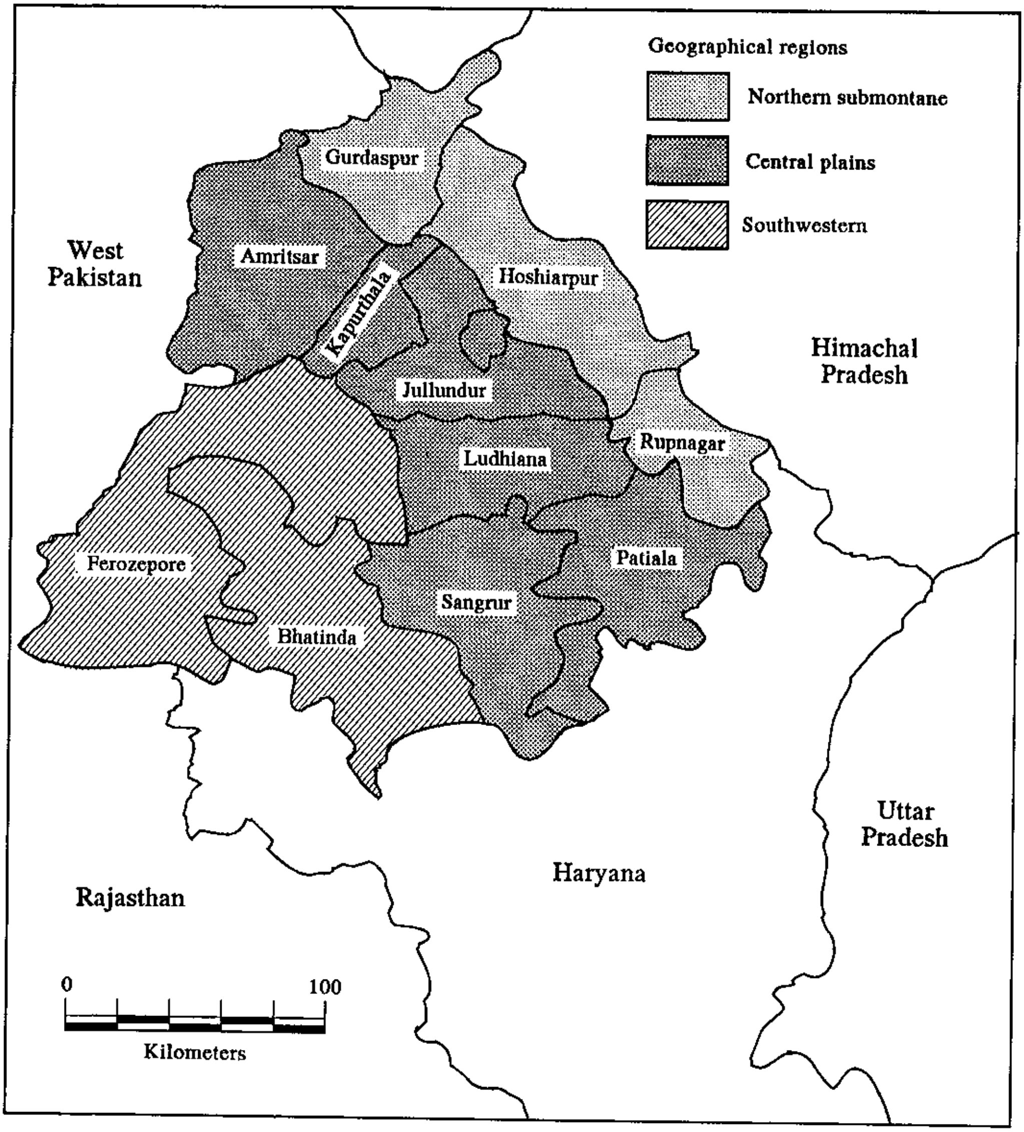
[5]The data include production in 11 of Punjab's 12 districts, although data from Faridkot are included along with Bhatinda and Ferozepore (see Appendix 1).

[6]The present-day district of Faridkot is included within Ferozepore and Bhatinda (see Appendix 1). Even though part of Sangrur lies in the southwestern region, all of Sangrur is shaded in the map (Figure 2) because the exact boundaries are unknown to the authors.

Figure 2—Map of the districts of Punjab



although it is sown earlier than most other *kharif* crops. Similarly, sugarcane is considered a *kharif* crop, although it is sown from February to April and harvested between December and March.

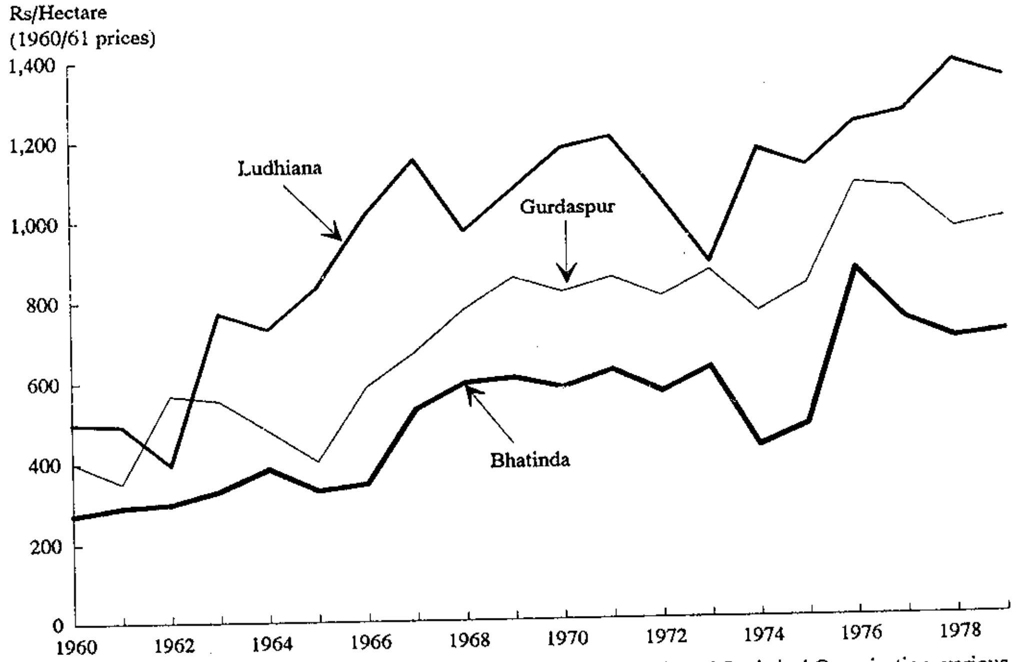
Because the physical environment does not change very rapidly over time, its main effect on output can be detected from cross-section comparisons. In the present study, this is done by analyzing district data.

To provide some perspective on the differential performance by districts, values of production per hectare for Ludhiana, Bhatinda, and Gurdaspur are illustrated in Figure 3. These districts are used throughout the discussion to demonstrate the variability in performance across the state. They were chosen because each is located in one of the three distinct geographical regions of Punjab described above.

Value of production per hectare increased in all three districts during 1960-80, and on the whole, the same performance rank was sustained across the three districts. However, performance varied considerably among the districts. In 1960, for example, the value of production per hectare in Ludhiana was 19 percent higher than in Gurdaspur. In 1966, this differential rose to 42 percent but moderated to 24 percent by 1980.

Growth has also varied by crop, largely due to the adoption of MVs. The yields of wheat and rice in Punjab increased 124 and 175 percent, respectively, during 1960-79.[7] However, the time pattern of this growth varied by crop. Growth in wheat yields outperformed rice yields by a margin of 18 percent during the 1960s, while rice yields increased 42 percent more than wheat yields in the 1970s. In

Figure 3 — Value of production per hectare in three districts, 1960-79



Sources: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years); and India, *Farm (Harvest) Prices of Principal Crops* (New Delhi: Directorate of Economics and Statistics, various years).

[7]To assess the improvement in yields over the sample period, the average yield during 1960-62 is compared with the 1977-79 average yield.

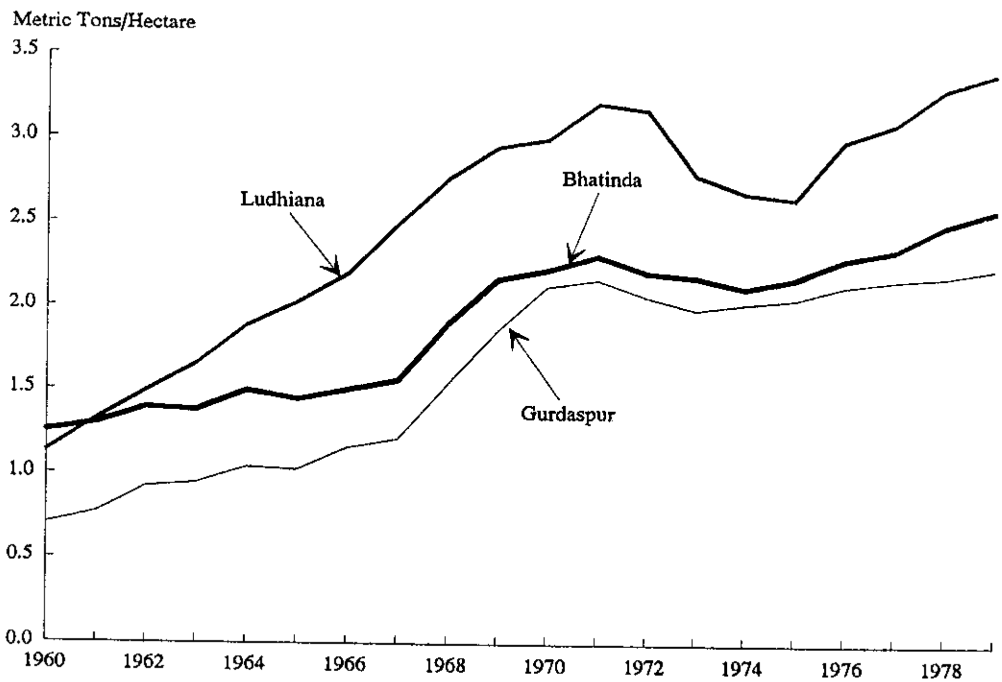
contrast to the spectacular performance of the rice and wheat yields, the yields of both gram and Desi cotton showed no improvement over the sample period. Maize and American cotton yields increased 46 and 30 percent, respectively, but a good part of this improvement occurred prior to the onset of the green revolution.

Figures 4 through 9 illustrate the changes in yields for these crops by district. For the three districts, there were substantial increases in yields of rice and wheat, and, in one district, American cotton. Ludhiana obtained the highest yields in wheat and maize; the yields of cotton and rice were particularly low in Gurdaspur and relatively high in Bhatinda.

Introduction of the Modern Varieties

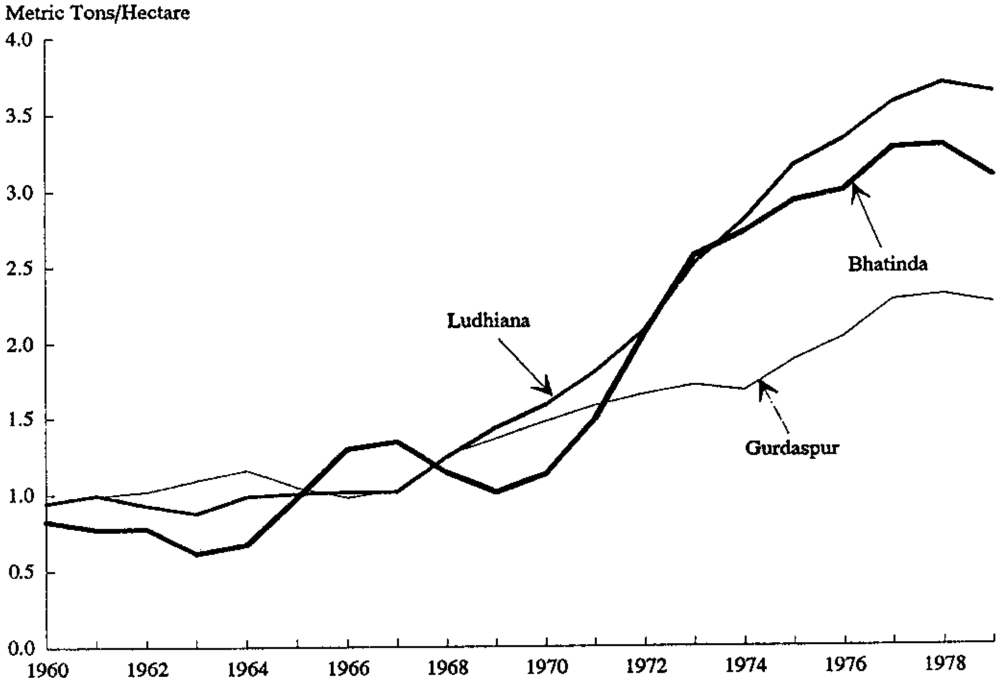
According to Mohan, Jha, and Evenson (1973), Punjab (and Haryana) consistently invested more heavily in agricultural research over the 1953-68 period than any other state in India. In 1968, research expenditures per community block were 25 percent higher in Punjab than in Haryana, which was second in spending, and 75 percent higher than in Gujarat, which was third. Although Mohan, Jha, and

Figure 4—Wheat yield in three districts, 1960-79



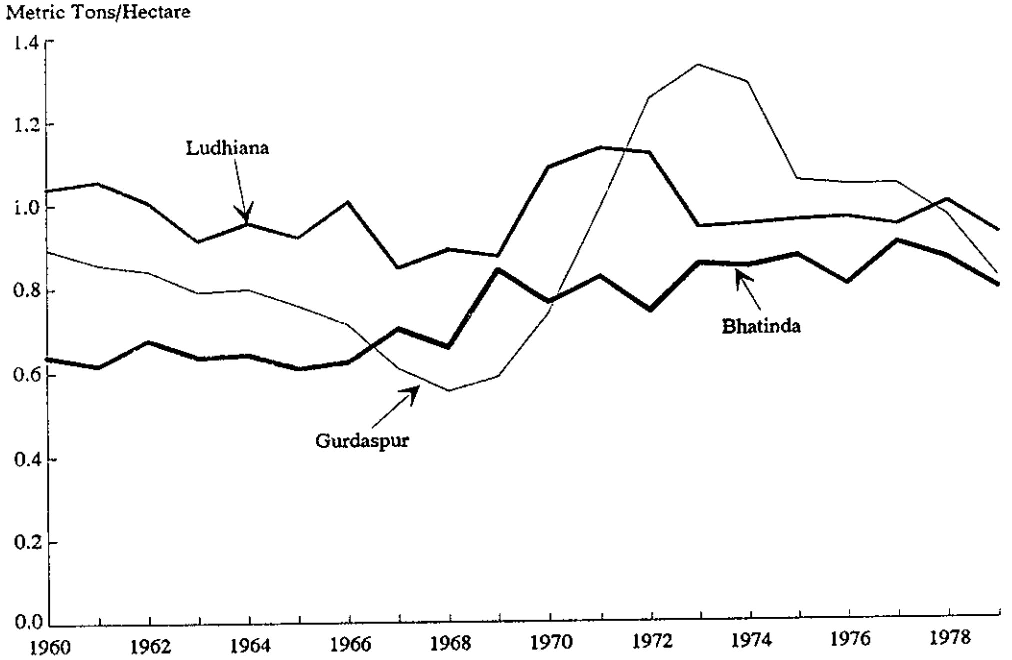
Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

Figure 5 — Rice yield in three districts, 1960-79



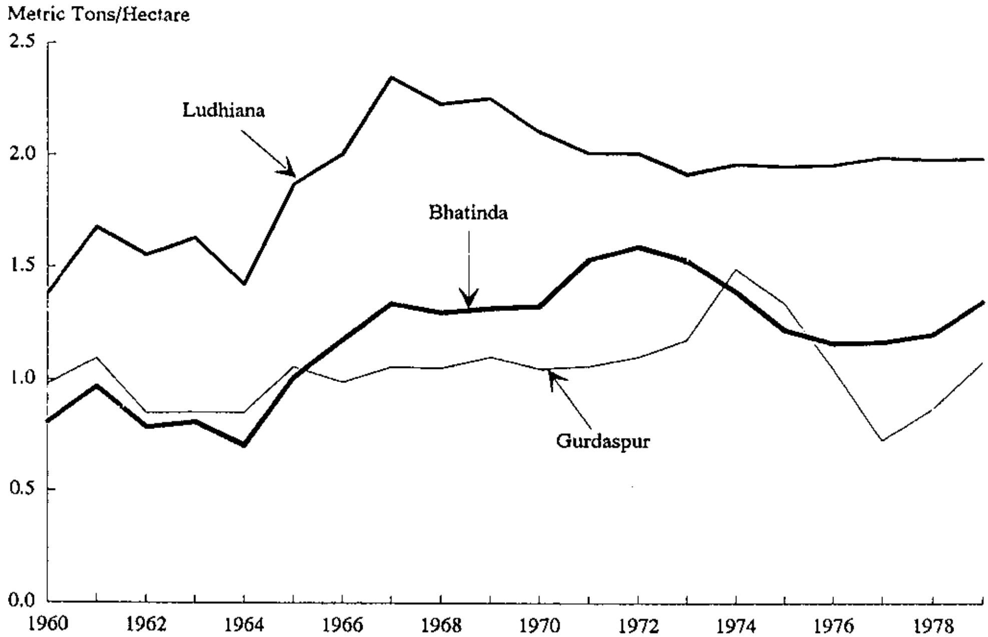
Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

Figure 6 — Gram yield in three districts, 1960-79



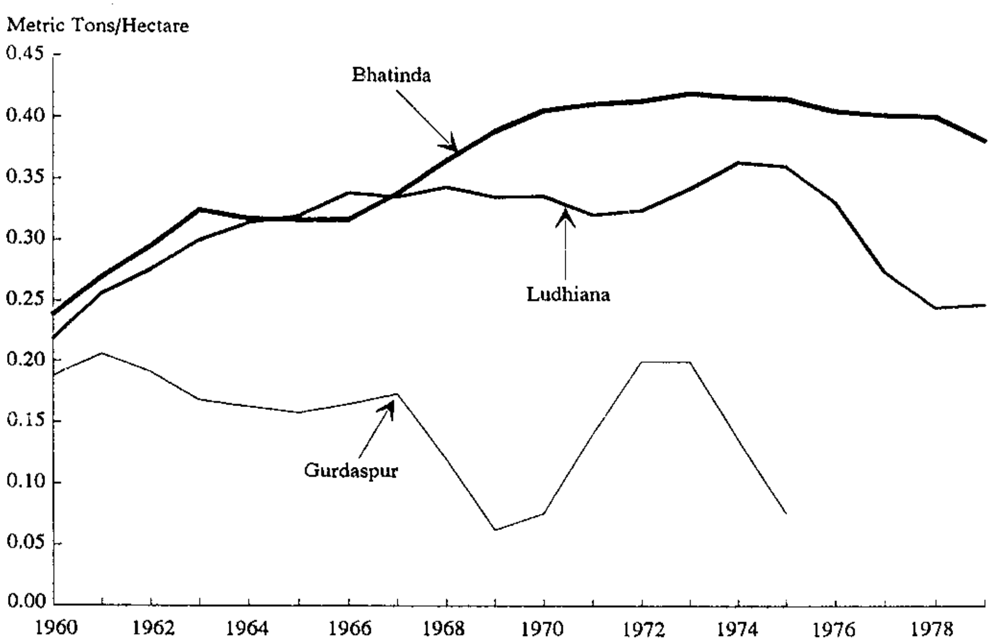
Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

Figure 7 — Maize yield in three districts, 1960-79



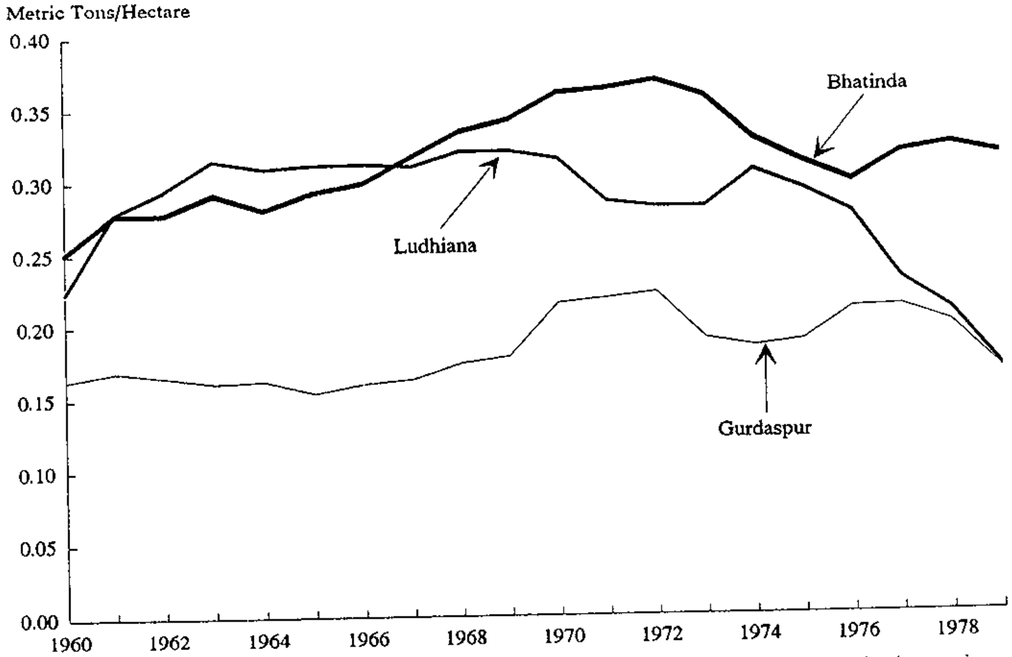
Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

Figure 8 — American cotton yield in three districts, 1960-79



Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

Figure 9 — Desi cotton yield in three districts, 1960-79



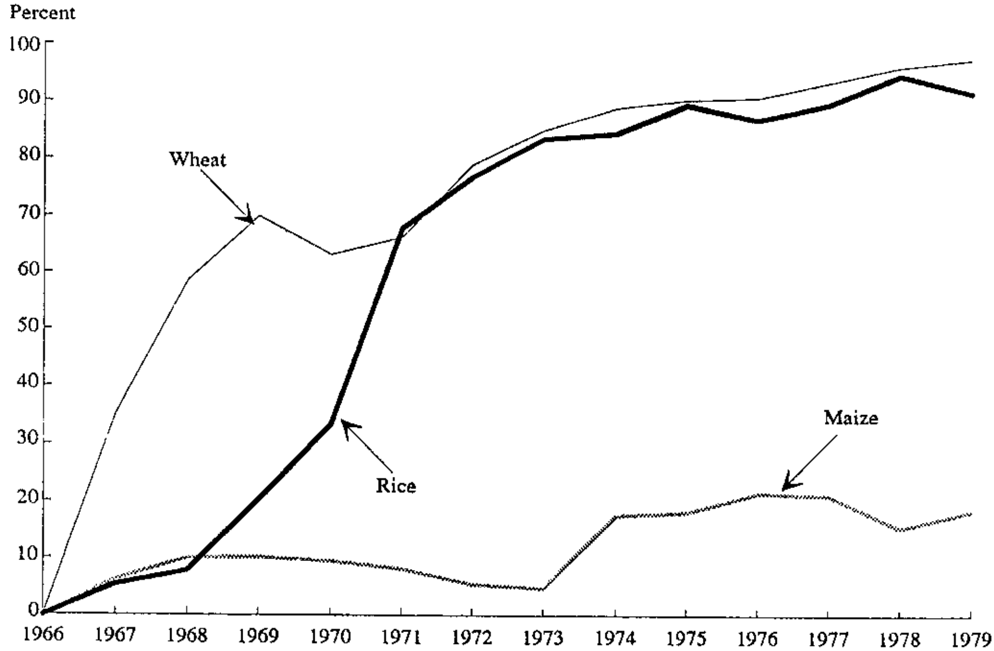
Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

Evenson did not relate research expenditure to economic performance by the state, the payoff on this investment in research seems evident from the performance of the Punjab Agricultural University, which played a key role in the development of new crop varieties.

For the most part, the changes in crop yields described above are attributed to the introduction of MVs. Mexican dwarf wheat varieties were first tested at the Punjab Agricultural University in 1964. Seed multiplication and production followed in 1966, and by 1968 the MVs for rice, maize, and *bajra* had also been released. Since then, the initial MVs have been continually modified to meet demand. For example, problems of acceptance by consumers were overcome by the replacement of the PV-18 variety of wheat, which had a small reddish grain, with the amber-colored grain of the Kalyan Sona variety. As another example, in 1972 the timing constraint that limited double cropping of the MVs of wheat and rice was overcome by the release of a new variety of rice that matured in four months.

The average adoption levels of the MVs of wheat, rice, and maize are presented in Figure 10. It is important to note that the adoption of MV wheat was extremely rapid, with over one-third of the area planted to wheat being sown to the new varieties in the first year of availability, and by 1969/70, only three years later, this rate had increased to about 70 percent. This indicates that factors that are often

Figure 10 — Proportion of area sown to modern varieties in Punjab, 1966-79



Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

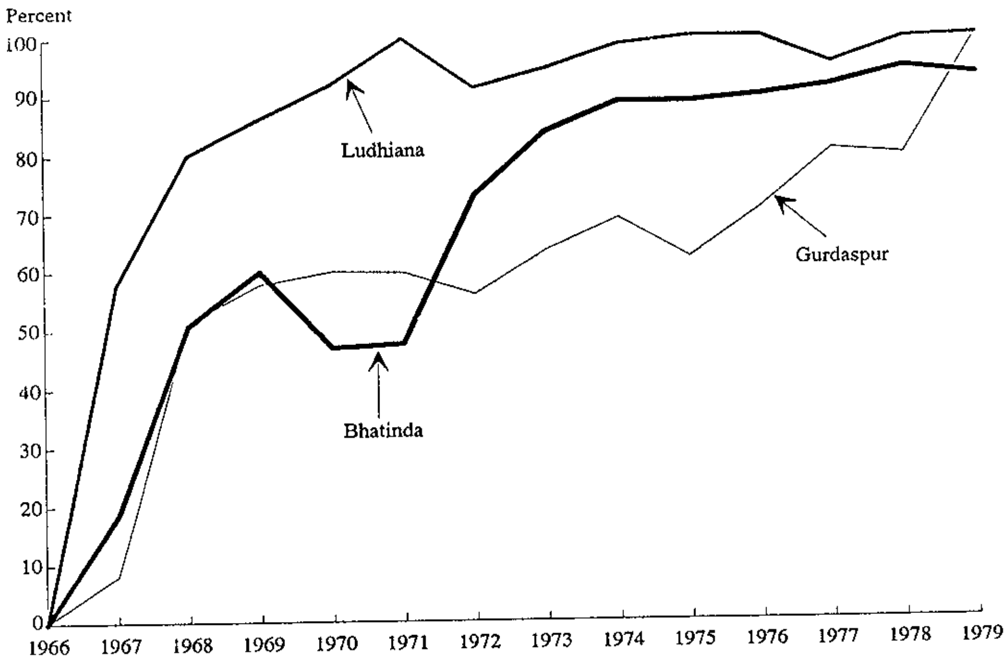
thought to slow down the pace of adoption of new varieties, such as lack of information, uncertainty, or institutional constraints, did not play an important role in the case of wheat. On the other hand, the rate of adoption slowed down after the first three years, which indicates that eventually the progress was hindered by constraints that were gradually removed. This subject will be dealt with in detail in the subsequent chapters.

Adoption of MV rice, on the other hand, was initially slow; by 1969/70 only 20 percent of the area sown to rice was planted in MV rice. To some extent this slow start can be attributed to the infeasibility of the wheat-rice rotation during the first years of the green revolution. However, by the early 1970s, adoption rates of MV rice soared, and by 1971/72, adoption rates of MV rice matched those of MV wheat.

Adoption of MV maize followed a completely different pattern. It was extremely slow and leveled off just below 20 percent in 1979. The lack of acceptance of the MV maize varieties is largely attributed to their poor resistance to disease and drought (Johar and Raikhy 1983). Again, this does not reflect lack of information as a constraint to adoption, but just the opposite.

The rates of adoption varied by districts. Figures 11 and 12 illustrate the acceptance rate of these varieties of wheat and rice in the districts of Bhatinda,

Figure 11--Proportion of wheat area sown to modern varieties in three districts, 1966-79



Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

Ludhiana, and Gurdaspur. Although there has been near complete adoption of wheat in these districts, the adoption of rice is still less than complete. This is particularly evident in Gurdaspur, where, 15 years after the onset of the green revolution, over 25 percent of the area planted to rice is still sown to traditional varieties. In this area, these may consist largely of the Basmati type, which is of high quality and brings a high price.[8]

Despite the almost complete adoption of MV wheat by the end of the sample period, the adoption paths of the three districts are very different. All three districts experienced rapid acceptance of the new varieties in the first two years following their initial introduction. In the next four years, however, adoption quickly tapered off in both Bhatinda and Gurdaspur but continued with great strength in Ludhiana. By 1971/72 the adoption process was nearly complete in Ludhiana, but was less than 60 percent complete in the other two districts. It was not until 1979/80 that the gap between these districts was eliminated.

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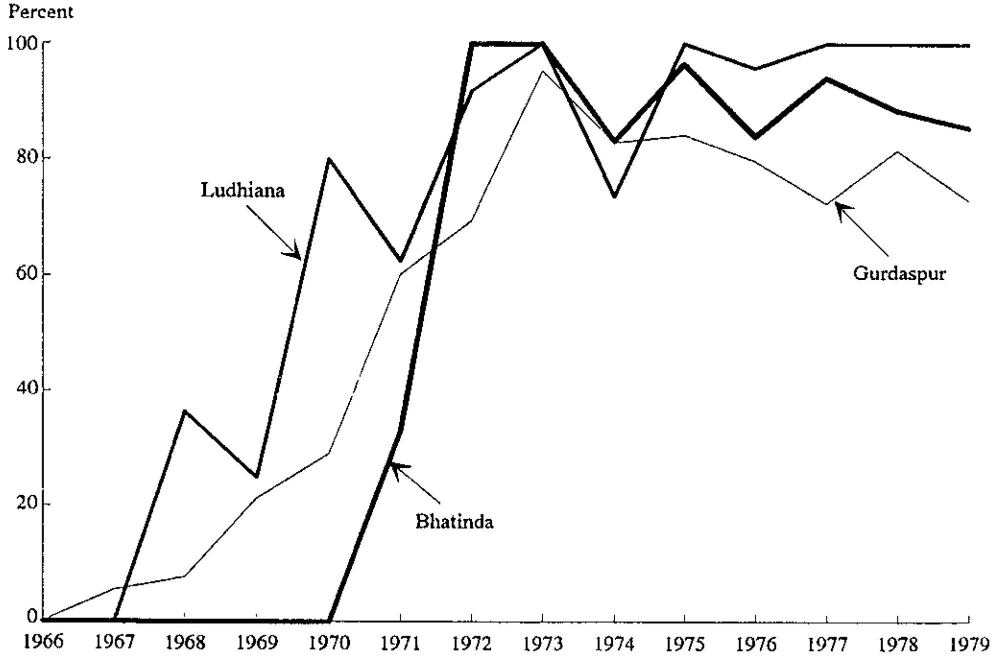
[8]This explanation was suggested to the authors by John Mellor in private correspondence.

Figure 12 — Proportion of rice area sown to modern varieties in three districts, 1966-79



Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

Just as in the case of MV wheat, adoption rates of MV rice in Ludhiana were much higher than those in Gurdaspur and Bhatinda during the early years of the green revolution. In fact, MV rice was not adopted in Bhatinda at all until 1970/71. All three districts experienced very rapid expansion in the proportion of area planted to MV rice during the early 1970s, each reaching the 90 percent mark by 1973/74. Since that time, however, adoption levels have tapered off in both Gurdaspur and Bhatinda. The remaining small shares of the traditional varieties in these districts may indicate the existence of ecological niches where the MVs do not fit.

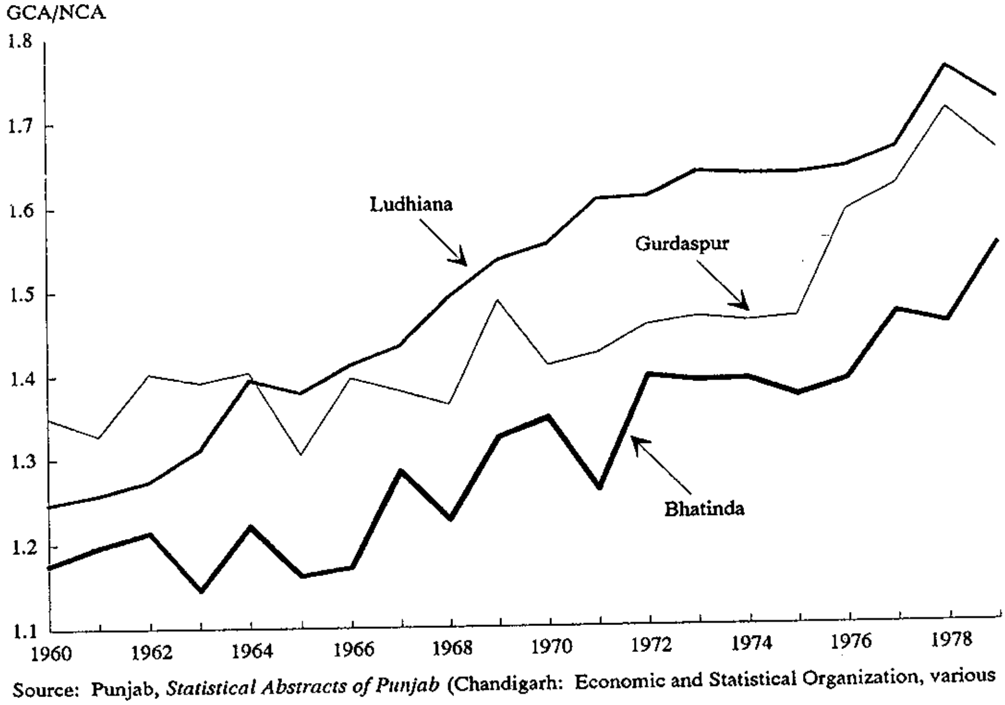
Land-Use Patterns

Over the period 1965/66-1980/81, the proportion of geographical area in the state being cultivated (net cropped area) increased from 76 to 83 percent, an increase of 414,000 hectares for the 11 districts in this study. In 1980, it was estimated that only 5 percent of the area in Punjab was covered by forests, compared with 22 percent in India as a whole (Chadha 1986). Thus the only hope for further increases in cultivatable area appears to be through reclamation of waterlogged area and area affected by alkalinity and salinity.

The increase in total area sown (gross cropped area) has been far more significant than the increase in net cropped area. Over the sample period, total gross cropped area in Punjab increased by 1.9 million hectares. Consequently, the intensity with which cultivatable area was cropped (gross cropped area/net cropped area) increased from 1.2 to 1.6, indicating a significant increase in double cropping. That is, the amount of land cropped twice in one year increased from 20 to 60 percent of total net cropped area. Figure 13 indicates the intensity with which this area was cropped in the various districts. Cropping intensity increased significantly in all three districts, particularly in Ludhiana.

Similar trends are seen in irrigated area. Between 1960 and 1979, net irrigated area in all 11 districts increased from about 2.0 million to 3.5 million hectares.[9] The growth in net irrigated area for Bhatinda, Ludhiana, and Gurdaspur, measured

Figure 13 — Cropping intensity in three districts, 1960-79



Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

Note: GCA/NCA (gross cropped area/net cropped area) is the intensity with which cultivatable area is cropped.

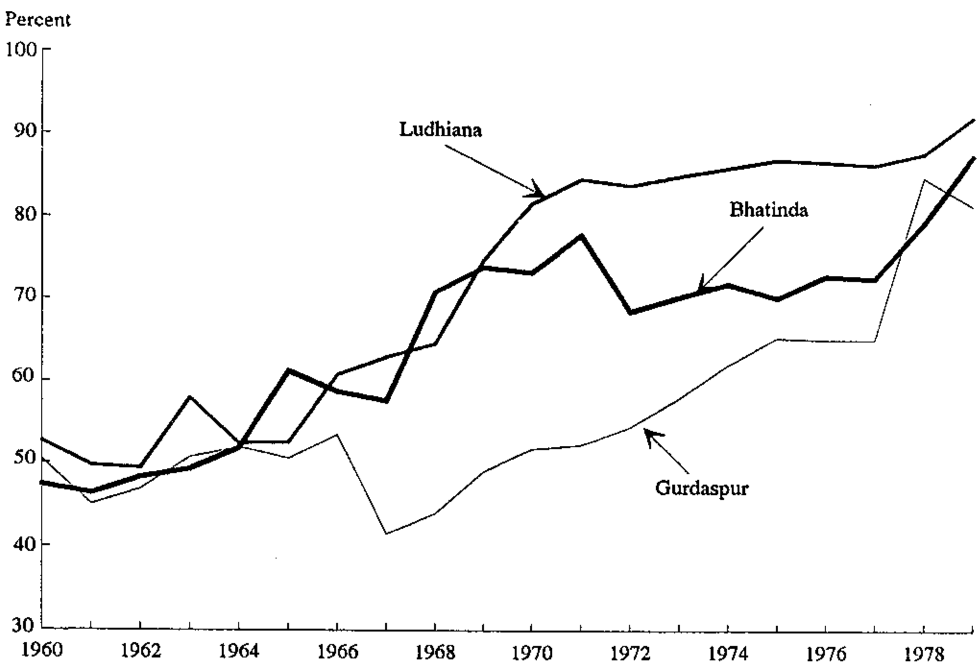
[9]Net irrigated area is the total physical area that can be irrigated, as opposed to gross irrigated area, which is the total irrigated area (includes land that is irrigated in each of the two seasons).

as a proportion of net cropped area, is illustrated in Figure 14. Although the percentage of cultivated area irrigated increased from approximately 50 percent to over 80 percent for those 3 districts, they have followed very different paths from the onset of the green revolution.

Growth in net irrigated area has been accompanied by an even larger increase in gross irrigated area because of an increase in area that is irrigated in both seasons. The intensity with which the net irrigated area in Bhatinda, Ludhiana, and Gurdaspur has been irrigated is illustrated in Figure 15. Although the intensity with which the land has been irrigated has increased, there were sharp variations throughout the sample period. In general, the sharp decreases correspond to years when new land was brought under irrigation.

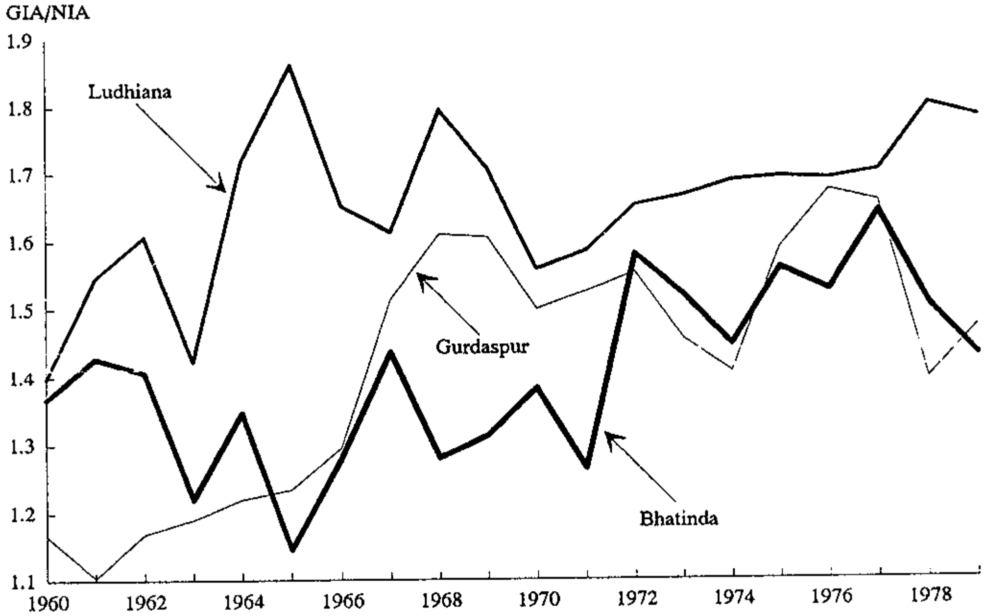
As noted above, there are two distinct growing seasons, *rabi* and *kharif*. The composition of crops grown in these seasons differs, as can be seen in Figures 16-18. Wheat and gram are the main *rabi* crops, and rice, maize, and cotton are the main *kharif* crops. Sugar (included in "other" in the three figures) is the only crop that is in the ground the entire year; all other crops are grown in only one season. As illustrated in Figures 16-18, a much larger proportion of both irrigated and dry land is cropped in the *rabi* season, when wheat has always been the dominant

Figure 14—Proportion of cultivated area irrigated in three districts, 1960-79



Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

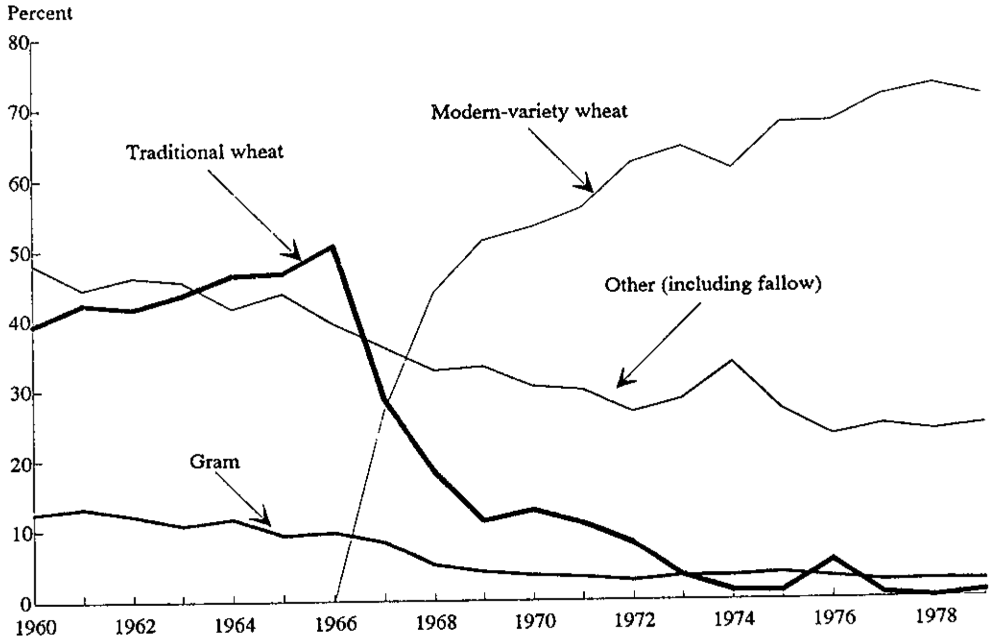
Figure 15— Irrigation intensity in three districts, 1960-79



Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

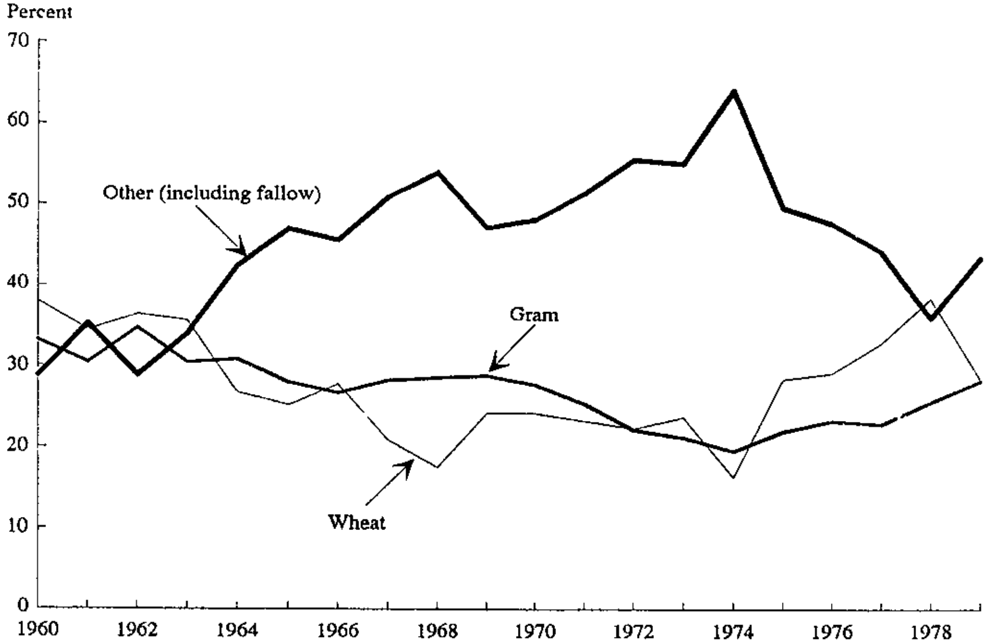
Note: GIA (gross irrigated area) is the total irrigated area, including land that is irrigated in both the *rabi* and *kharif* seasons. NIA (net irrigated area) is the total physical area that can be irrigated.

Figure 16—Allocation of rabi irrigated area in Punjab, 1960-79



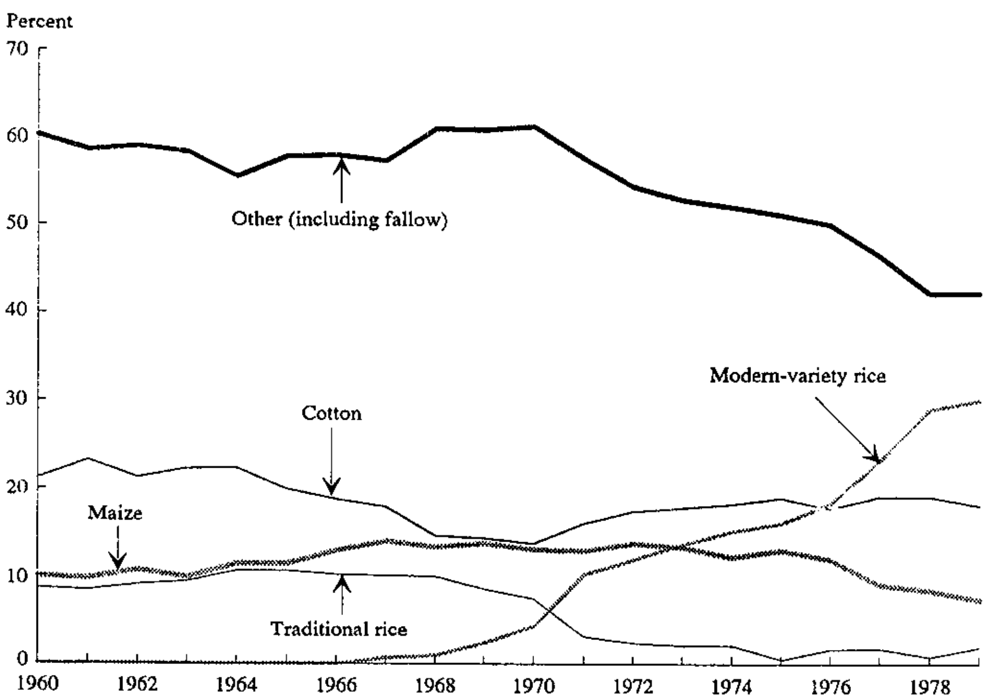
Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

Figure 17 — Allocation of rabi dry area in Punjab, 1960-79



Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

Figure 18—Allocation of kharif irrigated area in Punjab, 1960-79



Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

crop.[10] Gram has maintained a large share of the dry land during the *rabi* season, but after the onset of the green revolution its share of irrigated land declined significantly. In the *kharif* season, the most obvious change is the large increase in area occupied by rice. Prior to the green revolution, rice occupied less than 10 percent of the irrigated land; by 1979 this had risen to more than 30 percent. Cotton has maintained its share of irrigated land. The share of irrigated land allocated to maize has declined, while its share in dry land has increased slightly. The proportion of dry land cropped in the *kharif* season on the whole is quite small, reflecting the dry conditions of this season. Still, it has increased over the sample period because of changes in the area allocated to both rice and maize.

Source of Irrigation

Throughout its history, Punjab has been the beneficiary of heavy central and state government investment in canal irrigation systems. As a result of this heavy investment, the proportion of cropped area irrigated in Punjab was greater than any other state prior to the onset of the green revolution. Since that time, Punjab has maintained this lead by bringing even more land under irrigation. It is widely recognized that these changes in availability of irrigation have been critical in the success of the green revolution in Punjab (Gupta and Shangari 1980). In addition, it has been shown that there is a qualitative difference by source of irrigation (Westley 1986).

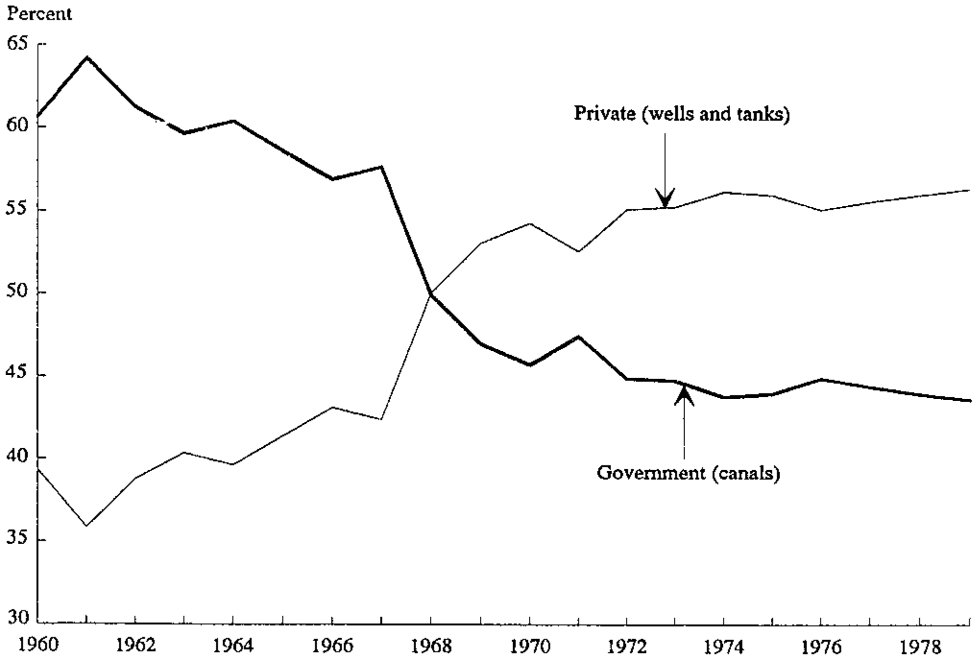
The increase in irrigated area has been largely due to increased investment in wells. For Punjab as a whole, well irrigation accounted for over 80 percent of the rise in net irrigated area between 1960 and 1979. As a result, the share of land irrigated by wells increased from less than 40 percent in 1960 to more than 55 percent in 1979, and the share of land irrigated by canals declined accordingly (Figure 19). Although the growth in wells was substantial for the state as a whole (Figures 19 and 20), Figure 21 illustrates clearly that the pace of growth varied considerably by district (see discussion below).

The increase in area irrigated by wells has largely been due to an increase in tubewells. According to Nair (1979), over 99 percent of the tubewells installed represented private investment of the cultivators. Tubewell irrigation has a distinct advantage over the canal irrigation system because groundwater supplies are influenced less by weather and other factors that affect surface water availability.[11] These guaranteed water supplies which can be applied in a timely fashion, became

[10]No figure is provided for the *kharif* dry-season varieties because they occupy such a small proportion of the dry cropped area available.

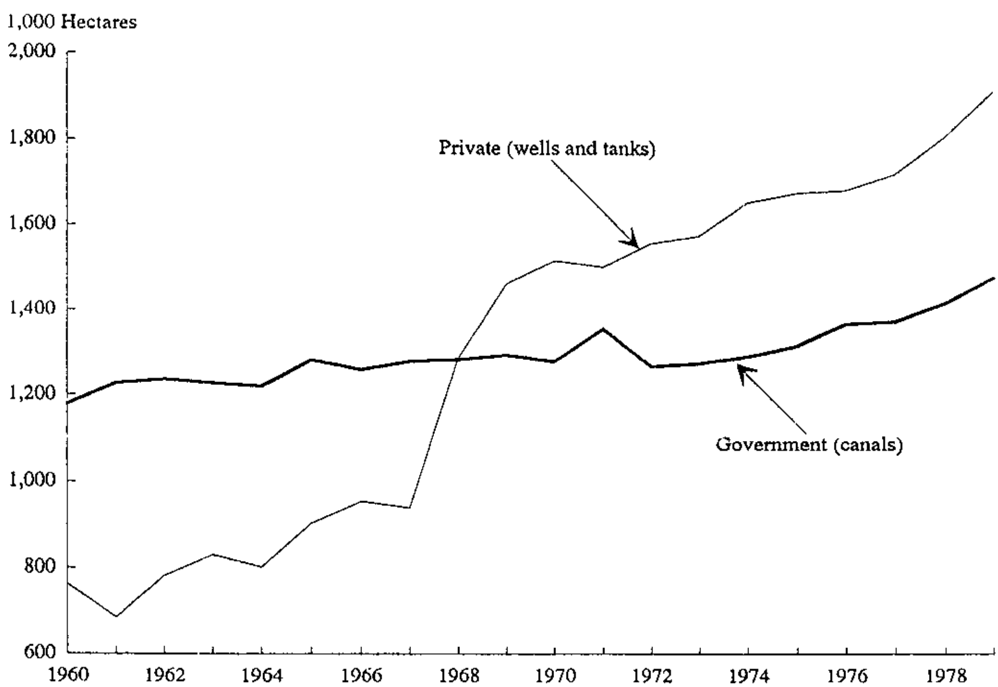
[11]Canal irrigation is less affected by weather in Punjab than in most places because of the Himalayan water sources.

Figure 19 — Allocation of irrigated area in Punjab, by source, 1960-79



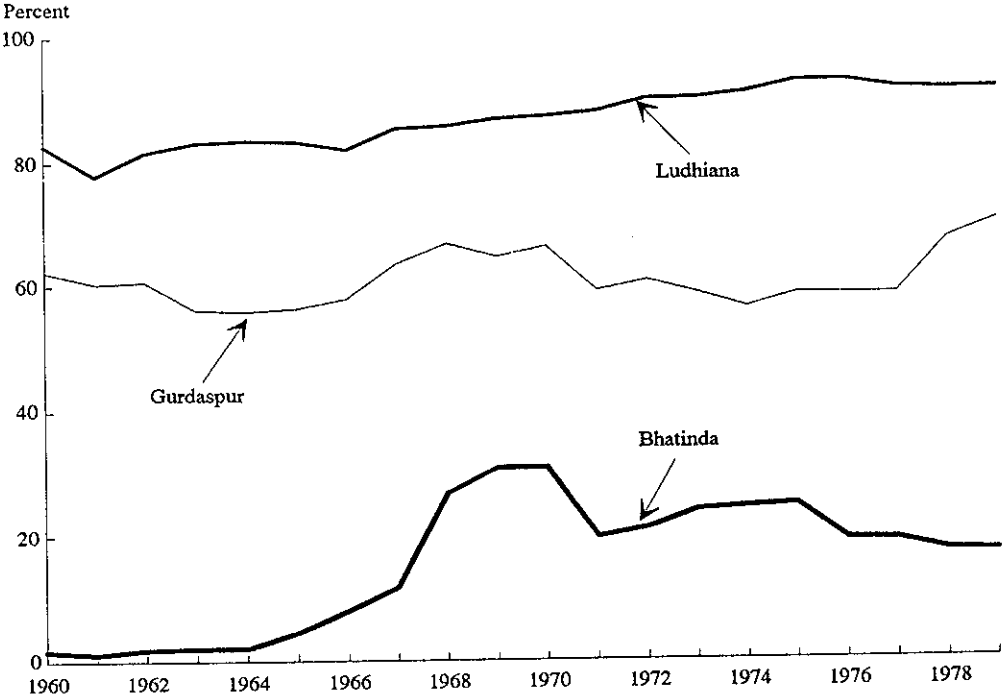
Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

Figure 20 — Amount of irrigated area in Punjab, by source, 1960-79



Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

Figure 21 — Net area irrigated by private wells in three districts, 1960-79



Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

particularly important following the introduction of high-yielding varieties (Westley 1986).[12]

A full data series of the breakdown of area irrigated by type of well is not available, but it is known that as of 1959/60 there were an estimated 231,000 traditional wells and only about 5,000 tubewells in Punjab. By 1981/82, the number of tubewells increased to about 610,000, thus accounting for well over 90 percent of the total area irrigated by wells (Westley 1986).

Despite all the claims in the literature of the importance of various factors in facilitating the adoption of tubewells, empirical evidence for many of the claims is scanty. Conclusions drawn have varied, depending on the source of data and the area and time period studied. Evidence of the importance of institutional credit and

[12]Although the tubewell technology was available in pre-independence time, tubewells were not abundant in Punjab, as the technology was only developed for larger, inappropriately sized engines. Over time, small-scale engines and tubewells were developed and the economic situation changed, making the "minimum economically feasible size of holding" much smaller (Westley 1986). The end result of all these changes has been a substantial increase in area irrigated by tubewells.

availability of electricity for Punjab as a whole is found in a 1979/80 survey of tubewells and pumpsets (Punjab 1980). According to this survey, the importance of available institutional credit may be overstated, as over 75 percent of the financing for tubewells came from personal sources of the cultivators and only 10 percent from cooperatives. (The provision of credit is discussed in more detail in a later section.) The same survey indicated that in 1979/80, 30 percent of the tubewells and pumpsets were operated by electricity and 66 percent by diesel, despite the higher cost of diesel pumps. This phenomenon is attributed, first, to insufficient geographical coverage of electricity supply, and second, to disturbances in electricity supply (Mehra 1983). The electricity supply problems are discussed below.

The characteristics of the technology available and the economic conditions are not the only determinants of source and quantity of irrigation. There are also some physical limitations. In the hilly districts, for example, a much lower percentage of land is irrigated, because the digging of tubewells is difficult in the mountains, and because the availability of only seasonal streams makes the area unsuitable for canals. On the other hand, the western part of the state is more suitable for canal irrigation than well irrigation, since the water table is deeper and much of the water is brackish and unfit for tubewells. In the central part of the state, canal and tubewell irrigation are both suitable (Randhawa 1974).

Figure 21 shows the proportion of net irrigated area irrigated by wells for the three representative districts. Bhatinda, which is located in the southwestern portion of the state, has the lowest percentage of area irrigated by wells, whereas Ludhiana, which lies in the central plains, has the highest percentage of area irrigated by private sources.

Electricity

From 1965/66 to 1979/80, power generation in Punjab increased by over 240 percent (Chadha 1986), and by 1976 all villages in Punjab had access to electricity (Mehra 1983). However, despite its general availability, Chadha (1986) estimates that by 1980/81, only 56 percent of the households were using electricity.

The fastest-growing source of demand for electricity during this period was agriculture. The proportion of total available electricity consumed by the agricultural sector increased from 14.5 percent in 1960/61 to 38.0 percent in 1970/71 and to 47.0 percent in 1979/80. A large part of the increase was as a source of power for the growing numbers of tubewells. According to Chaudhri and Dasgupta (1985), by 1975/76 as much as 43 percent of the power, whose cost was being subsidized by the Punjab State Electricity Board, was used specifically for tubewells.

Despite the impressive record of power generation, power has continued to be in short supply, and the gap between demand and supply has been widening. The growing number of applications for electrical connections pending is evidence of the shortage of power. In 1981/82, there were nearly 228,000 such applications, of which 34,000 had been waiting between one and two years, and 15,000 for over two years (Mehra 1983). Further, seasonal shortages and periods of low voltage sometimes occur in the busy summer months.

The problem has not only been one of increasing demand, but the supply has also been steadily deteriorating. According to Chadha (1986), there has been gross underutilization of installed capacity, partly because of recurring technical and management problems. Thus, although the government has played an important role in the provision of electric power, the availability of electricity still appears to be a constraint to agricultural growth.

Credit

Because the new higher-yielding varieties require more purchased inputs than the traditional varieties, credit has become increasingly important in recent years. During the green revolution, both the central and state governments continued to influence the credit market through their involvement with credit cooperatives and other related policies. Consequently, it has been argued that "easily available agricultural credit financed very rapid expansion in the use of production inputs" (Westley 1986, 88), and it is believed that credit has been much more readily available in Punjab than anywhere else in India.

As a result of one policy—nationalization of the banking system in 1969—the commercial banks of India entered the agricultural finance scene. From 1972 to 1981 they doubled their share of loans outstanding to agriculture for both short-term credit (from 17 to 34 percent) and long-term credit (from 22 to 44 percent), while overall institutional credit to agriculture increased 18 percent. This new direction in the credit market has been particularly important for Punjab, as indicated by bank credit to agriculture of 533 rupees per hectare in Punjab in 1980, compared with 217 rupees per hectare for India as a whole (Westley 1986).

Although the credit cooperatives, which were established in the early twentieth century, were expanded significantly during the green revolution, much of the literature is skeptical about the effectiveness of these institutions. Even though credit cooperatives increased their proportion of rural credit from 3 to 33 percent between the early 1950s and late 1970s, it is feared that they did not replace the traditional money lender as intended (Westley 1986). Mellor (1976, 38) argues that in India, as elsewhere in the developing world, credit cooperatives ". . . must still be seen more as a means of dispensing political patronage than as a development institution." The importance of credit as a constraint to purchases of fertilizers and seed and to investment in irrigation, mechanization, and so forth, is not analyzed explicitly in this study.

Fertilizer

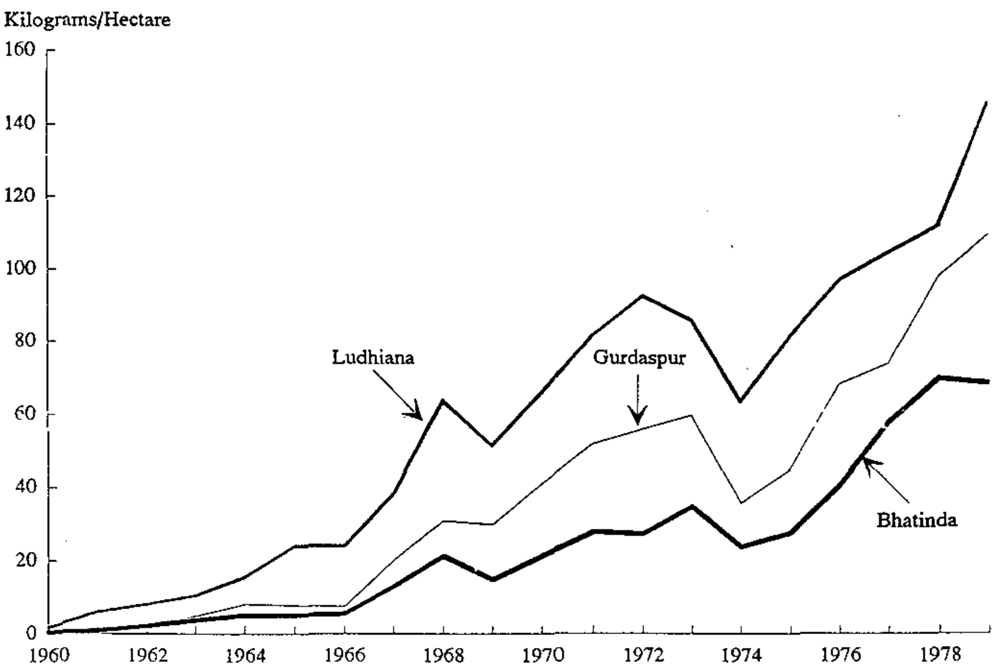
Until the early 1960s, commercial fertilizer use was extremely low. Chadha (1986) provides two reasons for these low levels of fertilization. First, the traditional seeds, in use up to this time, were not responsive to high fertilization rates, thus returns were too low to justify the expenditure on this costly input. Second, the extension services were not "up to the task," and there was a lack of adequate information on the fertilizer requirements of the different soils. The second reason implicitly assumes that the weak response to fertilizer is due to lack of knowledge. This may or may not be the case, but as it is not an important issue for this discussion it is not pursued further.

Because high-yielding varieties respond well to fertilization, once they were introduced, the use of fertilizer increased dramatically. For the districts included in this study, application of fertilizer per hectare increased from 1 kilogram in 1960 to 105 kilograms in 1979. The 1979 figure is almost as large as that for the United States (110 kilograms) and is 3.5 times the all-India consumption per hectare for the same year.

Figure 22 illustrates the trend in fertilizer use per cropped hectare in Bhatinda, Ludhiana, and Gurdaspur during 1960/61-1979/80. Not only is the increase in fertilizer use extraordinary, but so is the variation in usage by district. Consumption rates per hectare increased from almost zero for all three districts to 140 kilograms in Ludhiana, over 100 kilograms in Gurdaspur, but only 60 kilograms in Bhatinda.

The availability of tubewells is thought to have influenced the demand for fertilizer, because the assurance of adequate and timely water through use of tubewells allows more effective use of fertilizers (Chadha 1986).

Figure 22 — Fertilizer per cropped hectare in three districts, 1960-79



Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

It appears that despite the great increase in fertilizer use, in general, "sub-optimal" levels are still being used (Kahlon 1984; Kahlon and Kaul 1968). Some believe the use of fertilizer has been determined by its availability rather than factors affecting demand. For example, Nicholson (1984, 150) argues, "it was probably not the local distribution system that affected the access of the poor to inputs, but the allocation of fertilizer within the federal system by the national government, which created localized conditions of scarcity and plenty." For other views see Desai 1982.

Mechanization

Although the increase in mechanization in Punjab is often associated with the onset of the green revolution, there had been a substantial increase in the use of tractors before 1966. Table 3 illustrates the growth in tractors for Ludhiana, Bhatinda, and Patiala, as well as for Punjab as a whole, from 1956 to 1978. As can be seen, the increase in the number of tractors has been phenomenal.

Many reasons have been cited for the increase in mechanization: subsidization of tractors by the government, availability of cheap institutional credit, and large remittances from abroad (Chadha 1986). In addition to these factors, the growth in agricultural productivity during the green revolution helped make tractors profitable in situations where they had not previously been economically viable. However, scarcity of labor, which is largely seasonal in nature, is mentioned most often as the main reason for increased mechanization.

Binswanger (1978) argues that increases in wages have been responsible for the increase in mechanization. However, data on tractor availability indicate that the number of tractors increased considerably just prior to the green revolution, when real wages reached their all time low (see below). Further, the demand for labor increased during the green revolution, but as Schwarz (1986) notes, this increase in demand was met to a large extent by labor migration to Punjab from other states and thus prevented wages from reflecting the full impact of the increased demand.

However, market wages may not tell the whole story. If hired labor and operator labor are not perfect substitutes, then mechanization may have allowed

Table 3—Index of tractor numbers in Punjab agriculture, 1956-78

District	1956	1961	1966	1972	1978
Ludhiana	100.00	181.69	1,144.37	3,354.93	8,059.86
Bhatinda[a]	...	100.00	96.18	238.85	829.31
Patiala	100.00	124.39	215.96	978.80	2,507.76
Punjab	100.00	169.64	365.62	1,414.78	3,380.72

Source: Based on data from G. K. Chadha, *The State and Rural Economic Transformation: A Study of Punjab, 1950-1985* (New Delhi: Sage, 1986).

[a]Bhatinda data have not been adjusted for boundary changes.

better use of the operators' time. Thus it may have been an increase in the shadow wage rate of the farmers' time that generated the demand for tractors. This explanation is consistent with the argument that the demand for timely completion of field operations led to increased mechanization (Kahlon 1984). Unfortunately, data on numbers of tractors are not available on an annual basis; therefore, the importance of mechanization is not analyzed explicitly in this study.

Labor

A consistent time series is not available for labor in Punjab, so it is difficult to analyze the changes in the agricultural labor force that have occurred over time. Data are available every 10 years from the Indian census. These series are not completely consistent, as definitions have changed over time.

Despite a negligible change in the number of agricultural workers as a percentage of total workers, there has been a significant change in the composition of agricultural workers. In Table 4 the number of male agricultural laborers is disaggregated into two groups, cultivators and agricultural laborers, and changes in these groups are shown for 1961 to 1981 in both Punjab and India. The total number of male agricultural workers in Punjab grew 2.2 percent annually (compounded) during 1961-81, while the number of agricultural laborers grew 6.1 percent and the number of cultivators less than 1.0 percent. The all-India data exhibit similar trends, with the interesting exception that during 1971-81 the proportion of agricultural laborers in India declined. Thus, in comparison with the country as a whole, the agricultural growth in Punjab generated a large demand for laborers.

Although this study does not deal with the impact of migration on the changes that have occurred, and vice versa, the substantial migration that took place needs

Table 4—Occupational classification of rural male workers, 1961-81

Occupation	1961		1971		1981	
	Number	Percent	Number	Percent	Number	Percent
	(thousands)		(thousands)		(thousands)	
Punjab						
Cultivators	1,424	57.8	1,610	54.1	1,662	49.8
Agricultural laborers	307	12.5	739	24.9	967	29.8
Other	731	29.7	625	21.0	708	21.8
Total	2,462	100.0	2,974	100.0	3,337	100.0
	(millions)		(millions)		(millions)	
India						
Cultivators	62.5	60.7	64.5	55.5	74.1	55.3
Agricultural laborers	16.7	16.2	30.0	25.8	27.5	24.2
Other	23.8	23.1	21.6	18.6	27.5	20.5
Total	102.9	100.0	116.0	100.0	134.1	100.0

Source: Based on data from John R. Westley, *Agriculture and Equitable Growth: The Case of Punjab-Haryana* (Boulder, Colo., U.S.A.: Westview, 1986).
Note: Parts may not add to totals because of rounding.

to be mentioned. For years, Punjab has attracted labor from the neighboring states of Uttar Pradesh, Jammu and Kashmir, and Rajasthan. During the green revolution the number of migrants increased substantially, and they have started to come from places as far away as Bihar, Orissa, and Madhya Pradesh (Grewal and Sidhu 1979). Unfortunately, the available data describing the changes in the flow of labor from outside Punjab are sparse. For a more detailed analysis of labor see Schwarz 1986.

Price Policy and Prices

The key instrument in the agricultural pricing policy in India is the price at which the government procures foodgrains for the public distribution system.[13] The main features of this system, including restrictions on grain movement between regions, government procurement in surplus districts, distribution and rationing in urban areas, and administrative control over traders, date from the Bengal Famine of 1943 and have been applied in various combinations in response to changes in the volume of agricultural production. A major change took place in this policy during the 1960s with the establishment of the Agricultural Prices Commission. This Commission set procurement prices at a level remunerative to farmers to promote greater reliance on domestic, rather than imported, supplies of foodgrain for the public distribution system (Westley 1986).

This greater reliance on domestic sources of foodgrain for public distribution led to a significant increase in Punjab's contribution of foodgrain to this program. From the early 1950s to the mid-1960s, foodgrain procurement from Punjab averaged less than 5 percent of the wheat crop and approximately 33 percent of the rice crop. During the 1970s, however, government procurement accounted for approximately one-third of its wheat production and about three-quarters of its rice production (Krishna and Raychaudhuri 1980). As of 1980/81, Punjab's contribution was 45 and 64 percent of the rice and wheat procurements, respectively (Westley 1986).

The increase in tonnage of crops moving through the regulated markets in response to the new procurement policy of the 1960s caused serious problems. In response to these problems, the state government established additional markets and continued with its "crash" road program. By the mid-1970s, every village in the region was connected to market by its own all-weather road (Chadha 1986), and Punjab now has the most fully developed physical infrastructure for marketing in all of India (Westley 1986).

By essentially providing a guaranteed market for Punjabi foodgrain production, the procurement policy has helped sustain the growth in the agricultural sector without relying heavily on income-driven demand increases from the nonagricultural sector. Thus, Punjabi efforts have continued to be heavily biased toward the agricultural sector.

The foodgrain procurement program generally has relied heavily on market incentives, but on some occasions the government has intervened through various

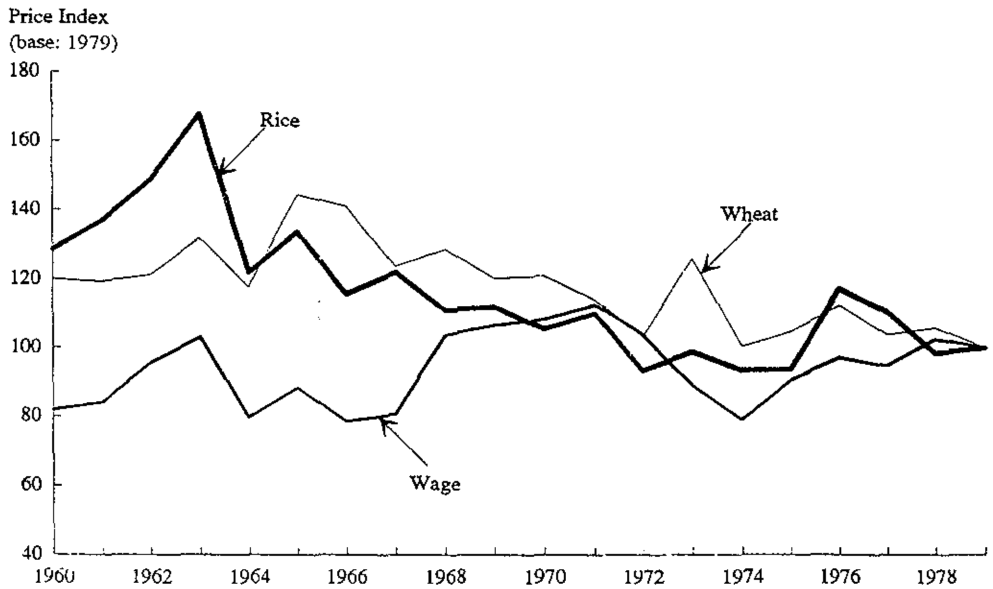
[13]For a review and description of the agricultural price policies in India see Kahlon and Tyagi 1983.

zonal restrictions on foodgrain movement. In 1973 these restrictions were taken to extremes as the government attempted a complete takeover of the wheat trade to ensure higher procurement levels. This full-control policy was quickly abandoned in 1974, and by 1977 the zonal restrictions were abandoned altogether. Since then, the government has generally purchased all grain offered at the procurement price, and this price has acted as a support price (Westley 1986).

Although the Agricultural Prices Commission sets procurement price levels, these prices are strictly speaking only recommendations, and states have some flexibility in setting their own prices. Since 1965, Punjab has generally set its prices slightly above the recommended levels (Krishna and Raychaudhuri 1980). Chadha (1986) provides evidence that the prices set by the state government in recent years have been greater than the cost of production (including rent for leased land and imputed costs for all family resources) for both wheat and rice. His figures indicate that during the green revolution the procurement price of wheat was as much as 42 percent higher than costs in 1967/68 and as little as 8 percent higher in 1975/76. This is in sharp contrast to the 1950s, when the full cost of wheat production was covered by only a small margin on some irrigated tracts.

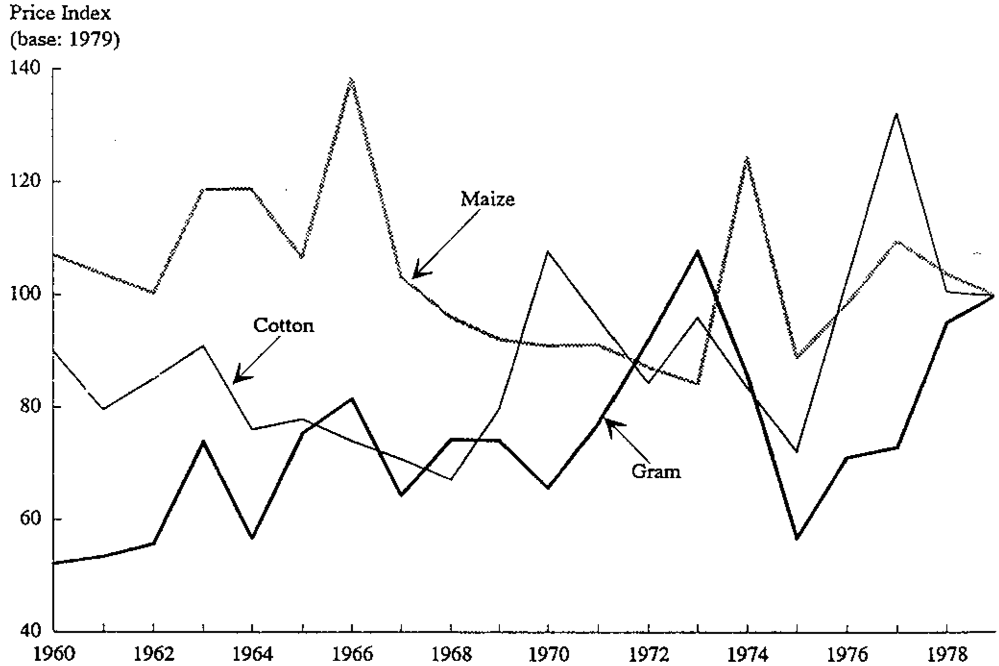
Figures 23 and 24 report the real mean wage rate and prices of all the crops analyzed in this study for all districts. Each price series is deflated by its own 1979 price. Figures 25 and 26 present the real harvest price of wheat and rice for the districts of Bhatinda, Ludhiana, and Gurdaspur. These prices are deflated by the consumer price index for Punjab (base = 1960/61).

Figure 23 — Average wage and harvest prices for wheat and rice in Punjab, 1960-79



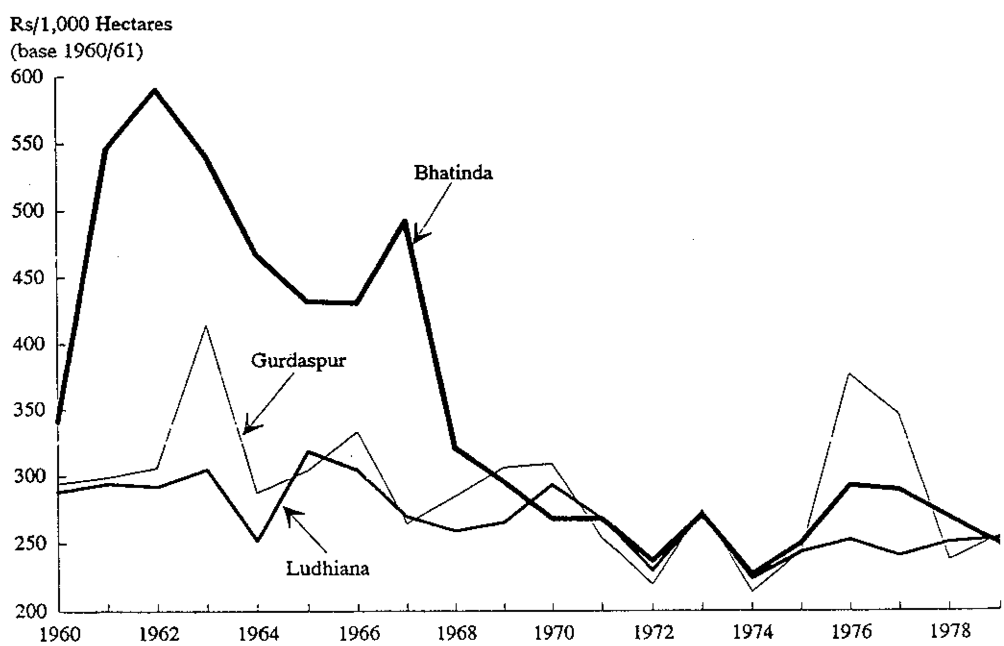
Source: India, *Farm (Harvest) Prices of Principal Crop* (New Delhi: Directorate of Economics and Statistics, various years).

Figure 24 — Average harvest prices for maize, cotton, and gram in Punjab, 1960-79



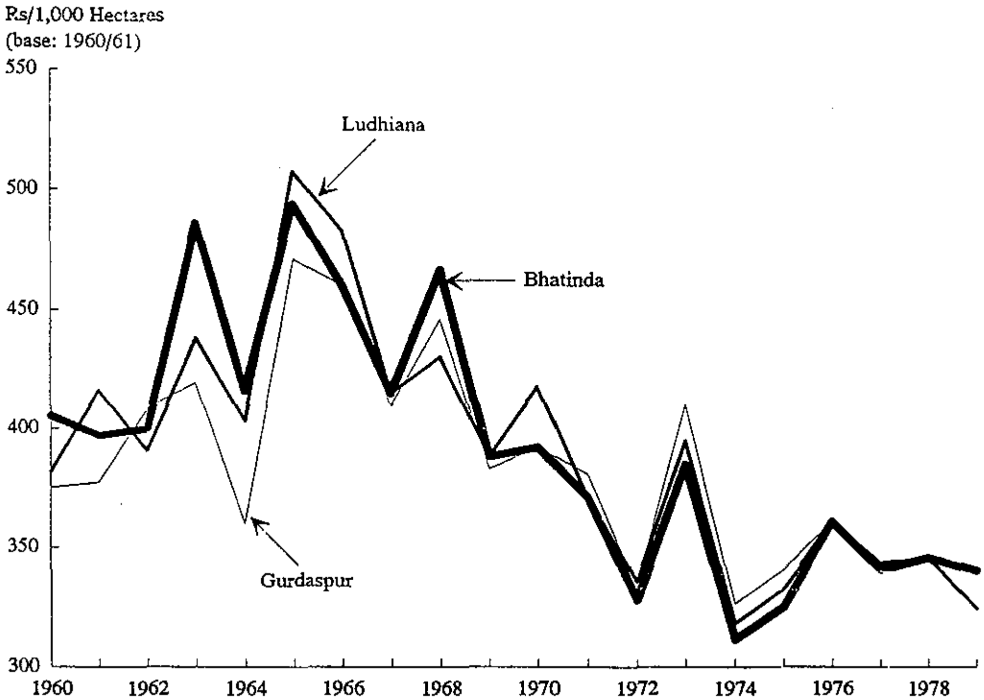
Source: India, *Farm (Harvest) Prices of Principal Crops* (New Delhi: Directorate of Economics and Statistics, various years).

Figure 25 — Real rice price in three districts, 1960-79



Source: India, *Farm (Harvest) Prices of Principal Crops* (New Delhi: Directorate of Economics and Statistics, various years).

Figure 26—Real wheat price in three districts, 1960-79



Source: India, *Farm (Harvest) Prices of Principal Crops* (New Delhi: Directorate of Economics and Statistics, various years).

As is evident from these plots, the movement in real prices has varied considerably over time. However, most striking is the declining trend in the prices of wheat and rice that began in the mid-1960s. The price of wheat increased somewhat in 1973, but returned to the trend line in the subsequent year. The downward trend in wheat price roughly followed that in world prices and was facilitated by increases in domestic production.

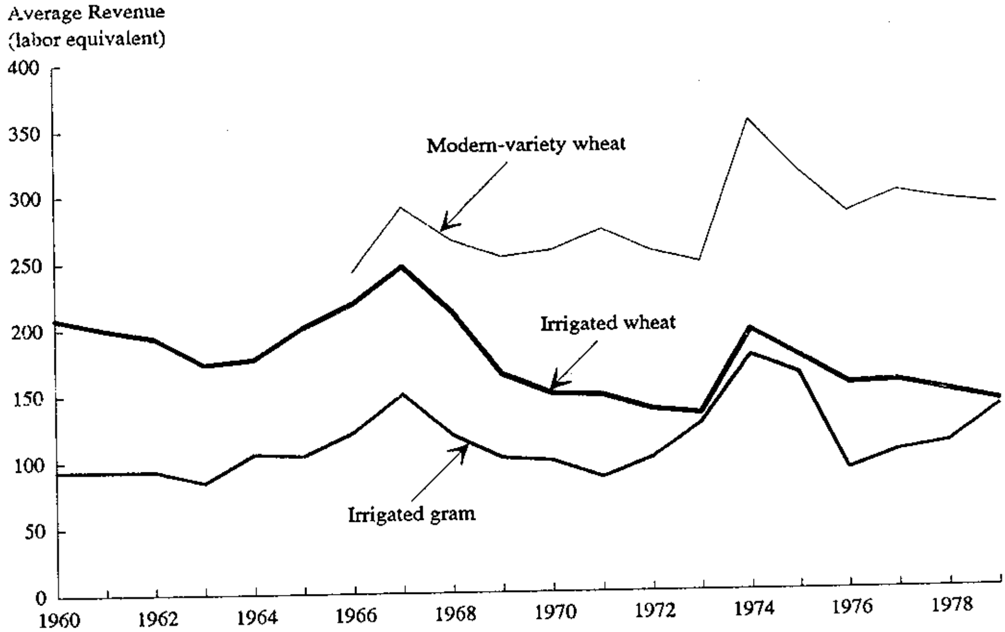
Figure 23 indicates that mean real wages reached an all-time low just before the onset of the green revolution. Wages then trended upward until the early 1970s. Following this increase, they declined until 1974. Some of this decline may be attributed to poor weather conditions. Thereafter, real wages begin to recover, but not sufficiently to surpass the peak in the early 1970s.

Expected Revenues

As explained in Chapter 5, a measure of expected revenue per hectare (deflated by the wage rate) is used as an indicator of the profitability of the different crop varieties. Expected revenues for the different crops (by techniques) in the *rabi* and *kharif* seasons are presented in Figures 27-30.[14] For the most part, the yields of all the traditional varieties (irrigated and dry) are constant over the sample period; thus, changes in the expected revenues of these varieties reflect changes in the expected prices (see Appendix 2 for a detailed discussion of the construction of these variables). Note that the expected revenue variables referred to here as MV wheat and rice expected revenues are the expected overall average revenue for wheat and rice, as changes in expected overall yields reflect changes in the yields of the MVs and changes in their share in total area.

The relative ranking of the *rabi* season crops according to average revenue is obvious—MV wheat dominates all other crops and techniques. Although the expected revenue of irrigated cotton in the *kharif* season has been very large throughout the sample period, the expected revenue of MV rice has surpassed it since 1973 (Figure 29). In terms of expected revenue during the last few years of the sample, dry cotton has outperformed irrigated and dry maize, which in turn have outperformed irrigated and dry rice. Although the range in expected revenues has expanded over the sample period, the ranking of the different crops for the most part has remained the same since 1969.

Figure 27— Expected revenues for irrigated wheat and gram and modern-variety wheat, rabi season, 1960-79



Sources: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years); and India, *Farm (Harvest) Prices of Principal Crops* (New Delhi: Directorate of Economics and Statistics, various years).

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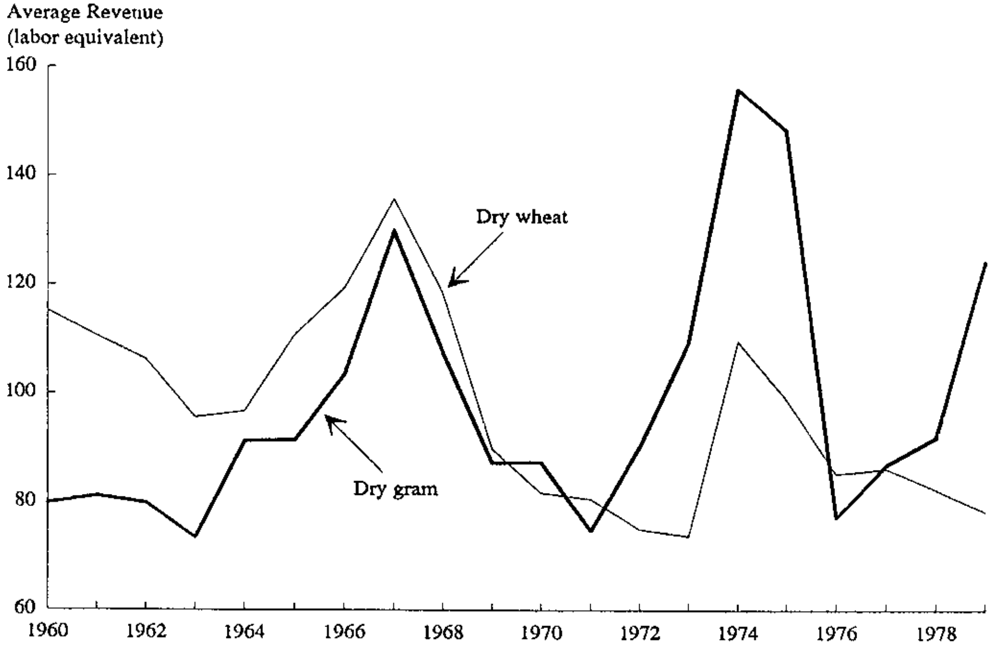
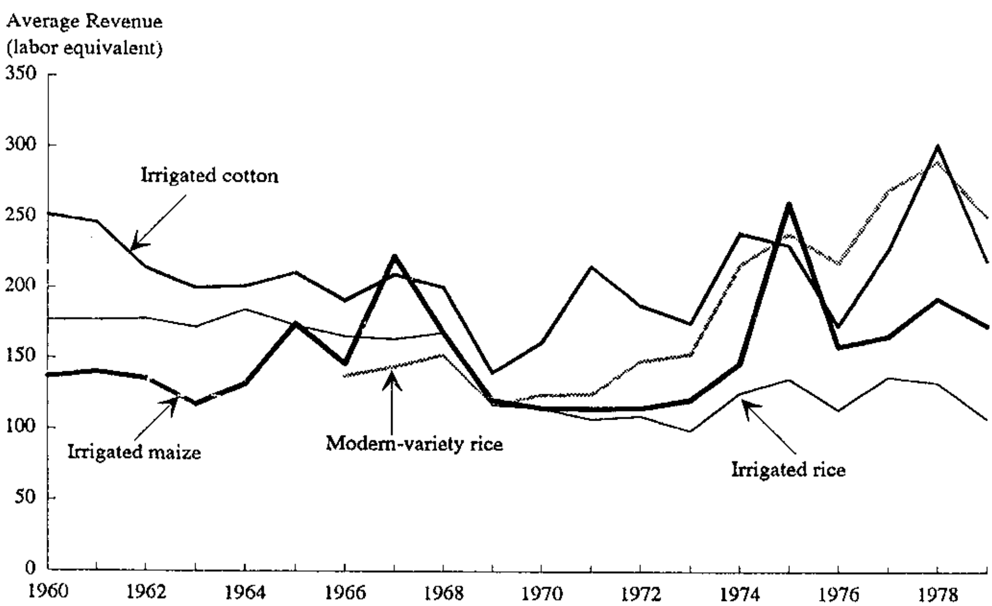
[14]All expected revenue variables (Rs/1,000 hectares) are deflated by wage (Rs/8-hour day).

Figure 28 — Expected revenues for dry wheat and gram, rabi season, 1960-79



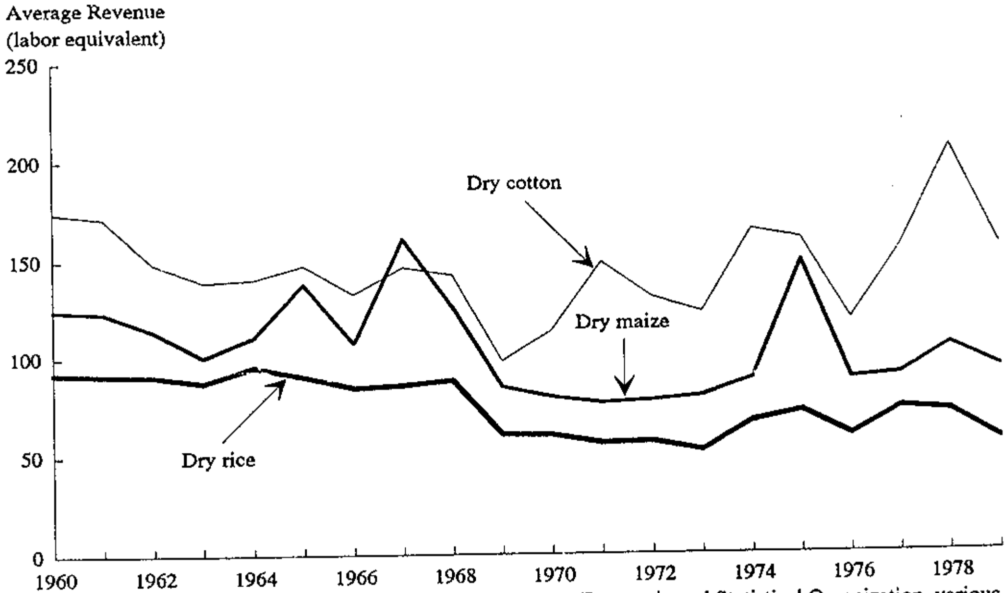
Sources: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years); and India, *Farm (Harvest) Prices of Principal Crops* (New Delhi: Directorate of Economics and Statistics, various years).

Figure 29 — Expected revenues for irrigated rice, maize, and cotton and modern-variety rice, kharif season, 1960-79



Sources: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years); and India, *Farm (Harvest) Prices of Principal Crops* (New Delhi: Directorate of Economics and Statistics, various years).

Figure 30 — Expected revenues for dry rice, maize, and cotton, kharif season, 1960-79



Sources: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years); and India, *Farm (Harvest) Prices of Principal Crops* (New Delhi: Directorate of Economics and Statistics, various years).

Summary and Conclusions

Much of the rapid growth in NDP experienced by Punjab during the period of study was generated by growth in agriculture that was largely due to growth in crop production resulting from improvements in the overall yields of wheat and rice and, to a lesser extent, improvements in the yields of maize and cotton. The pattern of growth in overall yields for the various crops, particularly wheat and rice, suggests that the main improvements came as a result of a shift to the new higher-yielding varieties rather than as a result of intensified cultivation of the existing varieties.

The pattern of transition from the traditional varieties to the MVs varied significantly by crop. The adoption of the new varieties was very fast in wheat, while the adoption of MV rice was initially somewhat slow, as the new rice varieties could not be integrated easily into the existing cropping practices. Once suitable varieties were introduced, however, adoption of MV rice was rapid. In the case of maize, lack of disease- and drought-resistant varieties prevented the new varieties from assuming a significant share of area planted in corn.

The extremely rapid adoption of MV wheat—and also of MV rice, once the more suitable rice varieties were introduced—indicates that factors usually associated with the rate of implementation of new technologies, such as imperfect information, uncertainty, institutional constraints, and the availability of human capital, did not play a prominent role in the adoption process. That is, these factors could not have changed much over the extremely short transition period and therefore could not have influenced the rate of adoption. It appears that the dominance of the new varieties was well perceived by all. Alternatively, the speed at which the new varieties were adopted, particularly MV wheat, suggests that the pace of transition was largely determined by physical constraints such as, initially, the availability of seeds, and later on, the availability of irrigation facilities and fertilizers.

The introduction of the new varieties was associated with an expansion in (net) cultivated land, (net) irrigated area, and the intensity of cultivation and irrigation, as measured by the ratio of gross to net cultivated and irrigated areas. The increase in irrigated area came about mainly by a substantial expansion in the number of tubewells.

The expansion of agricultural production increased the demand for labor considerably. This increase in demand was met largely by migration of labor from other states and thus did not lead to a substantial increase in the wage rates of hired labor. On the other hand, the increases in hired labor and value of production per hectare raised the marginal productivity of the operators' own time, and this in turn led to an increase in mechanization.

The real harvest prices of wheat and rice trended downward, reflecting not only the trend in world prices but also the increase in domestic production. When a decline in prices is accompanied by an increase in production, often the conclusion drawn is that incentives, or more specifically, prices, play no role in the production decisions by farmers. However, this conclusion is based on association and not causality. To overcome it, average revenue per hectare for the various crop varieties is a better measure of incentives than price for each particular crop. This measure of incentives indicates a substantial advantage of the MVs over the traditional varieties and thus helps explain the rate at which these varieties were adopted.

The effects of the physical environment, the initial levels of infrastructure, and the availability of human capital on choice of technique and overall level of output can be detected by making cross-district comparisons. Such comparisons provide an additional dimension to the time series variations and thus are used in the subsequent empirical analysis.

4

THE CONCEPTUAL FRAMEWORK

The main event in Punjab during the period under consideration is the introduction of the MVs of wheat, rice, and maize. An analysis of this period must explicitly take into account the effect of the change in technology on product supply and input demand. Such an approach, outlined in Mundlak (1987, 1988), is followed here.

Output is determined by inputs and technology. Given the available technology, the selected level of variable inputs depends on product and factor prices and constraints. Included among the constraints are quasi-fixed inputs, or inputs that cannot vary immediately, regardless of the reason, in response to price variations.

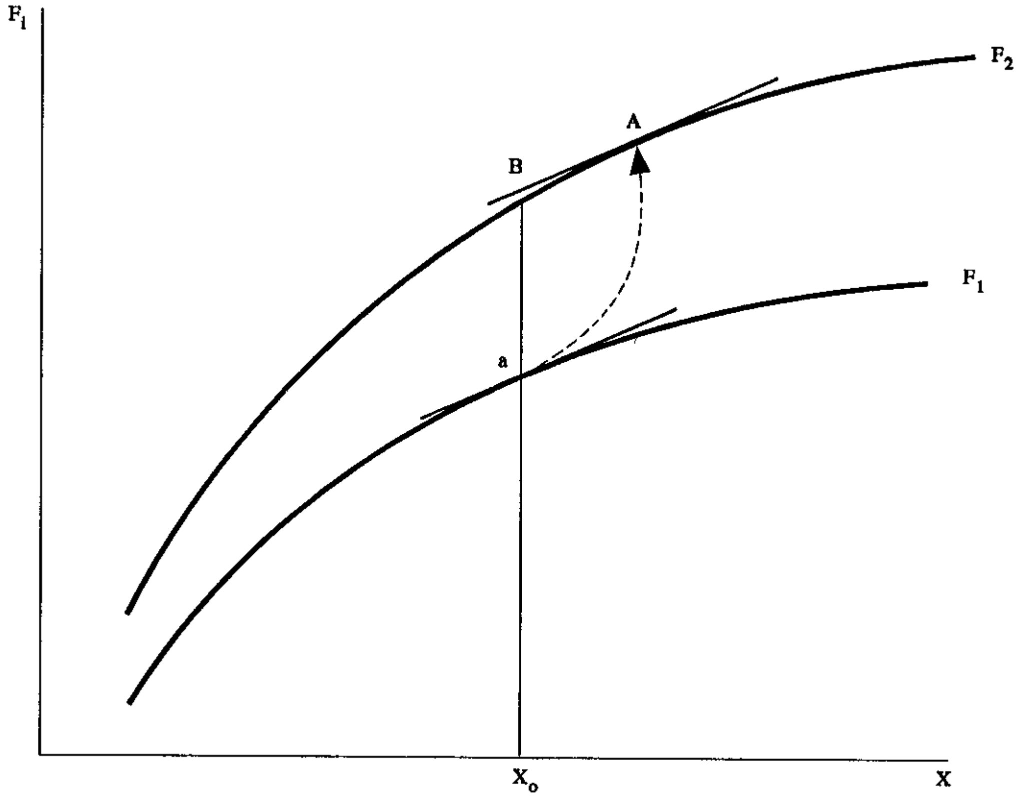
Technology is viewed as a collection of techniques, each technique being represented by a production function. The available technology set contains all the techniques that potentially can be used, whereas the implemented technology set contains those techniques that actually are implemented. Data on inputs and output describe only the implemented technology. Thus the distinction between available and implemented technology has important implications for empirical analyses. To illustrate, Figure 31 presents two production functions, F_1 and F_2, where the output of a given product is drawn as a function of a single input. All other inputs are assumed to be constant. The tangent lines represent a given market price. If the available technology consists of the two techniques, F_1 and F_2, and there are no other constraints to production, F_2 will be implemented as it dominates F_1. Consequently, data on inputs and output will describe F_2 only.

To examine cases where the data consist of observations describing more than one technique, suppose that a set of time series data that can be divided into two subperiods is obtained. In the first subperiod the technology consists only of F_1, and thus, given the market price illustrated, the observations will be clustered around point a. Now suppose that F_2 is introduced in the second subperiod and that producers move to employ the advanced technique generating observations clustered around point A. A sample consisting of the two clusters around a and A will not give an empirical production function that is identical with either one of the functions. The marginal productivity of the input will be exaggerated, and it is quite possible that the function will appear to be convex, rather than concave, in the input.

This presentation is so elementary that there can be no dispute that an explicit recognition of the relevant technology should be part of the analysis. In principle, this could be done by analyzing the data of the two subperiods separately. However, the implementation is not that simple when there is a period where the two techniques coexist. Ignoring the period of coexistence results in a loss of valuable information. Specifically, the important determinants of the speed of transformation to different techniques cannot be determined.

The transition to a new technique of production may be gradual for a variety of reasons: costs of adjustment, constraints to complete adoption, uncertainty about

Figure 31—Domination of old technique by new technique



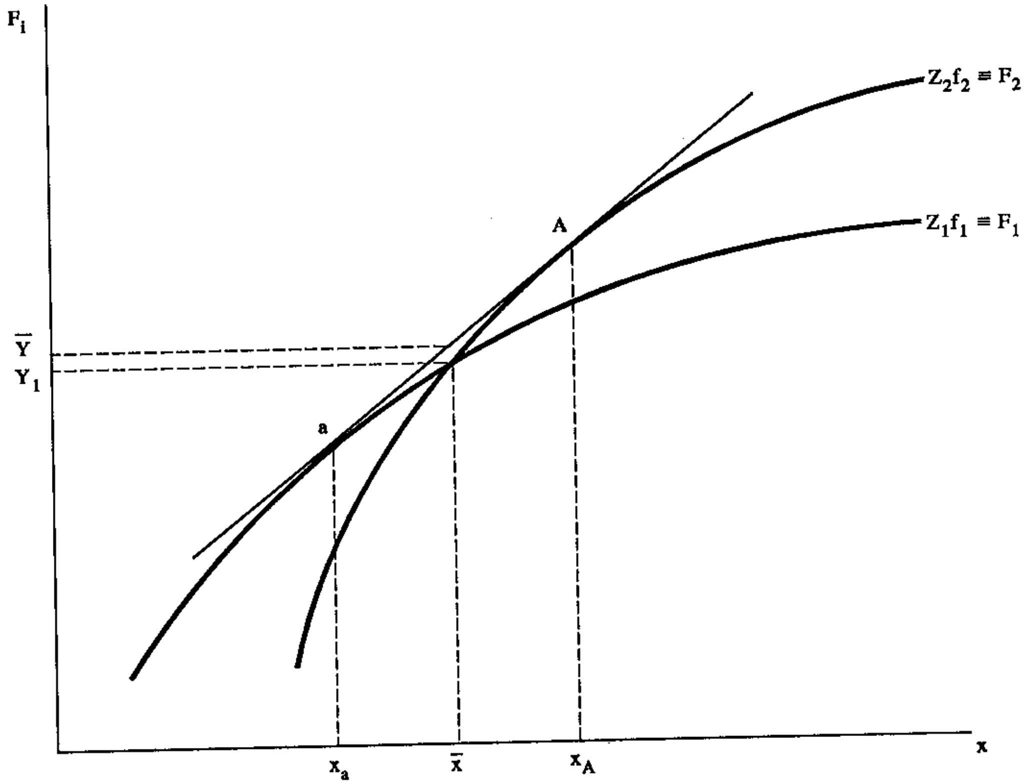
the new technique, and insufficient information. For an illustration, see Figure 31 and suppose that initially the level of input is X_o, and that this level cannot be changed in the short run. The movement to F_2 results in observations clustered around point B. The convergence to B may be gradual or incomplete for any of the reasons described. During the period of adjustment, observations will be scattered along the line segment aB. The average output per unit of X will trend upward as the share of F_2 in total output increases. The only way to explain this change of output is to relate it to the extent to which the advanced technique has been implemented. Therefore, to explain the rise in output, it is necessary to explain the pace of transition to the advanced technique.

Another possible scenario following the introduction of F_2 is that larger quantities of X become available as producers shift to the advanced technique. In this case, it is possible to obtain a path of convergence such as that observed in Figure 31 joining points a and A. Under this scenario, the average output per unit of X will be a function of X and the share of F_2 in total output. Again, an explanation of the rise in output requires an explanation of the pace of adjustment toward the new technique.

This study focuses on the extreme importance of resource scarcity in determining the transition process. The transformation to new techniques usually requires resources, and as a consequence the new more productive technique that dominates the traditional technique does not fully replace it immediately; the two techniques may coexist for a long time. For an illustration, see Figure 32, where the new technique (F_2) dominates the old technique (F_1) only for certain levels of inputs. Assume that the two techniques are represented by linear homogeneous production functions in land (Z) and an aggregate input (X). Let Y_i, X_i, and Z_i denote the output of, and quantities of, X and Z used by technique i, respectively. Then write $Y_i = Z_i f_i(x_i)$, where $x_i = X_i/Z_i$.

The implementation of the techniques will now depend on x, which represents the availability of X relative to Z. Obviously, when $x \leq x_a$, only F_1 will be employed, whereas when $x \geq x_A$, only F_2 will be employed. However, when $x_a \leq x \leq x_A$, the two techniques coexist. Given the linear homogeneity assumption for F_1 and F_2, it can be shown that the relevant production function for $x_a \leq x \leq x_A$ is $f(x) = \lambda f_1(x_1) + (1-\lambda) f_2(x_2)$, where $\lambda = Z_1/Z$, and $Z_1+Z_2 = Z$ (see Danin and Mundlak 1979 and Mundlak 1988). That is, the introduction of F_2 facilitates the coexistence of the two techniques when the aggregate input to land ratio lies within the interval (x_a, x_A). For instance, if x is fixed at $\bar{x}$, output can increase from Y_1 to $\bar{Y}$ by shifting some resources from the traditional technique, F_1, to the advanced technique, F_2.

Figure 32—Coexistence of old and new techniques



Given the discussion above, it is clear that the shape of the empirical production function fitted to data will depend on the distributions of prices and resource constraints prior to, and after, the introduction of the new technique. Given this framework, it is easy to illustrate how an empirical production function that does not explicitly recognize the existence of the different techniques will provide a distorted view of the underlying technology. Thus it is important to identify the underlying technology and constraints in order to obtain a useful empirical description of the production process. Failure to do so may distort considerably the view of the growth process and give results that do not make economic sense, including the wrong concavity of production or profit functions, as is often the case in empirical studies.

The Optimization Framework

The underlying optimization problem calls for a choice of inputs v_j,b_j that maximize the lagrangian function L:[15]

$$L = \Sigma_j p_j F_j\,(v_j,b_j,E) - \Sigma_j w v_j + \lambda\,(b - \Sigma_j b_j), \tag{1}$$

so that $F_j(\cdot)\ \varepsilon T$,

where

- T = the set of all available techniques, or simply, available technology;
- p_j = the price of the product of technique j;
- w = the vector of prices of the variable factors (v_j);
- b = the value of the constraint for the fixed factors of production that are allocated to the various techniques (b_j);
- E = the relevant characteristics of the environment in which technique j is implemented; and
- λ = a vector of shadow prices for the constraints.

The Kuhn-Tucker necessary conditions for a solution are

$$L_{v_j} = p_j F_{v_j} - w \leq 0, \tag{2}$$

$$L_{b_j} = p_j F_{b_j} - \lambda \leq 0, \tag{3}$$

$$\Sigma\,(L_{v_j} v_j + L_{b_j} b_j) = 0, \tag{4}$$

$$v_j \geq 0,\ b_j \geq 0, \tag{5}$$

[15]This optimization is made conditional on prices and does not deal specifically with the allocation of the quasi-fixed factors among farms. However, the solution at the aggregate level is equal to that achieved by a competitive system.

$$L_\lambda = \Sigma b_j - b \leq 0, \tag{6}$$

$$\lambda L_\lambda = 0, \tag{7}$$

where L_{v_j}, F_{v_j}, F_{b_j}, L_{b_j}, and L_λ are vectors of the first partial derivatives. The solution can be described as

$$v_j^*(s), b_j^*(s), \lambda_j^*(s),$$

where s represents the exogenous variables of this problem, which will be referred to as the state variables (s):

$$s = (b,p,w,E,T). \tag{8}$$

The solution to the maximization problem thus depends on the available technology (T), the environment (E), the constraints (b), and the product and variable input prices. It is important to note that the solution determines both the techniques used and the level of their use, as determined by the optimal allocation of fixed inputs (b_j^*) and variable inputs (v_j^*). This can be seen by rearranging equations (2), (3), and (4):

$$\Sigma_j (p_j F_{v_j} - w_j)v_j + \Sigma_j (p_j F_{b_j} - \lambda) b_j = 0. \tag{9}$$

If equation (2) or equation (3) is negative, then $v_j^* = 0$ or $b_j^* = 0$, respectively.

The optimal output of technique j is $y_j^* = F_j(v_j^*, b_j^*, E)$. The implemented technology (IT), the collection of all implemented techniques, is a subset of T. As such, the envelope of IT is in general not the same as the envelope of T. The difference, of course, is due to the constraints encountered by the decisionmaker.

The implemented technology, IT, can be described formally by

$$IT(b,p,w,E,T) = \{F_j(v_j,b_j,E) \mid [F_j(v_j^*,b_j^*,E) > 0], F_j \varepsilon T\}. \tag{10}$$

The number of implemented techniques depends on the number of constraints or the dimensionality of b. In this general formulation, no limit is set on the number of state variables except that it is finite. Thus it is possible to apply the formulation to a variety of applications.

Given the usual regularity conditions for F_j and given a particular set of state variables, equation (9) describes a well-behaved technology. Consequently, a profit function can be derived:

$$\pi(s) = \Sigma p_j F_j(v_j^*(s), b_j^*(s), E) - \Sigma w_j v_j^*(s). \tag{11}$$

The various theorems dealing with the duality between the profit function and the production function hold true conditional on s. Specifically, the frontier of IT(s) is dual to $\pi(s)$ and vice versa.[16] Using Hotelling's lemma, the factor demand is

[16]It is important to note that the exploitation of this property in empirical analysis is restricted because s varies over the sample. Thus, strictly speaking, each point in the sample comes from a different profit function, which in turn describes a different set of implemented technology.

$$-\frac{\partial\pi(s)}{\partial w} = v^*(s). \tag{12}$$

Note that (12) expresses the input demand aggregated over techniques.

Similarly, the supply of output of technique j is given by

$$y_j^*(s) = \frac{\partial\pi(s)}{\partial p_j}. \tag{13}$$

If there is more than one technique producing a given crop, then

$$\frac{\partial\pi(s)}{\partial p_i} = \Sigma_j y_{ji}^* = y_i^*, \tag{14}$$

where y_{ji}^* is the j^{th} technique used to produce the i^{th} crop and y_i^* is the total output of crop i. Finally, the aggregate value of supply is given by

$$y^*(s) = \Sigma p_i y_i^*(s). \tag{15}$$

It is important to note that, within this framework, a change in a state variable generates two effects on the optimal variable inputs and outputs. First, a change in a state variable may lead to variations in the optimal combinations of inputs and outputs along a given production function. This intratechnique effect is the effect usually considered in supply analyses. The second effect due to a change in a state variable describes the change in the optimal composition of techniques. It is referred to here as the intertechnique effect. The impact of these two effects on the relationship between changes in state variables and output by crop may be very different. Thus, a distinction between these two effects and an understanding of the relative importance of these effects is necessary to fully understand growth in output for crops that can be produced by more than one technique.

Optimization by Stages: Area and Yield

In general, production is not instantaneous, so input usage decisions can be revised as the information set changes. In terms of crop production, farmers decide how to allocate their area among the different crops and techniques given their information set at the time of planting (Mundlak 1963; Antle 1983). Once the crop has been planted, farmers can change output only by influencing yield. The extent to which yield, and thus output, can be altered later in the production process can only be determined empirically.

In terms of the crop production decisions, it is assumed that at stage 1 the optimization described by equation (1) is used to determine the initial allocations of land and other fixed inputs to the various techniques. Stage 2 of the decision problem can be formulated similarly except that this decision is made conditional on the optimal area allocations chosen in stage 1. That is, the optimal area allocations are included among the relevant state variables in the stage 2 decisions. To be more explicit, the vector of the state variables for stage 1 of the optimization problem is

$$s^1 = (b^1, p^1, w^1, E, T), \tag{16}$$

where b^1, p^1, and w^1 represent the constraints and the expected product and input prices at planting time, respectively. The state variables for the stage 2 optimization problem are

$$s^2 = (b^2, p^2, w^2, E, T), \quad (17)$$

where b^2 differs from b^1 in that it contains, among the other constraints, the area allocated to each crop and technique in stage 1 rather than the total area available, that is, b^2 contains $A_j = A_j(s^1)$. Further, p^2 and w^2 are producers' updated expected product and input prices. Consequently, the optimal inputs of stage 2 are functions of s^2 and s^1, and the optimal output can be written as

$$Q_j^* = F_j(A_j(s^1), v_j(s^1,s^2), b_j(s^1,s^2)). \quad (18)$$

Note that, within this framework, area is introduced explicitly as an input into the production function. Further, the other inputs are taken as the sum of their usage in the two stages, as input data are not detailed by stages.

Assuming that the production function is constant returns to scale in the inputs, equation (18) can be rewritten as a product of area and yield:

$$Q_j = A_j(s^1) Y_j(s^1,s^2). \quad (19)$$

The two components of equation (19), yield and area, can be estimated separately.

Quasi-Fixed Inputs

The decisions by producers to alter the availability of quasi-fixed inputs take into account the anticipated effect of changes in these inputs on costs and revenues over the lifetime of the investment.[17] The effect of these decisions on future streams of income distinguishes these longer-run decisions from the short-run decisions previously analyzed. It is this difference that allows the formulation of the decision process as a recursive problem that can be estimated in stages (Mundlak 1967). Such formulations of the investment decision are now common in the estimation of dynamic factor demand equations (compare Berndt and Field 1981).

To illustrate the recursive approach, consider a simple intertemporal optimization problem. Suppose there is only one output production function, $Q = F(v,K,T)$, where v is the variable input, K is capital, the quasi-fixed input, and T is technology. The supply price of K is q and it is assumed to be a function of the rate of investment and time, $q(I,t)$. All other variables (Q, K, and v) are functions of time. The net cash flow (R) of a competitive firm is

$$R(t) = p(t)\,F(K(t),v(t),T) - w(t)v(t) - q(t)[\dot{K}(t) + \delta K(t) + c(\dot{K})], \quad (20)$$

where $q(t)c(K)$ represents an internal cost of adjusting capital, $p(t)$ and $w(t)$ are the product and input prices, respectively, and δ is the rate of depreciation of $K(t)$. The

[17]This section is based on Mundlak 1987b.

nonstochastic formulation of the problem calls for selecting a time path of inputs that maximize the present value of the stream of R(t):

$$\text{Maximize} \int_0^{\infty} e^{-rt} R(t)\, dt, \tag{21}$$

subject to

$$K(0) = K_0, \text{ where } K_0 \text{ is given,}$$
$$I(t) = \dot{K}(t) + \delta K(t), \text{ and}$$
$$\lim_{t \to \infty} [e^{-rt} R(t)] = 0.$$

Given an interior solution, the first-order condition for the vector of variable inputs requires

$$\frac{\partial R(t)}{\partial v(t)} = 0, \quad \frac{\partial F(\cdot)}{\partial v(t)} = \frac{w(t)}{p(t)}, \tag{22}$$

and the Euler equation is

$$\frac{\partial R(t)}{\partial K(t)} - \frac{d}{dt}\left(\frac{\partial R(t)}{\partial \dot{K}(t)}\right) = 0. \tag{23}$$

Equation (22) implies that, along the optimal path, the quantity of input employed at time t has no effect on revenues in subsequent periods and that the optimal levels of this input are determined by equating the input's marginal product to its real price in each period. Consequently, the optimization can be solved in steps. The first step is to determine the optimal level of v(t), as a function of both prices and K(t), for each period. The solution from this optimization problem is substituted into equation (20) to obtain a restricted profit function:

$$\pi(K(t), v^*(t), s(t), T),$$

where s is a vector of state variables that, in this case, contains only w and p. Note that although not explicitly indicated here, v^* is also a function of K(t), T, and s(t).

Given this restricted profit function, the second stage in the optimization problem is to maximize

$$\int_0^{\infty} e^{-rt} \{\pi(K(t), v^*(t), s(t), T) - q(t)[\dot{K}(t) + \delta K(t) + c(\dot{K})]\}\, dt, \tag{24}$$

subject to the constraints of equation (21). Suppressing the dependence of the relevant functions on s and the time index, the Euler equation for this problem is

$$\frac{\partial \pi}{\partial K} - q(\delta + r - \hat{q}) - q(\hat{q} - r)c'(\dot{K}) + qc''(\dot{K})\ddot{K} = 0, \tag{25}$$

where $\hat{q} = \dot{q}/q$, $\ddot{K}$ is the first derivative of $\dot{K}$ with respect to time, and c' is the first derivative of c. In the absence of internal costs of adjustment, that is, $c(\dot{K}) = 0$, the optimal time path of K(t), say $K^*(t)$, is obtained by solving

$$\frac{\partial \pi}{\partial K} - q(\delta + r - \hat{q}) = 0, \tag{26}$$

which states that, at its optimal level, the value marginal productivity of capital is equal to the user cost, allowing for price appreciation. Since K^* is a function of the prices that enter the restricted profit function, a change in prices requires an adjustment in $K^*(t)$. This formulation assumes that the adjustment in capital can be performed in one step. As it is believed that firms do not adjust their capital stock instantaneously, the concept of cost of adjustment is introduced to account for the gradual adjustment from an arbitrary K(t) to the optimal level $K^*(t)$ (Gould 1968; Lucas 1967; Treadway 1969).

When dealing with the agricultural sector as a whole, and with a place such as Punjab, where agriculture constitutes an important sector of the economy, the relevant costs of adjustment are external to the sector rather than internal, as in the case of a single firm. In the case of Punjab, external costs of adjustment arise as the supply function for resources going into agriculture is upward sloping. That is, for agriculture to increase its share of total resources, it has to pay increasing prices. It is for this reason that the expected rates of return on capital in agriculture and in its alternative uses (nonagricultural) are considered important determinants of agriculture's share of total investment. This is reinforced when the farmers themselves face an upward-sloping supply function of capital.

The present analysis can be extended to accommodate the choice-of-technique framework by simply using equation (11) as the expression for π in equation (24). In terms of the current problem, however, the first stage in the decision process, which is conditional on a given time path for the quasi-fixed inputs, for example, K(t), is decomposed into two separate components—the area allocation decision and the determination of yields (see the discussion above). Thus the determination of the optimal path for the quasi-fixed inputs is the third and final stage in the optimization problem.

Empirical Specification

Based on the foregoing discussion of the conceptual framework, the empirical model constitutes three blocks of equations. The first block consists of equations describing the allocation of area to the various techniques of production, by season. Rather than explaining the allocation of net cropped area to the various possible techniques of production, the area allocation equations describe the allocation of net irrigated (dry) cropped area among the different possible irrigated (dry) crop varieties, for each season. Thus, the first block of equations can be summarized schematically as follows:

$$A_j/I = \alpha_0 + (\text{Incentives})\,\alpha_1 + (\text{Constraints})\alpha_2 + (\text{Environment})\alpha_3 + u\text{, and} \tag{27}$$

$$A_j/D = \alpha_0' + (\text{Incentives})\alpha_1' + (\text{Constraints})\alpha_2' + (\text{Environment})\alpha_3' + u', \tag{28}$$

where A_j/I (A_j/D) is the share of net irrigated (dry) area allocated to technique j. As illustrated, the allocation decisions are determined by three sets of variables: incentives, constraints, and environment. The α's are coefficients to be estimated, and u and u′ are random disturbance terms.[18] Note that in this specification the composition of techniques is endogenous and assumed to depend on, among other factors, the availability of resources and not vice versa as many other studies have assumed (for example, see Desai 1982, 31).

The second block of the model consists of a set of yield equations. The data include yields only by crop and not by technique, and thus constitute aggregates over techniques in the sense discussed above. Therefore, they depend on the implemented technology. Schematically, these equations can be expressed as follows:

$$Y_i = \beta_0 + (\text{Incentives})\beta_1 + (\text{Technology})\beta_2 + (\text{Fertilizer})\beta_3 + (\text{Environment})\beta_4 + u. \qquad (29)$$

The third and final block of equations describes the changes in the quasi-fixed inputs over time. They are described as follows:

$$K(t) = \tau_0 + (\text{Incentives})\,\tau_1 + (\text{Constraints})\tau_2 + (\text{Environment})\tau_3 + K(t-1)\tau_4 + u. \qquad (30)$$

The specific variables included in each block of equations and the results from estimation are described in Chapters 5 and 6. Although the blocks of equations are discussed separately throughout, all three blocks of equations are estimated simultaneously as a system. Given the outline of the model just presented, the three blocks of equations described form a block recursive system. As will become clearer following the more detailed discussions of the variables entering the different blocks of equations (in Chapters 5 and 6), the levels of quasi-fixed inputs (block 3) are determined solely by lagged endogenous and exogenous variables. The level of quasi-fixed inputs then enters the area allocation equations along with other predetermined variables. Finally, the area allocated to the various techniques, the level of quasi-fixed inputs, and other predetermined variables enter the yield determination equations. Given the recursive nature of this system, the system is estimated using the iterative Zellner efficient method. The omission of an equation explaining the "other crops" planted on irrigated and dry lands in both the *kharif* and *rabi* seasons eliminates the problem of the sets of area-share equations having a singular variance-covariance matrix (see the Cropping Alternatives subsection in Chapter 5). Symmetry conditions are imposed on the revenue variables within each set of area shares. Although the predicted shares from this system will not always be in the relevant range (0,1), as they would if a multinomial logit-type model were specified, the approach utilized allows us to impose symmetry restrictions on the parameters at every point in the sample. This additional information can be important in a data set plagued by multicollinearity.

[18] A more detailed discussion of the specific formulation is left for Chapter 5.

5

ESTIMATES OF THE SHORT-RUN YIELD AND AREA RESPONSES

The outline of both the yield and area relations presented in Chapter 4 is followed now by the empirical analysis. The data and variables used in the analysis and the results are discussed. The conceptual framework calls for a somewhat detailed analysis. In the case of Punjab, there are not only multiple techniques of production for each crop, but also two growing seasons and a sizable set of exogenous variables. The detailed structure of the model is unavoidable if the role of the various variables is to be revealed empirically. In addition, an understanding of the disaggregated level of results is more difficult than usual (yet rewarding) due to the possibility of variables exhibiting direct as well as indirect effects on the decisions examined. To facilitate the reading of this chapter, the results of the various stages in the decision process are summarized at the end of the appropriate sections.

Model Specification

The data base used in this study consists of yearly aggregate district-level data covering the period 1960-79. Although the data encompass the performance of 10 out of the 12 districts of present-day Punjab, the number of cross-sectional units is 9.[19] Thus the data set consists of 180 observations (India, various years a, b, c, d; Punjab, various years d).

Area Allocation Equations

As noted in Chapter 4, the area allocation equations describe the allocation of net irrigated (dry) cropped area among the different possible irrigated (dry) crop varieties for each season. Further, the determinants of the allocation decisions are classified into three sets of influences: incentives, constraints, and environment. Following a delineation of the cropping alternatives incorporated in this study, the

[19]A full data series is unavailable for Rupnagar for the sample period, thus this district is not included in the analysis. Changes in district boundaries during the sample period require that data describing the performance of Faridkot be incorporated into the data from Ferozepore and Bhatinda districts. Although data from Hoshiarpur are available, unresolvable inconsistencies in the values of some of the variables led to the deletion of this district from the analysis. Thus the total number of regional units included in the analysis is 9, summarizing the performance of 10 districts.

specific variables that capture the effect of the incentives, constraints, and environment on the area allocation decisions are described.

Cropping Alternatives. As suggested in Chapter 3, the agricultural economy of Punjab is diverse. Cropping activities still dominate the sector. The five major crops—wheat, rice, cotton (American and Desi varieties), maize, and gram—that account for 67 to 80 percent of the gross cropped area over the sample period are incorporated in this study. The various combinations of cropping activities by technique are summarized in Table 5. The "other" activities include fallow land as well as land sown to all other minor crops. The original data base delimits the area planted to dry and irrigated varieties for gram, cotton, and maize. No distinction is made between the two types of cotton, as data on the extent to which cotton is irrigated are not disaggregated by variety.

It is assumed that there are three techniques of production for wheat and rice, an irrigated MV and two traditional varieties (irrigated and dry). Information is available only on the area planted to MVs and on the total area of each crop irrigated. To disaggregate the crops by technique, it is assumed that all MVs in Punjab are irrigated (see Appendix 2 for a detailed description of the disaggregation process).

Although information regarding adoption of improved varieties for maize is available, the production of maize is only disaggregated into irrigated and dry techniques because the extent to which these improved varieties have been accepted has been relatively minor and has fluctuated considerably over time (see Chapter 3). A large part of this varied success is explained by the unreliable yields of the newer varieties and the problems some of these varieties have experienced with disease and drought. Because the data required to study the impact of these problems on the rate of adoption of the new varieties are not available in the data base, the distinction between irrigated high-yielding varieties and irrigated traditional varieties is not made.

Table 5—Cropping alternatives in the rabi and kharif seasons

Season	Techniques	
	Irrigated	Dry
Rabi	Modern-variety wheat	Wheat
	Traditional wheat	Gram
	Gram	Other
	Other	
Kharif	Modern-variety rice	Rice
	Traditional rice	Maize
	Irrigated maize[a]	Cotton
	Cotton (American and Desi)	Other
	Other	

[a] The irrigated maize category includes both improved and traditional varieties.

Incentives. As in the discussion in Chapter 4, the incentive measures include product and factor prices. Under uncertainty, prices are replaced by expected prices. In the spirit of the framework outlined in Chapter 4, area response to price, $\partial A_j/\partial p$, is viewed as a function of the state variables relevant to the stage 1 decision problem (s^1) rather than as a constant, as is usually assumed in supply response analyses. Making all such derivatives a function of all the state variables, however, introduces more interaction terms in the area equations than the data can sustain. Thus the analysis limits the dependence of $\partial A_j/\partial p$ on the state variables to a dependence on the implemented technology, the most critical variable in the study. To capture this effect, expected product prices appear as interaction terms with expected yield by variety. (The yields by variety are "expected" in the sense that the effect of random shocks, such as weather, on yield are ignored.) Thus the variables included to capture the relevant incentives for producers are expected average revenue per unit of land for each technique rather than the product price by itself.

The computation of revenue by techniques requires yields by techniques. The derivation of regional yields for the traditional varieties is described in Appendix 2. When overall crop yield, the yields of the traditional varieties, and area allocated to the different varieties are known, the yields of the MVs can be obtained as a residual. The results obtained by following this procedure show no upward trend in modern wheat yields. This finding is inconsistent with the widely held view that there was a continuous improvement in the MVs. This inconsistency can be attributed to the method of deriving the MV yields. To overcome this problem, a (lagged) three-year average of overall crop yield was used as an indirect measure. (By averaging the yields over the past three years, the effects of random disturbances such as weather are reduced. As noted above, it is in this sense that the term "expected" is used.)

To see the implication of using this overall crop yield variable, write a general expression for the share of area allocated to the MVs, $S_H(p\bar{y}, py_T, x)$, where p is the price of the crop, regardless of variety, $\bar{y}$ is a weighted average yield of the modern (H) and traditional (T) varieties, $\bar{y} = \lambda y_H + (1-\lambda)y_T$, and x represents all other variables in the share equation. The response to price is obtained by differentiating S_H with respect to p. Let S_1 and $-S_2$ be the partial derivatives of S_H with respect to the first two arguments (both derivatives are positive), and write $\partial S_H/\partial p = S_1\bar{y} - S_2y_T = \lambda S_1(y_H-y_T) + y_T(S_1-S_2)$. The result shows that the price effect on the area allocation decision depends on the difference in yields between the traditional varieties and MVs and on the degree of implementation as given by λ. The maximum impact of a change in price is achieved when the transition is completed, that is, when $\lambda = 1$.

Similarly, the effect of a change in the MV yield on its share in total area is given by $\partial S_H/\partial y_H = pS_1\partial\bar{y}/\partial y_H = pS_1\lambda$. This derivative obtains its maximum value at $\lambda = 1$, in which case it is equal to $\partial S_H/\partial\bar{y}$, which in turn is equal to the coefficient of the average yield term in the share equation. Hence, in the empirical analysis, the derivative of the MV share with respect to the average yield can be interpreted as the full impact of a change in y_H on the area allocation. This explains why in the subsequent discussion $p\bar{y}$ is labeled conveniently as "average revenue of the MV."

The prices used to form the expected revenue variables are product prices deflated by wage, all lagged one year.[20] The revenue variables are deflated by wage to ensure that the area share equations are homogeneous of degree zero in all prices. In this study, the representation of incentives by average revenue is essential in order to explain the choice between different techniques that produce the same crop and consequently receive the same output price. The use of average revenue rather than price as a measure of incentives is not new in area supply response studies. In fact, Mundlak and McCorkle (1956) show that average revenue is not always superior to price in terms of explaining the data. Thus the performance of the average revenue variables should be judged separately from the framework within which it is applied.

Constraints. The term constraint is used here to represent the quasi-fixed inputs, both private and public, that affect the implementation of technology. The decisions on area allocation are made conditional on the available land and irrigation facilities. Data on irrigation facilities at the district level are incomplete; therefore, net irrigated area is used as a measure of the irrigation capacity available in the short run. Others have made similar assumptions in empirical studies of this region (see, for example, Schwarz 1986 and Evenson 1983). However, an important difference between the assumptions of these empirical studies and the present study exists. Each of these studies uses gross cropped area and gross irrigated area as the relevant land and irrigation constraints, respectively. Their implicit assumption is that the intensity with which the land (irrigated and dry) is cropped is exogenous. This assumption is unrealistic, and therefore this study measures the relevant land and irrigation constraints by net cropped area and net irrigated area available, respectively. Thus the intensity with which the land is cropped is determined endogenously. Further, a distinction is made between land irrigated by private sources (wells and tanks) versus government sources (canals). The reason for this distinction is twofold. First, as indicated in Chapter 3, the literature suggests that tubewell irrigation is more suitable for MVs. Second, and more important, the distinction is essential for the subsequent analysis of the response of the quasi-fixed inputs to changes in prices and technology; the private and government sectors have different rules determining their investment behavior. The net area irrigated by government and that irrigated by private sources are both included in the area equations as a proportion of net cropped area.

The MVs require considerably more fertilizer per unit of land than the traditional varieties. Consequently, their introduction caused a dramatic increase in the demand for fertilizers. Desai (1986) reports that the all-India consumption of fertilizer nutrient increased from 339,000 metric tons in 1961/62 to 1.1 million tons in 1966/67 and to 8.2 million tons in 1984/85.[21] Meeting this augmented demand required considerable resources. Initially the demand was met by imports, which

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[20]Alternative specifications of price expectations were formulated. Results were robust to the different formulations, and thus the simplest specification (one-year lag) was maintained. The wage series (India, various years a) is the average wage (by district) for all field operations (plowing, seeding, and harvesting).

[21]All tons referred to in this study are metric tons.

were 389,000 tons in 1961/62 and then increased to 898,000 tons in 1966/67 and to 3.6 million tons in 1984/85. This shows that domestic production had to increase from meager quantities to a level of about 5.0 million tons. Such a growth of supply was gradual because of its heavy resource requirement. This in turn constrained the implementation of the MVs.

At the time of planting, farmers cannot know with certainty the quantities of fertilizer that will be available to them and therefore must base their planting decisions on expectations. The expected supply of fertilizers is measured by the supply available (used) last year (measured in terms of total nutrient content per net cropped area). As the data used are district level, the distribution of the overall supply to the districts may reflect demand pressures. Obviously, lagged supply values are independent of contemporaneous shocks in demand. No attempt was made to construct a more elaborate specification of expectations of fertilizer availability, as a strong response to increases in supply of fertilizers is captured well by the present procedure.

The availability of physical infrastructure, represented here by the availability of roads, has a potential influence on the area allocation decisions. Specifically, the availability of roads affects the degree to which the rural areas are integrated within the market. As annual district-level data are not available on other components of infrastructure, they are not included in the analysis. To the extent that these omitted variables are correlated with roads, they are partially represented by the road variable (kilometers of road per 1,000 hectares).

Environment. Environmental factors that affect the allocation decisions include the local agronomic and climatic conditions in the particular districts. These variables are difficult to quantify; therefore, fixed district effects are introduced. One environmental variable that is easy to quantify and on which data are available is rainfall. Thus, rainfall variables are incorporated to capture the importance of preplanting rain on the area allocation decisions. (For a discussion of the importance of rain in the decisions of the producers in Punjab see Herdt 1972.) Because the district effects will pick up the differences in mean rainfall across districts, the rainfall variables will capture the importance of the transitory, or random intraregional, intertemporal, component.

In addition to the fixed district effects, a pre-green revolution intercept shifter is included to allow the optimal mean shares of area allocated to the different varieties to change following the introduction of the MVs.

Yield Equations

Because yields are available only by crop and not by variety (technique), the dependent variables in the yield equations are overall yield by crop. Thus the overall crop yield depends on (among other factors) the composition of techniques chosen to produce each particular crop. The composition itself is endogenous within the system, but it is independent of the outcome of the current yields, so it is predetermined and not correlated with the disturbances of the yield equations. The relevant technology variables for wheat and rice include the proportion of wheat and rice area planted to MVs. The proportions of wheat and rice area sown with the irrigated traditional varieties are not included, as these variables are highly (negatively) correlated with the MV variables. For gram, maize, and cotton, the composition of implemented techniques is captured by the inclusion of the proportion of each particular crop area that is irrigated. Because overall cotton yield also depends on the allocation of total cotton area planted to the American and Desi varieties, the proportion of cotton area planted to American cotton—the more productive of the two varieties—is also included.

The constraint included in the yield equations is the amount of fertilizer available per cropped hectare. As there was excess demand for fertilizers, it is assumed that the quantity used was equal to the supply. Unlike the planting decisions that have to be made conditional on expectations, yields are affected by the actual quantities applied. Consequently, current values of fertilizers per net cropped area are used in the yield equations. The influences of the environment are captured by allowing for fixed district effects and by including a set of variables that measure the amount of rainfall during the critical months of the growing period for each of the crops.[22] Interaction terms are introduced to allow the yield response to rainfall and fertilizer to vary with the implemented technology. Initially, expected prices were included in the yield equations, but their direct effect on yields was not empirically significant. The issue of the insignificant direct effect of prices on yield versus their indirect effect on yield is discussed below.

The Area Allocation Decisions

Results: Area Allocation Equations

The variables used in the area share equations appear in Table 6 and the results are given in Tables 7-9. The results are examined by season. It is important to note that all the results from the area share equations describe the response of technique composition to changes in incentives and constraints (intertechnique effect). Thus the substitutability and complementarity found between techniques reflect all of these factors and not simply agrotechnical considerations. Highlighting the consistent structure underlying the results causes the discussion to become somewhat detailed.[23] The reader who is not interested in the details can proceed to the summary sections below.

Initially, low Durbin-Watson statistics in the *kharif* irrigated and dry share equations indicated that positive first-order autocorrelation was a problem.[24] To correct for the problem, each equation of the *kharif* area model was estimated by ordinary least squares. Following Parks (1967), the residuals from each of these equations were used to derive estimates of the first-order autocorrelation coefficient for each district. Data for each of these equations were then transformed as follows:

$$Y^*_{it} = Y_{it} - \rho_i Y_{it-1} \text{ and } X^*_{it} = X_{it} - \rho_i X_{it-1},$$

[22]For a description of the specific rainfall variables, see Table 15.

[23]To keep the length of the discussion manageable, the results for the "other" shares deleted for estimation purposes are not presented or discussed.

[24]Although not directly interpretable for cross-section times-series models such as this, the particularly low Durbin-Watson statistics (less than one) indicated an autocorrelation problem.

Table 6—Definition of variables: area equations

Variable	Definition	Equation(s)
Expected revenues[a]		
MV RICE	Modern-variety rice	Irrigated *kharif* shares
IRRIGATED RICE	Irrigated traditional rice	Irrigated *kharif* shares
IRRIGATED MAIZE	Irrigated maize	Irrigated *kharif* shares
IRRIGATED COTTON	Irrigated cotton	Irrigated *kharif* shares
DRY RICE	Dry traditional rice	Dry *kharif* shares
DRY MAIZE	Dry traditional maize	Dry *kharif* shares
DRY COTTON	Dry cotton	Dry *kharif* shares
MV WHEAT	Modern-variety wheat	Irrigated *rabi* shares
IRRIGATED WHEAT	Irrigated traditional wheat	Irrigated *rabi* shares
IRRIGATED GRAM	Irrigated gram	Irrigated *rabi* shares
DRY WHEAT	Dry traditional wheat	Dry *rabi* shares
DRY GRAM	Dry gram	Dry *rabi* shares
Constraints		
GOVERNMENT IRRIGATION	Net irrigated area, government canals[b]	All equations
PRIVATE IRRIGATION	Net irrigated area, private sources[b]	All equations
E FERTILIZER	Expectation of fertilizer available[c]	All equations
ROADS	Kilometers of road available per hectare	All equations
Environment		
JS	Preplanting rain (0.01 mm) June-September	All *rabi* equations
MAY	Preplanting rain (0.01 mm) May	Rice and maize equations
JUN	Preplanting rain (0.01 mm) June	Rice and maize equations
JF	Preplanting rain (0.01 mm) January-February	Cotton equations
DISTRICT	A dummy variable is introduced for each district[d]	All equations
PRE-INT	Intercept shifter: 1960-65	All equations

[a]All expected revenue variables (Rs/1,000 hectares) are deflated by wage (Rs/8-hour day).
[b]Both irrigation variables are deflated by net cropped area and thus measure the proportion of land irrigated by source.
[c]The expectation is captured by kilograms of fertilizer (nutrient) available per net cropped area (1,000 hectares) in the previous cropping year.
[d]The districts are listed in Tables 7, 8, and 9.

where ρ_i is the estimated first-order autocorrelation coefficient for district i, Y_{it} is the dependent variable for district i in time t, and X_{it} is the vector of independent variables for district i in time t. The transformed variables Y^*_{it} and X^*_{it} were then used in the *kharif* area share equations when the whole system was estimated.[25]

Rabi Season—Irrigated Area Shares. All coefficients on the own expected revenue variables are positive and significant.[26] The only significant competition for irrigated area, as indicated by a negative cross-revenue coefficient, is between MV and irrigated traditional wheat. Because the price of wheat is the same for the two varieties, the competition between these varieties reflects the differences in

[25]The first observation (t = 1960) for each cross-section was omitted from the full model because of these corrections in the *kharif* area share equations.

[26]The significance of the variables in each of these equations is judged by the size of the estimated coefficients relative to their standard errors. The discussion refers to coefficients with more than twice their standard errors as "significant."

Table 7— Estimates of irrigated and dry area allocation equations, rabi season

Explanatory Variable	Dependent Variable: Irrigated Shares: Modern-Variety Wheat	Irrigated Shares: Traditional Wheat	Irrigated Shares: Gram	Dry Shares: Wheat	Dry Shares: Gram
Expected revenues					
MV WHEAT	0.00123	-0.00089	-0.00005	...	...
	(6.15)	(-6.20)	(-1.12)		
IRRIGATED WHEAT	-0.00089	0.00041	-0.00008	...	...
	(-6.20)	(2.81)	(-1.59)		
IRRIGATED GRAM	-0.00005	-0.00008	0.00013	...	...
	(-1.12)	(-1.59)	(2.51)		
DRY WHEAT	...	...	...	-0.00077	0.00009
				(-3.04)	(0.53)
DRY GRAM	...	...	...	0.00009	-0.00084
				(0.53)	(-4.08)
Constraints					
PRIVATE IRRIGATION	0.74701	-0.73056	-0.25374	0.12686	-0.05379
	(6.24)	(-8.59)	(-9.51)	(1.68)	(-0.49)
GOVERNMENT IRRIGATION	0.23259	-0.17860	-0.10068	0.88662	0.02292
	(1.55)	(-1.63)	(-2.84)	(7.28)	(0.13)
E FERTILIZER	0.00125	-0.00090	0.00015	-0.00177	-0.00120
	(3.3)	(-3.08)	(-1.84)	(-4.57)	(-2.20)
ROADS	0.02376	-0.00590	0.00236	-0.00272	0.02521
	(2.35)	(-0.75)	(1.06)	(-0.33)	(2.15)
Environment					
JS	0.00123	-0.00095	0.0000003	0.000749	0.00067
	(3.16)	(-3.30)	(0.00)	(2.58)	(1.66)
GURDASPUR	-0.05227	-0.17313	-0.06371	0.32692	-0.08286
	(-1.04)	(-4.28)	(-5.40)	(10.67)	(-1.87)
AMRITSAR	-0.15295	-0.07346	0.01367	0.05845	-0.04848
	(-2.29)	(-1.43)	(0.87)	(0.77)	(-0.45)
KAPURTHALA	-0.27515	0.06405	0.02425	0.24449	-0.13994
	(-4.21)	(1.2)	(1.62)	(3.94)	(-1.59)
JULLUNDUR	-0.21511	0.13741	0.03074	0.15024	-0.05307
	(-5.19)	(4.04)	(3.26)	(4.35)	(-1.08)
FEROZEPORE	0.10528	-0.29953	-0.02341	-0.26142	0.0924
	(1.62)	(-5.9)	(-1.55)	(-4.81)	(1.20)
LUDHIANA	-0.14953	0.16194	0.03757	-0.01825	-0.07843
	(-3.71)	(4.96)	(4.09)	(-0.77)	(-2.34)
BHATINDA	0.09541	-0.32858	0.00056	-0.50382	0.30486
	(1.37)	(-6.04)	(0.03)	(-9.13)	(3.96)
SANGRUR	0.02996	-0.0954	0.03375	-0.28784	0.08314
	(0.71)	(-2.77)	(3.53)	(-8.14)	(1.77)
INTERCEPT	-0.22755	0.90415	0.18991	-0.00076	0.00009
	(-3.03)	(15.38)	(9.68)	(-3.04)	(0.53)
PRE-INT	...	0.82333	0.20667	...	...
		(14.91)	(10.84)		
R^2	0.949	0.8097	0.8811	0.9261	0.9351

Notes: The numbers in parentheses are t-statistics. See Table 6 for definitions of variables.

Table 8—Estimates of irrigated area allocation equations, kharif season

Explanatory Variable	Dependent Variable: Irrigated Shares			
	Modern-Variety Rice	Traditional Rice	Maize	Cotton
Expected revenues				
MV RICE	0.00020 (3.36)	-0.00012 (-2.80)	-0.00004 (-1.24)	0.00008 (3.35)
IRRIGATED RICE	-0.00012 (-2.80)	0.00011 (1.64)	0.00001 (0.2)	-0.00002 (-0.89)
IRRIGATED MAIZE	-0.00004 (-1.24)	0.00001 (0.2)	0.00015 (3.7)	-0.00003 (-1.97)
IRRIGATED COTTON	0.000085 (3.35)	-0.00002 (-0.89)	-0.00003 (-1.97)	0.00005 (2.3)
Constraints				
PRIVATE IRRIGATION	-0.17733 (-3.06)	0.03924 (0.91)	-0.02241 (-0.63)	-0.18747 (-4.34)
GOVERNMENT IRRIGATION	-0.11958 (-1.79)	-0.13078 (-2.69)	0.16236 (4.36)	-0.50589 (-10.18)
E FERTILIZER	0.00053 (3.55)	0.00018 (1.49)	-0.00002 (-0.28)	-0.00025 (-2.14)
ROADS	0.05195 (11.16)	-0.01477 (-3.69)	-0.01238 (-3.96)	0.01932 (5.03)
Environment				
MAY	-0.00083 (-1.00)	0.00014 (0.23)	0.00091 (1.74)	...
JUN	-0.00051 (-1.13)	0.00093 (2.64)	0.00011 (0.35)	...
JF	...	...	...	-0.00286 (-5.71)
GURDASPUR	-0.02332 (-0.39)	0.10256 (1.29)	-0.05467 (-2.88)	0.005565 (0.15)
AMRITSAR	-0.05293 (-1.33)	0.08609 (3.07)	-0.07677 (-3.37)	0.19235 (4.68)
KAPURTHALA	-0.01428 (-0.32)	-0.02592 (-0.80)	0.03263 (1.04)	-0.02636 (-0.76)
JULLUNDUR	-0.21858 (-7.13)	-0.02243 (-0.30)	0.18408 (9.06)	-0.03697 (-0.94)
FEROZEPORE	-0.09714 (-2.50)	-0.002709 (0.10)	-0.13594 (-5.61)	0.41264 (2.04)
LUDHIANA	-0.22896 (-5.72)	-0.05275 (-0.42)	0.2195 (10.70)	0.06424 (10.80)
BHATINDA	-0.34964 (-3.06)	0.0633 (0.76)	-0.16399 (-6.38)	0.61421 (10.80)
SANGRUR	-0.15378 (-4.86)	-0.04143 (-1.47)	0.02239 (1.08)	0.23828 (6.81)
INTERCEPT	0.09843 (2.23)	0.12779 (4.13)	0.14708 (5.20)	0.13102 (3.23)
PRE-INT	...	0.18413 (6.19)	0.10684 (3.91)	0.15831 (4.08)
R^2	0.9621	0.8759	0.9462	0.989

Notes: The numbers in parentheses are t-statistics. See Table 6 for definitions of variables.

Table 9—Estimates of dry area allocation equations: kharif season

Explanatory Variable	Dependent Variable: Dry Shares		
	Rice	Maize	Cotton
Expected revenues			
DRY RICE	0.00021	0.00003	0.00004
	(3.79)	(0.97)	(2.05)
DRY MAIZE	0.00003	-0.00001	0.00004
	(0.97)	(-0.21)	(-2.82)
DRY COTTON	0.00004	-0.00004	0.00003
	(2.05)	(-2.82)	(1.99)
Constraints			
PRIVATE IRRIGATION	0.04272	0.04301	0.00111
	(1.68)	(1.29)	(0.13)
GOVERNMENT IRRIGATION	-0.00294	0.04549	0.03319
	(-0.09)	(1.14)	(2.16)
E FERTILIZER	0.00010	-0.00065	-0.00006
	(0.96)	(-4.26)	(-1.21)
ROADS	-0.00097	0.0212	0.00009
	(-0.45)	(5.9)	(0.07)
Environment			
MAY	-0.00007	-0.00017	...
	(-0.14)	(-0.29)	
JUN	0.00067	0.00042	...
	(2.49)	(1.23)	
JF	...	...	-0.00060
			(-3.65)
GURDASPUR	1.02995	0.06954	0.00145
	(1.34)	(4.62)	(0.19)
AMRITSAR	-0.03020	-0.04115	-0.00737
	(-1.47)	(-1.21)	(-0.83)
KAPURTHALA	-0.05619	-0.05283	-0.00202
	(-1.47)	(-1.21)	(-0.84)
JULLUNDUR	-0.06503	0.03269	-0.00368
	(-3.96)	(2.46)	(-0.84)
FEROZEPORE	-0.04859	-0.07296	-0.01119
	(-3.04)	(-3.28)	(-1.64)
LUDHIANA	-0.06235	-0.03627	-0.00069
	(-10.74)	(-1.85)	(-0.15)
BHATINDA	-0.04600	-0.11088	-0.00558
	(-2.71)	(-2.05)	(-0.81)
SANGRUR	-0.05609	-0.08985	-0.00143
	(-4.64)	(-6.50)	(-0.32)
INTERCEPT	0.01851	0.03808	0.00376
	(1.75)	(2.33)	(0.72)
R^2	0.9058	0.9103	0.6815

Notes: The numbers in parentheses are t-statistics. See Table 6 for definitions of variables.

yields. The higher yields of MV wheat result in an increase in its share at the expense of the traditional variety as the price of wheat increases.

The results suggest that the constraints are very important in the area allocation decisions. The importance of the constraints in determining the pace of transition from the traditional to MV wheat is reflected by the positive and significant coefficients of the constraints in the MV wheat equation and the negative and significant coefficients of the same variables in the irrigated traditional wheat equation. Specifically, the transition to MV wheat is influenced positively by an increase in fertilizer and irrigated area. The larger and more significant coefficient on the private irrigation variable in the MV wheat equation indicates that the availability of private irrigation is more conducive to the adoption of MV wheat than the availability of government irrigation. As more irrigated area and fertilizer became available, area allocated to MV wheat increased at the expense of gram. The availability of roads encouraged the transformation to MV wheat, and the monsoon rains favor MV wheat over the traditional varieties. For the most part, the district effects are significant, reflecting the importance of the local environmental conditions on the planting decisions.

Rabi Season—Dry Area Shares. The coefficients on the own-revenue variables are negative and significant. Since the expected yields of traditional dry wheat and gram are constant over the period of study, the changes in the expected revenues of these techniques reflect movement in prices. Consequently, the negative coefficients indicate that an increase in price reduces the shares of the dry land allocated to these varieties. Recall from the irrigated share results that higher wheat and gram prices, and therefore revenues, increased production of these crops on irrigated area. Thus, irrigated varieties of wheat and gram are substitutes for the dry varieties. Further, the availability of fertilizer encourages the shift from dry to irrigated varieties. To a large extent, the competition between the irrigated and dry varieties as prices and the availability of fertilizers change may reflect the fact that during the *rabi* season land is being cultivated as intensively as possible given the resources available.

An increase in irrigated area, particularly area irrigated by canals, has a positive effect on area allocated to dry wheat. This finding may be capturing the effect of the crop rotation practice of growing dry wheat on area irrigated in the previous season (and therefore categorized as irrigated area rather than dry cropped area).

Kharif Season—Irrigated Area Shares. All own-revenue coefficients are positive and, with the exception of traditional rice, also significant. The only significant revenue competition is between MV and irrigated traditional rice and irrigated cotton and maize. As in the case of wheat, the common price for MV and irrigated traditional rice indicates that the revenue competition exhibited by these varieties reflects their different yields. The higher yield for MV rice increases its share in irrigated area. In addition, there is another significant cross-revenue effect—irrigated cotton appears to be a complement to MV rice.

With the exception of the coefficient on government irrigation in the maize equation, all of the significant coefficients on the two irrigated area variables are negative. This shows clearly that expansion of irrigated area favored the *rabi* season crops at the expense of the *kharif* season crops.

An increase in the availability of fertilizer increased the area allocated to both the MV and the traditional varieties of rice. This finding is consistent with the fact that rice is fertilizer-intensive. In contrast to rice, fertilizer availability has a negative and significant effect on area allocated to irrigated cotton and a neutral influence on area allocated to irrigated maize. MV rice and cotton seem to have benefited the most from the expansion of roads.

Apparently, the preplanting rainfall is positively associated with the traditional rather than the MV rice. It also has a positive influence on maize area and a negative effect on cotton area.

Kharif Season—Dry Area Shares. Two out of the three own-revenue coefficients are positive and significant. This finding is in marked contrast to the *rabi* dry share results where all own-revenue coefficients were negative and significant. The crops analyzed constitute only a small fraction of the dry area in the *kharif* season and, consequently, there is more potential for their expansion in response to higher prices.

An increase in area irrigated by tubewells has a favorable effect on all three dry crops. This is similar to the result for dry wheat in the *rabi* season and may be capturing the effect of the rotation practice of growing dry crops on land irrigated in the previous season.

As in the irrigated share equations, as more fertilizer becomes available, the proportion of land allocated to maize and cotton decreases. Rain is not particularly important in the area allocation decisions in the dry season. The one exception to this finding is June rainfall in the rice equation.

To help summarize the discussion so far, Tables 10 and 11 highlight the qualitative intertechnique effects of the variables in the area share equations whose coefficients are larger than their standard error (in absolute value). The quantitative importance of these intertechnique effects are summarized below in the form of area elasticities.

Table 10—Qualitative area allocation results, rabi season

	Irrigated			Dry	
Variable	Modern-Variety Wheat	Traditional Wheat	Gram	Wheat	Gram
Constraints					
PRIVATE IRRIGATION	+	–	–	+	0
GOVERNMENT IRRIGATION	+	–	–	+	0
E FERTILIZER	+	–	–	–	–
ROADS	+	0	+	0	+
Expected revenues					
MV WHEAT	+	–	–	. . .	. . .
IRRIGATED WHEAT	–	+	–	. . .	. . .
IRRIGATED GRAM	–	–	+	. . .	. . .
DRY WHEAT	. . .	. . .	. . .	–	0
DRY GRAM	. . .	. . .	. . .	0	–

Notes: All coefficients with t-statistics less than |1.0| are assumed to be not significantly different from zero. See Table 6 for definitions of variables.

Table 11—Qualitative area allocation results, kharif season

Variable	Irrigated				Dry		
	Modern-Variety Rice	Traditional Rice	Maize	Cotton	Rice	Maize	Cotton
Constraints							
PRIVATE IRRIGATION	–	0	0	–	+	+	0
GOVERNMENT IRRIGATION	–	–	+	–	0	+	+
E FERTILIZER	+	+	0	–	0	–	0
ROADS	+	–	–	+	0	+	0
Expected revenues							
MV RICE	+	–	–	+	...	...	...
IRRIGATED RICE	–	+	0	0	...	...	...
IRRIGATED MAIZE	–	0	+	–	...	...	...
IRRIGATED COTTON	+	0	–	+	...	...	...
DRY RICE	...	...	...	...	+	0	+
DRY MAIZE	...	...	...	...	0	0	–
DRY COTTON	...	...	...	...	+	–	+

Notes: All coefficients with t-statistics less than |1.0| are assumed to be not significantly different from zero. See Table 6 for definitions of variables.

Area Elasticities by Technique

The foregoing discussion dealt with shares of the various crops on either irrigated or dry area. Now the area response in terms of elasticities will be calculated. Elasticities are calculated by first simulating the model with all exogenous right-hand variables (state variables) fixed at their sample levels to establish base-run results. Then, to evaluate the effect of a 1 percent increase in the price of wheat, for example, the sample values of the price of wheat are increased by 1 percent for all years and districts, and the model is simulated again. The elasticities calculated reflect differences in the mean area of each crop and variety over the sample period between this later simulation and the base run. Because the quasi-fixed inputs are fixed at their sample values, the elasticities calculated are considered short run.

The response of the system to a shock in a state variable depends on the level of implemented technology. The area response becomes stronger in absolute value as the productivity of the implemented techniques increases. Consequently, the elasticities vary over time. To avoid reporting too many results, the examination of the time path of the responses is postponed until the section dealing with output. The following discussion concentrates on the effect of particular changes in state variables on technique choice and on the implied relative importance of the various state variables. This can be done by examining the average elasticities for the period as a whole. The average results for the period are summarized in Tables 12-14.

The conditional, or short-run, own-price elasticities of the area allocated to the superior varieties are all positive, ranging from 0.045 for irrigated cotton to 0.35 for MV wheat. (The superior varieties are wheat and rice MVs and irrigated gram, maize, and cotton.) There is pronounced price competition between MV and traditional wheat, irrigated and dry. In the case of rice, the MVs compete with the irrigated traditional varieties but are complementary to the dry varieties. Again, the

Table 12 — Average short-run area elasticities, rabi season

Variable[a]	Wheat Crop Area: Modern Variety	Irrigated Traditional	Dry	Total	Gram Crop Area: Irrigated	Dry	Total
Expected prices							
WHEAT	0.349	-1.978	-0.268	-0.033	-0.470	0.028	-0.147
GRAM	-0.010	-0.101	0.035	-0.011	0.285	-0.279	-0.079
Expected yields							
MV WHEAT	0.672	-2.700	...	0.142	-0.218	...	-0.077
IRRIGATED GRAM	-0.010	-0.101	...	-0.016	0.286	...	0.101
Constraints							
IRRIGATION[b]							
PRIVATE	1.169	-2.524	-1.593	0.306	-1.497	-1.232	-1.323
GOVERNMENT	0.601	-0.414	-0.574	0.349	-0.196	-1.792	-1.224
AREA[c]							
PRIVATE IRRIGATION	0.746	-0.554	-0.032	0.415	-0.281	0.055	-0.065
GOVERNMENT IRRIGATION	0.319	1.571	0.710	0.470	0.878	0.098	0.372
DRY	-0.202	0.938	0.707	0.106	0.589	1.063	0.897
E FERTILIZER	0.137	-0.822	-0.390	0.009	-0.186	-0.216	-0.206
ROADS	0.162	-0.304	-0.039	0.069	0.176	0.302	0.257

Notes: Elasticities are calculated by simulating the model (with fixed quasi-fixed inputs) with the appropriate changes (for example, wheat price = wheat price × 1.01) and comparing results with the base run predictions. Elasticities reflect average changes in the area for Punjab over the sample period from the base run.

[a]See Table 6 for definitions of variables.

[b]The expansion in irrigated area occurs through a conversion of dry land to irrigated land.

[c]The expansion in net cropped AREA is analyzed under three different assumptions: the expansion occurs through an increase in PRIVATEly irrigated lands, the expansion occurs through an increase in land irrigated by the GOVERNMENT, and the expansion occurs through increase in net DRY area.

differences between the wheat and rice results may reflect differences in the intensity with which land is cultivated in the two seasons.

A strong positive area response with respect to expected yields is observed for the superior varieties. An increase in yields of the MV wheat and rice favors them at the expense of the traditional varieties. In the cases where only one technique exists for the production of a given crop, the elasticities with respect to yield and price are identical. This is not the case for MV wheat and rice where the two diverge, because the composition of techniques changes in response to the shock under consideration. In terms of the current formulation, it can be shown that the elasticity of S_H with respect to price is equal to the sum of the elasticities with respect to y_H and with respect to y_T. The latter is negative and therefore the elasticity with respect to y_H is larger than the price elasticity.[27] Holding total area constant, this result also applies to area rather than share. As expected, the area responses with respect to expected yields of MV wheat and rice are considerably larger than those with respect to price.

[27] In accordance wih the discussion on p. 59, terms are rearranged as shown below:

$$\frac{\partial S_H/S_H}{\partial p/p} = p\lambda S_1 y_H/S_H + p[(1-\lambda)S_1 - S_2]y_T/S_H = \frac{\partial S_H/S_H}{\partial y_H/y_H} + \frac{\partial S_H/S_H}{\partial y_T/y_T}.$$

Table 13 — Average short-run rice area elasticities

Variable[a]	Rice Area: Modern Variety	Irrigated Traditional	Dry	Total
Expected prices				
RICE	0.188	−0.193	0.261	0.068
MAIZE	−0.039	0.015	0.054	−0.006
COTTON	0.130	−0.056	0.117	0.046
Expected yields				
MV RICE	0.294	−0.363	...	0.031
IRRIGATED MAIZE	−0.039	0.015	...	−0.012
IRRIGATED COTTON	0.130	−0.056	...	0.037
Constraints				
IRRIGATION[b]				
PRIVATE	0.098	0.697	−1.039	0.276
GOVERNMENT	0.094	−0.311	−0.678	0.002
AREA[c]				
PRIVATE IRRIGATION	0.336	0.696	0.109	0.434
GOVERNMENT IRRIGATION	0.326	−0.120	−0.111	0.175
DRY	0.126	0.020	0.539	0.091
E FERTILIZER	0.211	0.208	0.123	0.151
ROADS	1.268	−0.926	−0.068	0.405

Notes: Elasticities are calculated by simulating the model (with fixed quasi-fixed inputs) with the appropriate changes (for example, rice price = rice price × 1.01) and comparing results with the base-run predictions. Elasticities reflect average changes in the area for Punjab over the sample period from the base run.

[a]See Table 6 for definitions of variables.

[b]The expansion in irrigated area occurs through a conversion of dry land to irrigated land.

[c]The expansion in net cropped AREA is analyzed under three different assumptions: the expansion occurs through an increase in PRIVATEly irrigated lands, the expansion occurs through an increase in land irrigated by the GOVERNMENT, and the expansion occurs through increase in net DRY area.

The area elasticities with respect to the various constraints are also summarized in Tables 12-14. The area elasticities with respect to an increase in both private and government irrigation through the conversion of dry cropped area indicate that the competition among the irrigated and dry varieties varies by crop.[28] In the *rabi* season, area allocated to MV wheat increases at the expense of all the other irrigated and dry varieties as the availability of privately irrigated land increases. These elasticities are all large in absolute value, indicating a substantial change in the composition of techniques. The negative elasticities for the dry varieties with respect to irrigated area are consistent with, and thus supplement, the earlier finding that the *rabi* irrigated varieties are substitutes for the *rabi* dry varieties. The relative magnitude of the MV wheat area elasticities with respect to private and government irrigated areas is consistent with the contention in the literature that tubewells (private) are more conducive to the adoption of MV wheat than are government canals.

In terms of the *kharif* crops, all varieties of cotton are losers as dry area is converted to private or government irrigated lands. Irrigated maize and MV rice

[28] Later in this discussion, area response to an increase in irrigated area brought about by bringing new land into production is also analyzed.

Table 14 — Average short-run maize and cotton area elasticities

Variable[a]	Maize Area Irrigated	Maize Area Dry	Maize Area Total	Cotton Area Irrigated	Cotton Area Dry	Cotton Area Total
Expected prices						
RICE	-0.042	0.025	-0.032	0.048	0.274	0.054
MAIZE	0.160	-0.010	0.133	-0.020	-0.406	-0.028
COTTON	-0.055	-0.062	-0.056	0.045	0.446	0.053
Expected yields						
MV RICE	-0.049	...	-0.042	0.059	...	0.058
IRRIGATED MAIZE	0.160	...	0.135	-0.020	...	-0.020
IRRIGATED COTTON	-0.055	...	-0.047	0.045	...	0.044
Constraints						
IRRIGATION[b]						
PRIVATE	0.564	-1.754	0.216	-0.016	-1.124	-0.033
GOVERNMENT	0.748	-0.754	0.516	-0.302	-0.722	-0.306
AREA[c]						
PRIVATE IRRIGATION	0.477	0.244	0.436	0.414	-0.156	0.405
GOVERNMENT IRRIGATION	0.546	0.151	0.481	0.198	0.714	0.207
DRY	-0.086	0.963	0.080	0.237	0.715	0.246
E FERTILIZER	-0.013	-0.411	-0.069	-0.065	-0.312	-0.068
ROADS	-0.363	0.885	-0.175	0.302	0.026	0.298

Notes: Elasticities are calculated by simulating the model (with fixed quasi-fixed inputs) with the appropriate changes (for example, rice price = rice price × 1.01) and comparing results with the base-run predictions. Elasticities reflect average changes in the area for Punjab over the sample period from the base run.

[a]See Table 6 for definitions of variables.

[b]The expansion in irrigated area occurs through a conversion of dry land to irrigated land.

[c]The expansion in net cropped AREA is analyzed under three different assumptions: the expansion occurs through an increase in PRIVATEly irrigated lands, the expansion occurs through an increase in land irrigated by the GOVERNMENT, and the expansion occurs through increase in net DRY area.

both benefit, while the dry varieties of both these crops are adversely affected. Area allocated to irrigated traditional rice increases if the dry land is converted to well irrigation, but decreases if the land is irrigated by government canals. Irrigated traditional rice has a larger positive elasticity with respect to an increase in private irrigation than does MV rice. This finding is explained by the competition between MV wheat and MV rice for these resources described earlier. These same findings are not seen when the land is converted to canal irrigation, as MV wheat does not have as much of a distinct advantage over the other varieties on these lands.

The responses to a change in net cropped area are examined under three different scenarios: the additional area is irrigated privately, the additional area is irrigated by government canals, and the additional area is not irrigated. When the increase in net cropped area occurs through an increase in net dry area, the area allocated to all varieties increases, with the exception of MV wheat and irrigated maize. An expansion in cropped area through an increase in area irrigated by government canals increases area allocated to all crop varieties except irrigated traditional and dry rice. On the other hand, if the increase in net cropped area comes in the form of more land irrigated by tubewells, area allocated to dry cotton, irrigated and dry wheat, and irrigated gram decreases. The adverse effect of an expansion in private irrigation on more varieties when compared with a similar expansion in government irrigation can be explained by the bias of private irrigation toward the adoption of MV wheat.

An increase in the availability of fertilizer has a positive effect on all varieties of rice, which again reflects the fertilizer intensity of rice. As expected, MV rice benefits the most. The increase in rice area as more fertilizer becomes available occurs at the expense of all the other *kharif* varieties. In the *rabi* season, MV wheat competes for land with irrigated traditional and dry wheat and irrigated gram as more fertilizer becomes available. Further, the availability of roads is positively related to the rate of transformation from the traditional varieties to the MVs of rice and wheat.

Summary of Area Allocation Decisions

At this point, it is useful to summarize the discussion of the area allocation results. First, and foremost, the results suggest that changes in the availability of quasi-fixed inputs have very significant intertechnique effects. In particular, the area elasticities indicate that the pace of transition to the MVs of both wheat and rice is positively influenced by the availability of all the quasi-fixed inputs. Second, given fixed levels of the quasi-fixed inputs, it is clear that changes in incentives lead to important changes in the composition of techniques. However, the magnitude of the area elasticities suggests that the intertechnique effects due to changes in the availability of quasi-fixed inputs are often severalfold larger than the same effects due to changes in the incentives (in absolute value).

Somewhat more specifically, the area elasticities indicate that all the own-price elasticities for the superior varieties of each crop are positive and fairly inelastic. Similarly, the area responses of the superior varieties to changes in their respective expected yields are also positive. The responses of MV wheat and rice area to changes in their expected yields are more than twice their response to own expected price.

The results also suggest that the dry and irrigated varieties in the *rabi* season compete with each other as incentives change and the constraints are relaxed, while some of the *kharif* irrigated and dry varieties do not. Further, the *kharif* varieties compete with the *rabi* varieties for irrigated area. In general, an expansion in irrigated area favors the *rabi* crops at the expense of the *kharif* crops. As noted earlier, this finding is consistent with the possibility that further increases in irrigated crops in the *rabi* season require land to be left fallow in the *kharif* season.

The implications of the intertechnique effects due to changes in incentives and the availability of quasi-fixed inputs are assessed by obtaining elasticities of the total area allocated to each crop (over all techniques).

The own-price elasticities of total area planted to wheat and gram in the *rabi* season are all negative. For instance, a value of −0.033 is obtained for wheat. On the other hand, the corresponding values for the *kharif* crops are all positive. Given this finding and the fact that the own-price area elasticities for the superior varieties of each crop are all positive, it appears that the competition between varieties of a particular crop is greater in the *rabi* season than in *kharif* season. In contrast to the own-price elasticities, the area elasticities by crop with respect to the expected yield of the superior varieties are all positive.

Although the area elasticities by variety suggest considerable substitutions within the varieties of both wheat and rice as the availability of the quasi-fixed inputs increased, the net effects for total wheat and rice area due to changes in any of these variables are all positive. Further, the magnitude of these elasticities are large relative to the elasticities of wheat and rice area with respect to the incentive variables.

In addition, the area elasticities indicate that area allocated to maize increases as net cropped and irrigated area increase, yet decreases as the availability of roads and fertilizers increases. Area allocated to cotton increases as new land is brought into production but decreases as dry cropped land is irrigated and as the availability of fertilizer increases.

Determination of Yield

The specific variables included in the yield equations and the results are described in Tables 15 and 16, respectively. Note that no price variables are included in any of the final yield equations, as their coefficients were all insignificant. This finding is discussed in detail below.

With the exception of gram yield, the equations fit the data well. The significant technology variables indicate the importance of the composition of techniques, chosen in the earlier planting decisions, in the determination of overall yield by crop. That is, these variables indicate the importance of the amount of area allocated to MV wheat and rice and to irrigated gram, maize, and cotton in overall yield enhancement. The technology effect is particularly important in wheat, rice, and maize. To assess the full impact of a change in the choice of technique on yield, the coefficients on the interaction variables of technology with fertilizer and rain should also be considered. However, with the exception of the technology-fertilizer variable in the cotton equation and the technology-rain variable in the wheat equation, the coefficients on these variables are not significantly different from zero and therefore are ignored.

The availability of fertilizer per net cropped area has a positive effect on the yields of all crops. However, the effect is weak and, with the exception of cotton, is not significant. The least significant intratechnique effects due to an increase in

Table 15—Definition of variables: yield equations

Variable	Definition	Equation
Technology		
IRRIGATED COTTON	Proportion of cotton area irrigated	Cotton
IRRIGATED MAIZE	Proportion of maize area irrigated	Maize
MV RICE	Proportion of rice area in modern varieties	Rice
MV WHEAT	Proportion of wheat area in modern varieties	Wheat
IRRIGATED GRAM	Proportion of gram area irrigated	Gram
AMERICAN COTTON	Proportion of cotton area in American variety	Cotton
Constraint		
FERTILIZER	Fertilizer available per net cropped area (nutrient kilograms of N,P_2O_5,K_2O/hectare)	All
Environment		
COTRAIN	District rainfall (cm) June-September	Cotton
KHARAIN	District rainfall (cm) July-September	Maize, rice
RABRAIN	District rainfall (cm) October-April	Wheat, gram
DISTRICT	A dummy variable is introduced for each district[a]	All

Note: All yields are measured in metric tons per hectare.
[a]The districts are listed in Table 16.

Table 16—Estimates of yield equations

Explanatory Variable	Dependent Variable: Yield				
	Wheat	Gram	Rice	Maize	Cotton
Technology					
MV WHEAT	1.19928 (12.12)	...	...	...	...
IRRIGATED GRAM	...	0.2215 (0.64)	...	...	...
MV RICE	...	...	1.32789 (7.18)	...	...
IRRIGATED MAIZE	...	...	...	2.07472 (4.66)	...
IRRIGATED COTTON	...	...	...	...	0.41771 (3.15)
AMERICAN COTTON	...	...	...	...	0.11413 (4.49)
Constraints					
FERTILIZER	0.00316 (1.30)	0.00141 (1.66)	0.00189 (1.00)	0.00201 (1.46)	0.00116 (2.2)
FERTILIZER × TECHNOLOGY	−0.00301 (−1.27)	−0.00314 (−1.69)	0.00115 (0.59)	−0.00121 (−0.74)	−0.00135 (−2.45)
Environment					
RAIN[a]	−0.00955 (−2.12)	−0.00437 (−0.64)	0.00212 (0.94)	−0.00118 (−0.36)	0.002306 (1.58)
RAIN[a] × TECHNOLOGY	0.00342 (0.53)	0.00622 (0.35)	0.00183 (0.59)	−0.01200 (−2.82)	−0.002679 (-1.69)
GURDASPUR	−0.04956 (−0.52)	0.15099 (1.50)	−0.26179 (−2.14)	0.28494 (1.86)	−0.01734 (−0.55)
AMRITSAR	0.02278 (0.28)	0.24668 (1.61)	−0.04082 (−0.36)	−0.4578 (−3.03)	−0.05036 (−3.62)
KAPURTHALA	−0.14989 (−1.87)	−0.06487 (−0.67)	0.08303 (0.73)	−0.44721 (−3.07)	−0.01692 (−1.07)
JULLUNDUR	−0.01944 (−0.24)	0.18406 (1.96)	0.09981 (0.86)	−0.07571 (−0.58)	−0.01692 (−1.12)
FEROZEPORE	−0.05916 (−0.73)	0.03467 (0.37)	0.15042 (1.26)	−0.77452 (−5.32)	0.04403 (2.70)
LUDHIANA	0.56211 (6.83)	0.15204 (1.39)	0.10365 (0.89)	0.13624 (0.93)	0.02481 (1.80)
BHATINDA	0.0199 (0.24)	−0.0135 (−0.15)	0.2426 (2.03)	−0.80803 (−4.77)	0.04682 (3.25)
SANGRUR	−0.02861 (−0.35)	0.06731 (0.69)	0.02659 (0.23)	−0.45212 (−2.73)	0.0337 (2.09)
INTERCEPT	1.43853 (16.44)	0.71832 (5.80)	0.93329 (6.13)	0.41233 (1.32)	−0.14679 (−1.18)
R^2	0.8314	0.172	0.8334	0.5388	0.7164

Notes: The numbers in parentheses are t-statistics. See Table 15 for definitions of variables.
[a]The relevant rain variables include RABRAIN for wheat and gram yields, KHARAIN for rice and maize yields and COTRAIN for cotton yields.

fertilizer are found in the wheat and rice yield equations. These responses to fertilizer are obtained conditional on the composition of techniques and thus reflect the intratechnique effect or the change in yield due to movements along the relevant production functions. It is important to emphasize that these results are not necessarily inconsistent with the findings that yields are responsive to fertilizers in field experiments. What happens in practice is that results from such experiments are used to develop fertilizer recommendations, which are disseminated to farmers in one form or another. Thus, individual farmers do not have to experiment over the entire domain of potential fertilizer doses, and observed intratechnique variations over the implemented range of doses are relatively small. This is particularly true with aggregated data, since any interfarm differences are not detected.

The difficulty in capturing an intracrop input response, or in this case, an intratechnique input response, has been discussed in the literature. For example, Mundlak (1959) found no correlation between preharvest labor inputs and yields of sugar beets in Israel. In this particular case, the explanation of the finding was similar to that above; all farmers carried out the same recommended operations. Observed variations in labor inputs reflected other factors, including variations in the timing of the operation, and thus did not reflect a movement on a given production function.

If levels of other inputs applied to a specific variety also follow closely the recommendations given to farmers, one would expect to observe, as in this study, that once a farmer has chosen a particular technique of production, prices do not significantly affect yields. A similar finding was also reported in Mundlak and McCorkle 1956. More recently, although in a somewhat different context, a similar view has been developed by Just et al. (1990).

It is only against this background that one can fully assess the importance of the intertechnique response. Recall that an increase in the availability of fertilizer has a strong positive effect on the share of irrigated land allocated to modern wheat and rice. Thus the yield results suggest that the main effect of fertilizer on the overall yields of wheat and rice is through changes in crop composition. This result can be illustrated in terms of Figure 32 by letting $\overline{x}$ represent the quantity of fertilizer available per unit of land. As x increases beyond $\overline{x}$, farmers do not change the rate of application on each variety, but the composition of varieties changes. Bapna (1981, 35) made a similar observation, also in the Indian context; ". . .the increase in the use of fertilizer was mainly because of extension of area under fertilizer rather than due to higher per hectare dosage. . . . The same is true of irrigation."

As noted above, the only significant interaction term involving fertilizer is the technology-fertilizer variable in the cotton equation. This finding also reflects an intertechnique response. Recall that an increase in the availability of fertilizer significantly reduces the area allocated to irrigated cotton. Given the higher yields of irrigated cotton, overall cotton yield should decrease as more fertilizer becomes available.

For the most part, the rainfall variables and the rainfall-technology interaction variables are insignificant. An exception to this finding is the negative coefficient on rainfall in the wheat yield equation. A possible explanation of this result relates to the effect of rainfall on area allocations. Larger rainfall during the growing season increases the area of dry traditional wheat, and this in turn reduces the average yield. The negative coefficient on the technology-rain interaction term in the maize yield equation may be explained using similar reasoning. The negative coefficient indicates that maize yields decrease as more rain becomes available and that the extent of the decrease is positively related to the amount of area that is planted to irrigated maize. Given that areas with more rainfall during the *kharif* season are likely to grow more (lower-yielding) dry maize than the other drier districts, this finding is not surprising.

The district effects are particularly important in the determination of maize and cotton yields. For the most part, they appear to capture the influence of soil type and climate in crop rotations. The results confirm the fact that the light and sandy soils of the arid southwest (Bhatinda, Ferozepore, and Sangrur) are unsuitable for the production of maize. The lack of significant district effects in the gram yield equation reflects the fact that gram can be grown on a whole range of soil types. The lower yields of rice and wheat in Gurdaspur reflect the fact that Gurdaspur has the highest rainfall of all districts and consequently grows more unirrigated crops than any of the other districts. The particularly high yields of wheat and maize in Ludhiana may reflect, in part, the impact of the special attention Ludhiana has received as a participant in the Intensive Agricultural District Program since 1961/62 and also its close proximity to the Punjab Agricultural University, where much of the work on the new varieties has taken place.

The total effect of the state variables on the overall yields for each crop is observed by deriving elasticities of yield with respect to the state variables. These elasticities incorporate the direct effect of the state variables included in the yield equations and the indirect effects of these variables on the composition of techniques—a major determinant of yield levels. The results appear in Table 17.

Even after the indirect effects of the state variables are taken into account, their overall effects on yields are small when compared with their effects on area allocation. With the exception of cotton, all own-price elasticities, though small, are positive. For the most part, a much stronger response in overall yield occurs as the constraints are relaxed. The strongest effects are observed for rice yields with respect to the availability of fertilizer and roads, and for wheat and maize yields with respect to the conversion of dry land to (private or government) irrigated area. When compared with the other crop yields, the response of gram and cotton yields to changes in the constraints is small.

Summary: Yield Results

To summarize the yield results, three observations are made. First, yields increase as the share of the MVs and irrigated crops increase. This is hardly a surprising result. Yet it reemphasizes the importance of the area allocation equations. In particular, yields are affected indirectly by the level of the constraints.

Second, the empirical results are consistent with the common knowledge that fertilizers are important in increasing yields. However, the direct or intratechnique effect of fertilizers on yields, holding variety composition constant, is not very pronounced. The main effect is through the change in variety composition (intertechnique). As indicated in Chapter 3, resource constraints may have limited the availability of fertilizer and thus constrained yields directly as well as indirectly through the choice-of-technique decision.

Table 17—Average overall yield elasticities

Variable	Wheat	Gram	Rice	Maize	Cotton
Expected prices					
WHEAT	0.073	-0.009	...	...	...
GRAM	0.000	0.009	...	...	...
RICE	...	...	0.046	-0.004	-0.011
MAIZE	...	...	-0.009	0.010	0.009
COTTON	...	...	0.024	0.007	-0.009
Constraints					
IRRIGATION[a]					
PRIVATE	0.176	0.008	-0.077	0.272	0.050
GOVERNMENT	0.049	0.056	0.023	0.075	0.059
AREA[b]					
PRIVATE IRRIGATION	0.057	-0.005	-0.085	0.047	-0.016
GOVERNMENT IRRIGATION	-0.044	0.018	0.018	-0.032	0.042
DRY	-0.065	-0.039	0.000	-0.107	-0.014
FERTILIZER[c]	0.051	0.026	0.092	0.092	-0.013
ROADS[d]	0.015	0.001	0.252	-0.124	-0.044

Notes: Elasticities are calculated by simulating the model (with fixed quasi-fixed inputs) with the appropriate changes (for example, rice price = rice price × 1.01) and comparing results with the base-run predictions. Elasticities reflect changes in the mean area for Punjab over the sample period from the base run. Note that these elasticities incorporate the indirect effect of a change in choice of technology on yield.

[a]The expansion in irrigated area occurs through a conversion of dry land to irrigated land.

[b]The expansion in net cropped AREA is analyzed under three different assumptions: the expansion occurs through an increase in PRIVATEly irrigated lands, the expansion occurs through an increase in land irrigated by the GOVERNMENT, and the expansion occurs through an increase in net DRY area.

[c]Availability of fertilizer per net cropped area.

[d]Kilometers of road available per hectare.

Last, the importance of the local environment on productivity is well illustrated by the significant district effects.

Output Elasticities

The area and yield results are now combined to obtain the determinants of output in the short run. The importance of the incentives and the availability of quasi-fixed inputs in the determination of output is assessed by analyzing the short-run or conditional output elasticities for the five major crops. (For a discussion of how these elasticities are calculated, see the earlier section, Area Elasticities by Technique.) Elasticities of total aggregate production with respect to the various variables are also calculated.[29] The average elasticities for the period as a whole are summarized in Table 18.

To a large extent, the results reiterate the previous results. With the exception of gram, all own-price elasticities are positive and generally small. These findings are in line with results reported in other studies (for example, Askari and Cum-

[29]The change in total production is calculated using a Normalized Quadratic Quantity Index (see Diewert 1976).

Table 18 — Average short-run crop output elasticities

Variable	Wheat	Gram	Rice	Maize	Cotton	Total Production[a]
Expected prices						
WHEAT	0.107	-0.156	...	...	...	0.066
GRAM	-0.010	-0.071	...	...	...	-0.014
RICE	...	...	0.114	-0.036	0.043	0.035
MAIZE	...	...	-0.016	0.144	-0.020	0.005
COTTON	...	...	0.070	-0.049	0.043	0.005
All prices	0.096	-0.227	0.168	0.059	0.067	0.075
Expected yields						
MV WHEAT	0.251	-0.079	...	...	...	0.170
IRRIGATED GRAM	-0.014	0.106	...	...	...	-0.002
MV RICE	...	...	0.109	-0.043	0.051	0.012
IRRIGATED MAIZE	...	...	-0.020	0.144	-0.017	0.008
IRRIGATED COTTON	...	...	0.062	-0.048	0.041	0.006
Constraints						
IRRIGATION[b]						
PRIVATE	0.483	-1.316	0.194	0.489	0.017	0.331
GOVERNMENT	0.398	-1.168	0.025	0.592	-0.247	0.246
AREA[c]						
PRIVATE IRRIGATION	0.473	-0.070	0.349	0.483	0.389	0.419
GOVERNMENT IRRIGATION	0.426	0.391	0.193	0.449	0.249	0.383
DRY	0.041	0.858	0.091	-0.027	0.232	0.107
FERTILIZER[d]	0.060	-0.180	0.243	0.023	-0.080	0.062
ROADS[e]	0.084	0.257	0.658	-0.298	0.254	0.152

Notes: Elasticities are calculated by simulating the model (with fixed quasi-fixed inputs) with the appropriate changes (for example, rice price = rice price × 1.01) and comparing results with the base-run predictions. Elasticities reflect average changes in crop output for Punjab over the sample period from the base run.

[a]Change in total production is calculated using a Normalized Quadratic Quantity Index (see Diewert 1976).

[b]The expansion in irrigated area occurs through a conversion of dry land to irrigated land.

[c]The expansion in net cropped AREA is analyzed under three different assumptions: the expansion occurs through an increase in PRIVATEly irrigated lands, the expansion occurs through an increase in land irrigated by the GOVERNMENT, and the expansion occurs through an increase in net DRY area.

[d]Availability of fertilizer per net cropped area.

[e]Kilometers of road available per hectare.

mings 1976). The own elasticities of output with respect to expected yields for each of the superior varieties are positive and are highest for wheat.

The output elasticities with respect to the constraints indicate output response to a change in the particular constraint being analyzed, holding all other constraints at their sample values. The output elasticities of wheat and rice with respect to all the constraints are sizable and positive. They appear particularly sizable when compared with the price elasticities. This, once more, indicates that the constraints were indeed binding. Note that among the quasi-fixed inputs, changes in the availability of irrigation (private and government) lead to the largest increases in total crop production.

As indicated earlier, the response of the system to a change in a state variable will depend on the productivity of the implemented technology; the more productive the implemented technology, the greater the response (in absolute value). Figures 33-36 show selected results describing the time pattern of the output elasticities. The short-run output elasticity of wheat with respect to its own price changes from nearly zero in the pre-modern variety period to roughly 0.22 at the end of the period (Figure 33). The elasticity of rice output with respect to its own

Figure 33—Short-run output elasticities with respect to own price, 1962-79

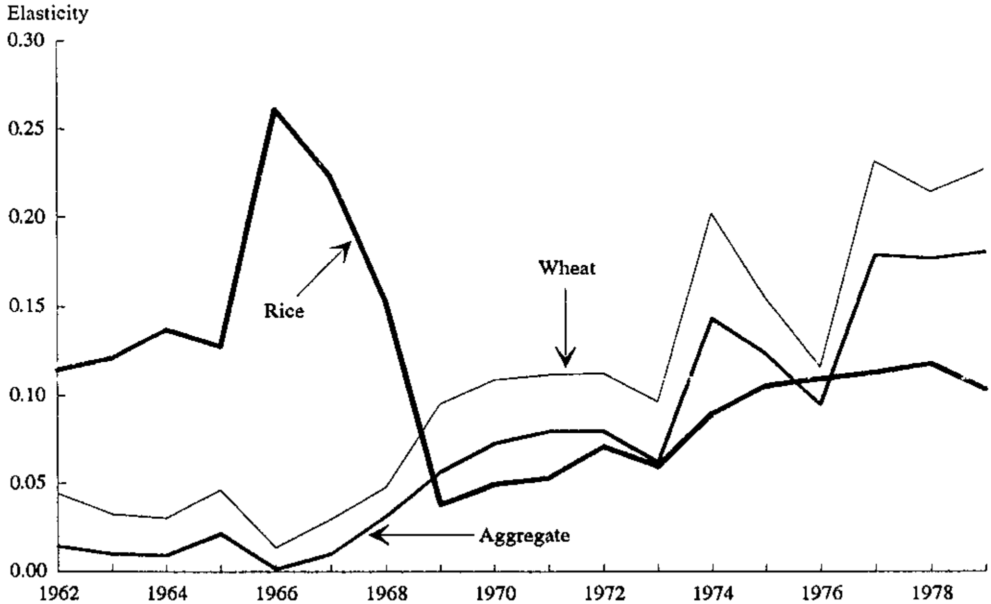


Figure 34—Short-run output elasticities with respect to private irrigation, 1962-79

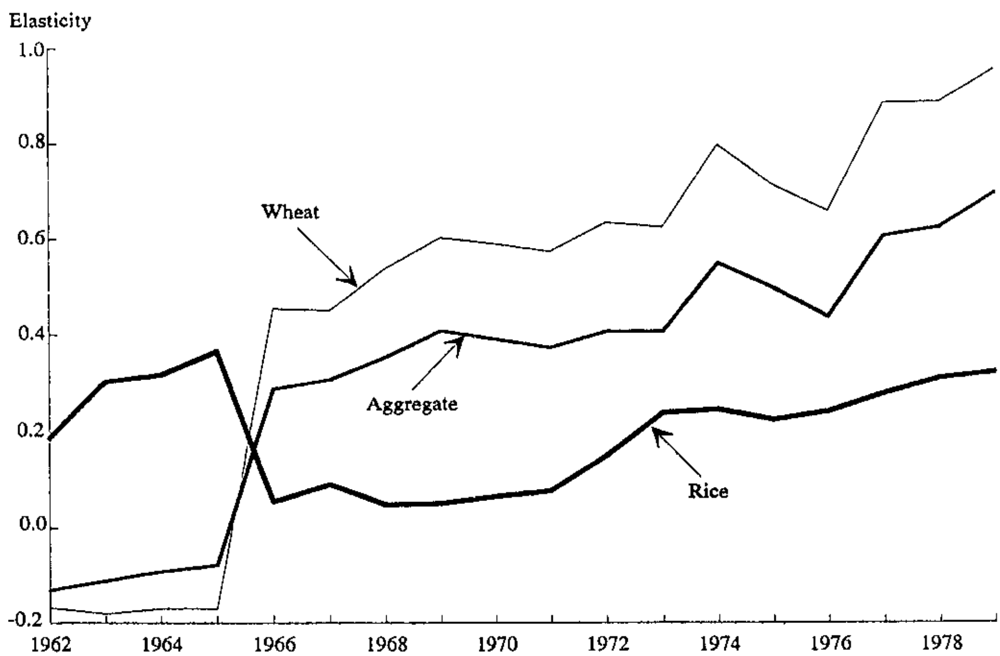


Figure 35— Short-run output elasticities with respect to fertilizer, 1962-79

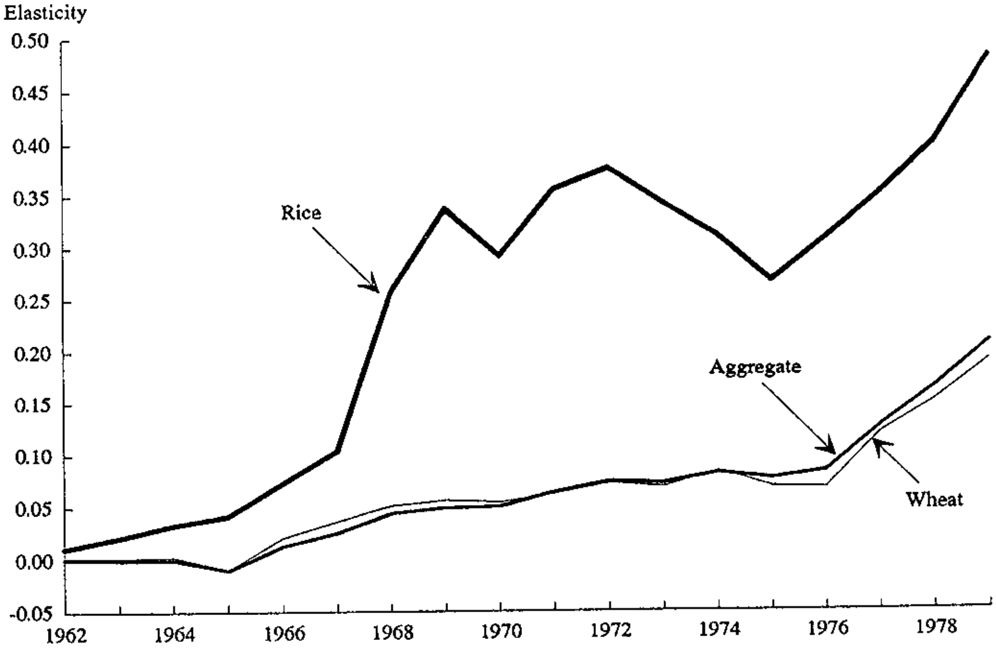
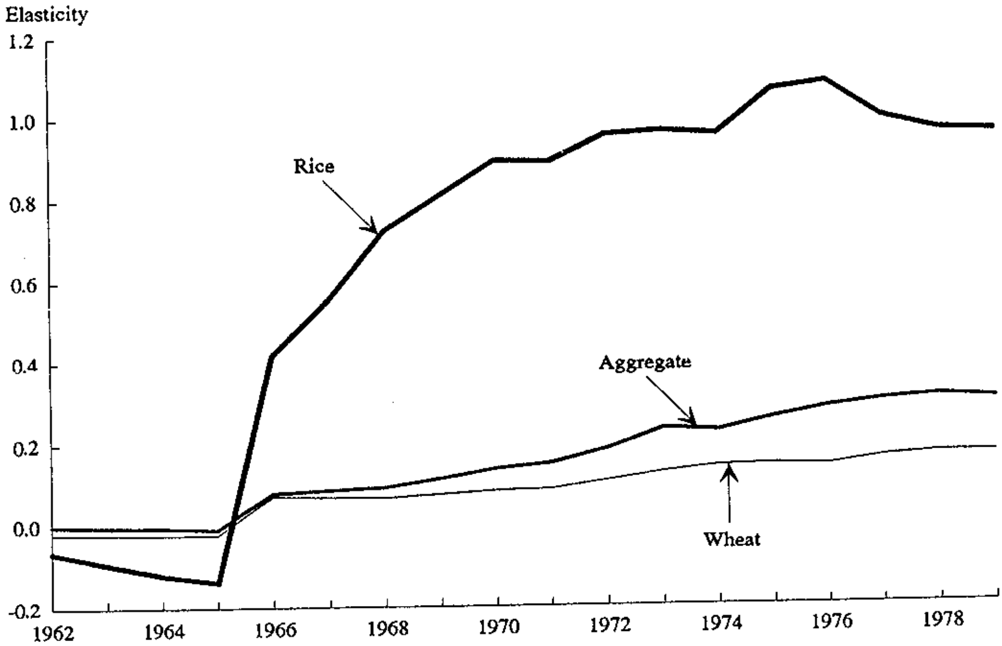


Figure 36— Short-run output elasticities with respect to roads, 1962-79



price was initially stable around 0.13, but then increased to 0.25 in 1966. Beginning in 1966, with the appearance of MV wheat, the own-price elasticity of rice dropped sharply, reaching an all-time low of 0.04 in 1969. From 1969 onward, the own-price elasticity increased with the growing importance of the MV of rice. By the end of the study period, the elasticity appeared to be stabilizing around 0.11. When all prices increased, the short-run aggregate output or supply elasticity changed from nearly zero in the early 1960s to 0.18 in 1979. This finding indicates that when new techniques appear, aggregate output increases as prices increase.

Turning to the output elasticities with respect to the constraints, Figure 34 shows the elasticity of wheat output with respect to an increase in private irrigated area, holding total net cropped area constant. Before the onset of the green revolution, the output elasticity of wheat was negative and very small. Once MVs of wheat were introduced, the elasticity jumped from −0.17 in 1965 to 0.45 in 1966. It then continued to climb as more and more land was sown to the MVs, reaching an elasticity close to 1.0 by the end of the study period. The time pattern of the rice output elasticity with respect to this same variable is very different, reflecting the different adoption path of MV rice. In the early 1960s, the elasticity was between 0.19 and 0.37. By 1966, it had dropped to 0.05, but thereafter started to increase gradually, reaching 0.32 in 1979. Reflecting the increases in overall productivity over the study period, the elasticity of aggregate output with respect to private irrigation increased from a small negative value in the early 1960s to 0.70 at the end of the study period.

While the elasticities of output with respect to irrigation are sizable, those with respect to fertilizers are considerably smaller. Prior to the onset of the green revolution, the elasticities of output for both wheat and rice with respect to fertilizer were negligible (Figure 35). This is consistent with the weak intratechnique response discussed above. As the MVs were adopted, these elasticities increased, reaching 0.19 and 0.48 for wheat and rice, respectively, by 1979. A comparison of these elasticities with the same output elasticities with respect to private irrigation indicates that the scope for increasing output through the application of more fertilizer, holding irrigation fixed, is much smaller than that generated by increasing irrigation with fertilizer supply held constant.

Finally, the elasticities with respect to roads are plotted in Figure 36. They increased from small negative values in the early 1960s to 0.17, 0.96, and 0.30 for wheat, rice, and aggregate output, respectively, in 1979. These results suggest that roads were more important in the transition to MV rice than wheat.

6

THE LONG-RUN RESPONSE

The Framework

The analysis has brought forth the importance of irrigation and fertilizer availability in the transition to the MVs of wheat and rice and to increased output of other crops. The large elasticities with respect to these quasi-fixed inputs indicate that the pace of the transition was largely determined by the pace of their expansion. The next step is to examine the determinants of the levels of these inputs. In so doing it is important to keep in mind that the increased availability of fertilizer and canal irrigation reflects decisions made by the government and thus is exogenous to the individual farmer. On the other hand, expansions in area irrigated by tubewells and other wells and net cropped area largely reflect decisions made by farmers themselves.

Although the decisions to expand the quasi-fixed inputs are made by both the private and public sectors, some of the factors affecting these decisions are similar. The similarities stem from the fact that expansion decisions require scarce resources; therefore, the diversion of resources to agriculture requires that their value productivity in agriculture is greater than that in other uses. Despite the similarities, however, farmers decisions differ from those of the government in that farmers consider only private returns. If the government's sole objective were to maximize per capita private consumption over time and there were no externalities, it would behave in the same way as the private sector. Given that the provision of public goods usually involves externalities, the behavior of the two sectors will differ. In reality, however, the behavior of the two sectors differs for other reasons as well. Governments usually have other motives and objectives, including the desire to stay in power. This study will only try to determine empirically the importance of economic incentives in the government's investment decisions.

The most drastic change in irrigation took place in area irrigated by private sources, which more than doubled between 1966 and 1979 (see Figure 20). Over the same period, land irrigated by government sources increased only by 17 percent. Thus, while in 1966 the areas irrigated by private and public sources were 953,000 and 1.26 million hectares, respectively, the corresponding figures in 1979 were 1.91 million and 1.48 million hectares.[30] Although both the private and public sectors seem to have responded to the favorable economic conditions of the period, the particularly large increase in private irrigation is an important indication of the intensity with which farmers will respond when the opportunities arise.

[30]Note that the data on the quasi-fixed inputs described here include only the quasi-fixed inputs in the 10 districts incorporated in this study (see Chapter 5).

The framework for the analysis of changes in the quasi-fixed inputs over time is provided by equation (26); an optimal level of capital stock is achieved when its net marginal-value productivity is equal to its user cost. The net marginal-value productivity of capital is obtained by differentiating the restricted profit function with respect to capital. It measures the change in value output, net of the cost of variable inputs, associated with a change in capital stock by one unit.

The solution to equation (26), which gives the optimal time path of capital, can be written as $K^*(z)$, where $z = [s,r,T,q,qc(\dot{K}),\dot{q}]$ and s is the vector of state variables (z) entering the restricted profit function (equation [11]) defined in equation (8), r is the discount rate, T is the available technology, q is the price of K, $qc(\dot{K})$ is the cost of adjusting K, and $\dot{q}$ is the first time derivative of q. The demand for investment is the difference between the optimal level of capital and that currently available:

$$I^d[z(t)] = K^*[z(t)] - K(t). \quad (31)$$

The generalization of this discussion to more than one quasi-fixed input is straightforward.

Equation (31) represents the decisions made at the farm level, where all prices are exogenous. Thus the variables should have a farm index, say i. The aggregate demand for investment at the sector level is obtained by summing equation (31) over all farms. Just as in the case of investment at the farm level, the aggregate demand for investment is a function of the state variables (z) indicated in equation (31). At the sectoral level, however, these variables are no longer necessarily exogenous to the investment decision. This is particularly true for prices, and more specifically, for the price of the capital good, q, which is determined by the supply and demand for that good. If the supply of capital is perfectly inelastic, an increase in demand will be absorbed entirely by an increase in the shadow price of capital. On the other hand, if the supply is perfectly elastic, an increase in the demand for capital is fully reflected in increases in investment, and the price of capital does not change. In the intermediate case, when the supply curve of capital is upward-sloping, increases in investment demand result in an increase in both the price of capital and the level of the capital stock.

For the problem at hand, where quasi-fixed inputs are fixed in the short run, an increase in the demand for agricultural products only leads to an increase in the shadow prices of the constraints. As the shadow prices of the constraints increase, however, resources should move into the agricultural sector. Because resources are limited and have to be bid away from other activities where their return is not as high, the process can take considerable time. This implies that the level of investment in agriculture, or more generally in any sector, will depend on the overall availability of resources and on the profitability of the particular sector in question relative to the rest of the economy. The profitability of the agricultural sector depends on the cost of the variable inputs and product prices, which in turn reflect the overall demand for food. Because prices are also influenced by government policies, a clearer view of the role of the demand for food is assessed by including additional factors that also reflect changes in demand.

Although this conceptual framework forms the basis of the analysis, compromises had to be made in its implementation to deal with the available data. Nevertheless, the qualitative nature of the results is instructive.

In general terms, it is hypothesized that the flow of resources to the agricultural sector depends on the profitability of this sector relative to the nonagricultural sector, the overall level of resources in the economy as a whole, and additional factors influencing or reflecting demand conditions.

Similar hypotheses have been tested empirically in other studies by explaining the share of total investment allocated to agriculture as a function of the expected intersectoral differential rates of return, the composition of the capital stock, and related variables (Mundlak and Strauss 1979; Cavallo and Mundlak 1982; Coeymans and Mundlak 1987; Barkley 1988; and Mundlak, Cavallo, and Domenech 1989). Once the share of total investment allocated to agriculture and total investment itself is determined, agricultural investment is obtained. In turn, this investment can be allocated to the various major agricultural capital items according to their profitability. This approach to explaining investment requires data on investment, capital stock, and sectoral rates of return, none of which are available at the district level. Such data could be assembled by states for India, but such an effort is beyond the scope of this study.

Alternatively, the approach taken here is to explain the important components of investment: net cropped area (AREA), net irrigated area by source (PRIVATE and GOVERNMENT), and the availability of fertilizer per net cropped area (FERTILIZER) using the available data. The variables entering these equations are discussed below.

The measure of relative sectoral rates of return is a ratio of the average revenue per hectare from the various cropping activities relative to per capita income in nonagriculture. The nonagricultural income is calculated for the state as a whole, whereas the agricultural measure varies by district. The changes in the profitability of agriculture brought about by technical change are captured by this variable. This variable (SECPROF) is expressed as an index, with the average value of the same variable for 1960-66 serving as the base.

A direct measure of resource availability is not available, as there are no annual data on total capital by district. As an alternative, per capita output is utilized. This measure, introduced by Mundlak and Hellinghausen (1982), can be shown to represent the availability of comprehensive (physical and human) capital under the assumption that the aggregate production function, properly specified, is constant returns to scale in labor and all forms of capital, physical and human. Hence, average labor productivity can be written as $y = F(k_p,k_h)$, where y is the aggregate output per unit of labor and k_p and k_h are vectors of the various physical and human capital components divided by the labor force. This expression indicates that y can be interpreted as a natural aggregate of human and physical capital. The per capita state output measured in constant prices (INCOME) is included as a proxy for y.

As equation (31) indicates, the level of investment also depends on the existing capital stock. The available stock is represented by the lagged dependent variable. In the case of the AREA equation, rather than including lagged net cropped area, its individual components (lagged PRIVATE and GOVERNMENT IRRIGATION area and DRY area) are included separately. Such a decomposition allows the various components of lagged net cropped area to have different effects on the investment decisions. A similar argument explains the inclusion of the same components in the equation explaining private irrigation. Population pressure, measured by population density, is included to represent the expected increase in demand for agricultural output. Finally, lagged total fertilizer per cropped hectare is included as an indication of fertilizer availability.

As indicated earlier, the allocation of resources by the government may in fact be influenced by factors similar to those influencing the private sector. Thus, even though the government may have objectives different from those of individuals, the very fact that resources are limited implies that government should give more weight to areas or projects that are most productive. Districts vary by their productivity and therefore by their rate of return. To examine whether the agricultural productivity of one district relative to the other districts has an influence on the government's resource allocation decisions, a measure of the value of production per net cropped area of each district relative to the average productivity per hectare for the state (DISTPROF) is constructed and included in the fertilizer and government irrigation equations.

In addition to the profitability variable, the allocation of fertilizer to the various districts of Punjab (per net cropped hectare) is determined by the availability of roads and the availability of irrigation.

Results

Definitions of variables included in the equations to explain the four quasi-fixed inputs are summarized in Table 19. The equations were estimated simultaneously with the rest of the system. The results are presented in Table 20.

Table 19— Definition of variables: quasi-fixed input equations

Variable	Definition
Dependent variables	
AREA	Net cropped area (1,000 hectares)
PRIVATE IRRIGATION	Net irrigated area (private) (1,000 hectares)
GOVERNMENT IRRIGATION	Net irrigated area (government) (1,000 hectares)
FERTILIZER	Total fertilizer/net cropped area (kilograms of nutrients/hectare)
Independent variables	
DRY AREA	Net cropped area not irrigated (1,000 hectares)
SECPROF	Index: value of agricultural production/nonagricultural net domestic product (NDP) (t−1)[a]
POPDEN	Population/area (people/million hectares)
INCOME	Real state NDP (Rs 10 million) per capita
E FERTILIZER	Fertilizer (t−1)
DISTPROF	Value of production/hectare (t−1) deflated by average value of production/hectare (t−1) for all districts
ROADS	Roads (kilometers)/1,000 hectares
DISTRICT	A dummy variable is introduced for each district[b]

[a]This variable is expressed as an index with the average value of the the same variable serving as a base.
[b]The districts are listed in Table 20.

Table 20 — Estimates from capital equations

Explanatory Variable	Dependent Variable: AREA	PRIVATE IRRIGATION	GOVERNMENT IRRIGATION	FERTILIZER
Incentives				
SECPROF	-2.10395 (-0.57)	33.7034 (7.06)	...	...
DISTPROF	...	...	-3.058 (-0.39)	13.756 (1.73)
POPDEN	0.01951 (3.13)	-0.019 (-1.99)	...	...
Availability of resources				
INCOME	-0.59157 (-0.24)	2.607 (0.63)	2.136 (0.97)	...
E FERTILIZER	...	0.139 (1.69)	...	...
ROADS	...	...	...	25.698 (12.61)
Other				
DRY AREA (t-1)	0.06734 (1.03)	-0.096 (-1.14)	0.026 (0.42)	...
PRIVATE IRRIGATION (t-1)	0.14044 (2.05)	0.806 (8.88)	0.019 (0.29)	-0.016 (-0.38)
GOVERNMENT IRRIGATION (t-1)	0.08352 (0.86)	0.132 (1.31)	0.664 (8.75)	-0.066 (-1.55)
Fixed effects				
GURDASPUR	-123.64 (-7.60)	-15.42939 (-0.93)	8.82658 (0.91)	-27.54788 (-1.09)
AMRITSAR	-5.22488 (-0.22)	-28.9003 (-1.93)	60.19312 (5.97)	28.47981 (0.73)
KAPURTHALA	-222.7 (-12.39)	-26.97111 (-1.24)	-7.98002 (-0.5)	55.45109 (0.58)
JULLUNDUR	-122.7 (-8.66)	-25.32409 (-1.32)	-6.59003 (-0.82)	2.15611 (0.09)
FEROZEPORE	439.19 (10.14)	-63.18901 (-1.38)	138.79 (4.16)	47.62404 (1.65)
LUDHIANA	-83.20416 (-7.6)	21.35437 (1.53)	-2.80727 (-0.39)	49.99803 (1.57)
BHATINDA	267.65 (8.94)	-63.32079 (-1.98)	118.57 (4.95)	34.97265 (1.26)
SANGRUR	70.66944 (6.00)	-20.18259 (-1.91)	31.84535 (4.06)	8.78769 (0.33)
INTERCEPT	292.7 (12.42)	44.39443 (1.25)	-1.12094 (-0.05)	-38.2759 (-1.5)
R^2	0.9977	0.9492	0.992	0.9228

Notes: Numbers in parentheses are t-statistics. See Table 19 for definitions of variables.

Recall that the two key determinants of investment are largely represented by state-level variables.[31] Thus they measure only variations over time that are uniform to all districts. Further, both these variables exhibit a trend that reflects the increase in productivity over the relatively short period analyzed. As a consequence, multicollinearity, as indicated by high R^2's and low t-values for many of the coefficients, appears to be a problem. To help alleviate the problem, some variables included in the initial specification of the equations have been dropped. Thus the results should be interpreted as suggestive until substantiated with additional evidence. With this caveat, the results are now reviewed.

The overall fit (R^2) of each equation is high. The quasi-fixed input most responsive to economic stimuli is area irrigated by private sources. Recall that, among the quasi-fixed inputs analyzed, private irrigated area increased the most over the period under consideration. What is more important is that these changes occurred as a result of decisions made by farmers themselves. Private irrigated area shows a very distinct response to the measure of differential intersectoral productivity (SECPROF). It also responded positively to the proxy for comprehensive capital (INCOME) but the coefficient is not significant. The population density has a negative sign, opposite to that obtained in the net cropped area (AREA) equation. In terms of Ricardian analysis, this result suggests that population pressure favored the extensive margin at the expense of the intensive margin. For this explanation to hold, the expansion of the extensive margin requires resources. Because the verdict on this hypothesis is not crucial for the present analysis, it is left as a working hypothesis for future investigation.

Note that the steady state response of private irrigated area to changes in the state variables is larger than that indicated by the reported coefficients, which have to be augmented by taking into account the coefficients of the lagged dependent variables.

In 1965/66, 76 percent of the geographical area in Punjab was being cultivated. Thus the scope for expansion in net cropped area has been rather limited. Figure 37 indicates that it only changed approximately 10 percent over the sample period. The results suggest that changes in net cropped area are best explained by increasing population pressure as represented by population density and by area irrigated by private sources. Thus, expansions in net cropped area are indirectly responsive to changes in incentives and the availability of comprehensive capital.

As indicated, area irrigated by government sources expanded only by 17 percent over the period 1965-79 (Figure 20). The changes in area irrigated by government sources may reflect the supply conditions of unused water sources suitable for canal irrigation. This may partially explain the results, which indicate that area irrigated by government sources is not influenced by the economic variables under consideration.

The amount of fertilizer allocated to the various districts was positively and strongly affected by the availability of roads and positively affected by the differential productivity of each district (DISTPROF). Thus it appears that the fertilizer

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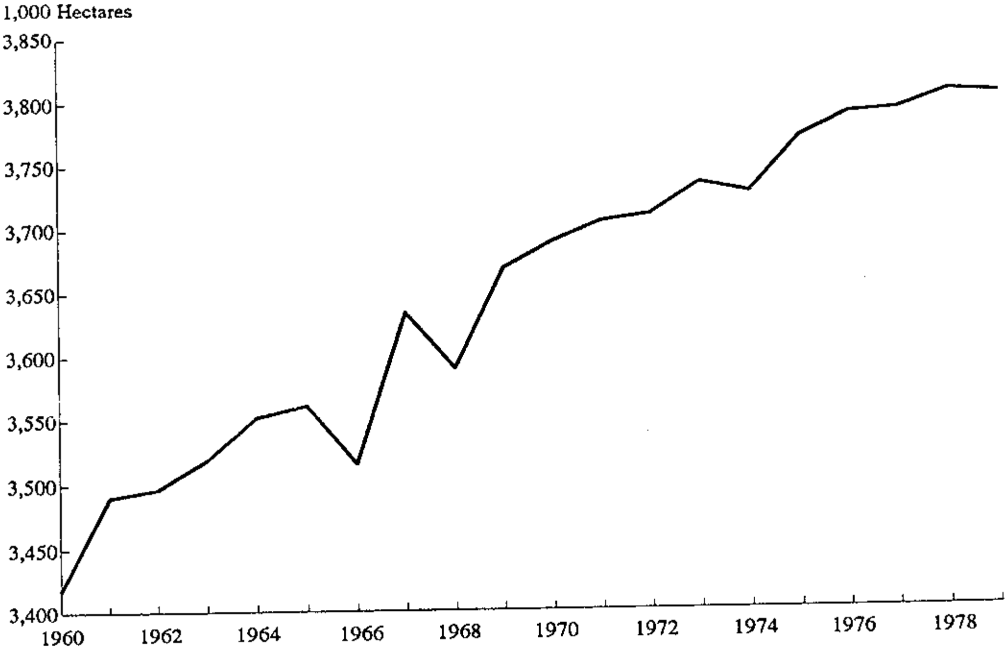
[31]These variables are the measure of the total availability of resources (INCOME) and (the denominator in) the measure of the relative sectoral rates of return (SECPROF).

Figure 37—Net cropped area, 1960-79



Source: Punjab, *Statistical Abstracts of Punjab* (Chandigarh: Economic and Statistical Organization, various years).

equation describes the distribution of the existing fertilizer supply to the various districts rather than changes in total supply.

To summarize, the results suggest that the decisions made by farmers regarding irrigation, and indirectly regarding net cropped area, were responsive to the increase in profitability spurred by the introduction of the MVs. The review in Chapter 3 shows that farmers also increased their investment in tractors. This suggests that the various components of physical capital were complementary and therefore expanded together.

A similar response to incentives was not found for the government decisions regarding investment in irrigation, although some response is detected for fertilizer. Even so, the level of these inputs, particularly fertilizers, increased over the same period. Chapter 3 indicates that the same is also true regarding the provision of electricity in the rural areas. Thus, one can conclude that the government has been responsive to economic incentives, but as expected, the exact decision process has not been revealed in the empirical analysis.

The Long-run Path

The various equations of the system are now assembled in order to obtain the long-run response of the system to changes in the state variables. These responses will differ from the short-run responses discussed in Chapter 5. For instance, an increase in product price changes the differential returns in favor of agriculture. This causes an expansion of private irrigation, which in turn increases net cropped area. Changes in product prices also affect the differential returns to land across districts and thus affect the allocation of fertilizers to the various districts. Thus a change in product price affects acreage allocation, yield, and therefore output, directly as well as indirectly through the changes in the constraints just described. The change in yield, in turn, also affects the differential profitability of agriculture and thereby produces a secondary effect. The sum of all these effects can be obtained by inducing a shock to, and dynamically simulating, the system. By comparing the results derived from this exercise with the results from a (dynamic) base run, long-run elasticities can be obtained.

The results are reported in two parts. First, Table 21 presents the average elasticities of the quasi-fixed inputs with respect to a change in each of the prices, the availability of roads, and the availability of fertilizers. The most striking findings in Table 21 are the particularly large elasticities of net area irrigated by private sources with respect to each of the price variables and with respect to the two constraints. These large elasticities illustrate clearly that farmers responded positively and strongly to the changes in economic incentives over the study period.

Table 22 presents the average long-run output elasticities with respect to the same state variables. The long-run output elasticities with respect to price are all large (in absolute value) relative to their short-run counterparts. For instance, the elasticity with respect to wheat price is 0.784 for wheat output and 0.563 for aggregate output. The corresponding values for the same short-run elasticities are 0.107 and 0.066, respectively (Table 18). An increase in all prices by 1 percent leads to an increase in the output of all crops except gram. The average long-run elasticity of aggregate output with respect to a change in all real prices is 0.77 percent. This is a very sizable aggregate supply elasticity.

Table 21— Average quasi-fixed input elasticities

Variable	PRIVATE IRRIGATION	GOVERNMENT IRRIGATION	AREA	FERTILIZER
Expected prices[a]				
WHEAT	0.944	-0.047	0.027	0.268
GRAM	0.134	-0.006	0.004	0.054
RICE	0.118	-0.006	0.004	0.028
COTTON	0.073	-0.004	0.002	0.032
MAIZE	0.124	-0.006	0.003	0.036
All prices	1.395	-0.070	0.040	0.419
Constraints				
ROADS[a]	0.341	-0.008	0.011	1.302
FERTILIZER[b]	0.256	-0.007	0.008	. . .

[a]To calculate these elasticities, the full model was simulated with all quasi-fixed inputs endogenous (PRIVATE IRRIGATION, GOVERNMENT IRRIGATION, net cropped AREA, and FERTILIZER). Average elasticities for the sample period are reported.
[b]These elasticities are calculated by simulating the full model and fixing FERTILIZER = FERTILIZER (SAMPLE) × 1.01. All other quasi-fixed inputs (PRIVATE IRRIGATION, GOVERNMENT IRRIGATION, and net cropped AREA) are endogenous.

Table 22 — Average long-run output elasticities

Variable	Wheat	Gram	Rice	Maize	Cotton	Production[a]
Expected prices[b]						
WHEAT	0.784	-1.568	0.277	0.366	0.058	0.563
GRAM	0.061	-0.318	0.038	0.041	0.028	0.013
RICE	0.082	-0.148	0.164	-0.013	0.041	0.093
MAIZE	0.085	-0.132	0.016	0.221	-0.024	0.069
COTTON	0.039	-0.192	0.087	-0.037	0.076	0.029
All prices	1.054	-2.360	0.580	0.578	0.180	0.770
Constraints						
ROADS[b]	0.443	-0.458	1.111	-0.153	0.153	0.436
FERTILIZER[c]	0.262	-0.632	0.316	0.148	-0.087	0.210

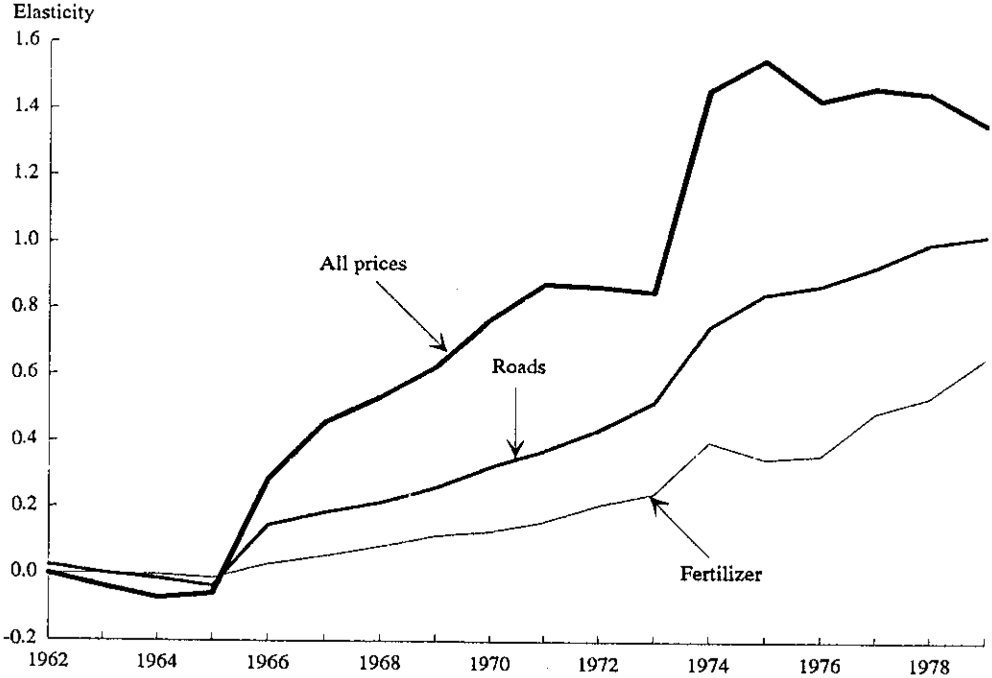
[a]Change in total production is calculated using a Normalized Quadratic Quantity Index (see Diewert 1976).
[b]To calculate these elasticities, the full model was simulated with all quasi-fixed inputs endogenous (PRIVATE IRRIGATION, GOVERNMENT IRRIGATION, net cropped AREA, and FERTILIZER). Average elasticities for the sample period are reported.
[c]These elasticities are calculated by simulating the full model and fixing FERTILIZER = FERTILIZER ×1.01. All other quasi-fixed inputs are endogenous.

Next, the time profile of the long-run responses is examined. The time paths of the aggregate output elasticities with respect to a change in all real prices (aggregate supply elasticity), a change in the availability of fertilizer, and a change in the availability of roads are all illustrated in Figure 38.

As indicated in Chapter 5, the response of the system to a shock in a state variable depends on the implemented technology. The more productive the implemented technology, the greater the response (in absolute value). This phenomenon is well illustrated by the plots of the aggregate output elasticities in Figure 38. Perhaps the most startling of all the results is the size of the aggregate supply elasticity toward the end of the transition period. Before the onset of the green revolution, the aggregate supply elasticity was close to zero, but by the time the transition to the MVs was, for the most part, complete, the aggregate elasticity of supply reached a level between 1.3 and 1.5. Similar results were found for the elasticities of aggregate output with respect to the availability of roads and fertilizers. Both of these elasticities were negligible in the early 1960s, but by the end of the period the elasticity of aggregate output with respect to fertilizers was 0.7 and the elasticity of aggregate output with respect to roads was 1.0. Very similar results were obtained for the other long-run elasticities.

One limitation of this study is that not all relevant capital inputs are included in the empirical model. An important question is what effect this omission has on the results obtained and the interpretations given. As the various forms of capital are largely complementary, it is likely that by omitting these variables, the coefficients on the included variables are biased upward and thus their elasticities are exaggerated. However, since the correlation between the various capital components is not perfect, not all the effects of the missing variables are taken into account. Therefore, the long-run output elasticities obtained tend to underestimate the actual elasticities. As the estimates of the elasticities calculated are already considerably higher than those obtained in conventional supply analyses, it may seem strange even to consider that the elasticities could be even higher. However, this is a bad criterion for assessing the reasonableness of the elasticities. As indicated in Mund-

Figure 38—Long-run aggregate output elasticities with respect to state variables, 1962-79



lak 1988, if techniques coexist and factor prices remain constant, the transition to the more productive techniques will occur as the constraints to adoption are relaxed. The implication, of course, is that supply is perfectly elastic. This result is obtained under the assumption that factor prices remain unchanged in the transition process. Factor prices did not remain unchanged in Punjab as the factor supply curves are upward-sloping. Thus the product supply elasticities are smaller than infinity but very reasonable indeed.

7

CONCLUSIONS

Much of the rapid growth in NDP experienced by Punjab during the period of study was generated by growth in agriculture. Most of this growth is attributed to growth in crop production resulting from improvements in the overall yields of wheat and rice and to a lesser extent from improvements in the yields of maize and cotton. The pattern of growth in overall yields for the various crops, particularly wheat and rice, suggests that the main improvements came as a result of a shift to modern higher-yielding varieties rather than as a result of intensifying the cultivation of existing varieties. Given that, in general, economic growth is driven by technical change, an understanding of the many factors that influenced the rate of implementation of new techniques in Punjab contributes to an understanding of agricultural growth.

In Punjab, the shift to MV wheat and rice was very fast. The first year the modern wheat varieties were introduced they were sown to 30 percent of the total wheat area. This proportion increased to 70 percent by only the third year. The experience in rice was similar, once suitable rice varieties were introduced. The extremely rapid adoption of MV wheat and rice indicates that factors usually associated with the rate of implementation of new techniques, such as imperfect information, uncertainty, institutional constraints, and inadequate human capital, did not play a prominent role in the adoption process. That is, these factors could not have changed much over the extremely short transition period, and therefore could not have influenced the rate of adoption. Alternatively, the speed at which the new varieties were implemented suggests that the pace of transition was largely determined by the productivity of the MVs relative to the traditional varieties and the existence of physical constraints.

To assess the relevance of this working hypothesis, the growth in Punjab agriculture is modeled utilizing a choice-of-technique framework. Given that much of the agricultural growth can be attributed to the implementation of new techniques of production, a complete understanding of the growth process requires that the factors affecting the decision to implement these techniques be identified explicitly.

The techniques analyzed are the major crops in Punjab, identified by variety, season of growth, and method of production (dry versus irrigated). It is hypothesized that in the short-run, area allocation decisions are influenced by the expected revenues of the different techniques; the availability of fertilizers, irrigation, and cropped area; and the local environment. Overall yields by crop are assumed to be determined by the composition of techniques implemented, the availability of fertilizers, and the local physical environment. The effect of the local physical environment, the initial levels of infrastructure, and the availability of human capital on choice of technique and overall level of output are detected by the inclusion of fixed district effects.

Because resources are scarce and therefore have to be attracted to agriculture from other uses, changes in the availability of fertilizers, irrigation, and cropped area are hypothesized to depend on the overall availability of resources and the differential rate of return between agriculture and nonagriculture. The relative importance of these factors depends on whether the decisions are made by the public or private sector. Equations analyzing the investment decisions of both the private and public sectors are estimated simultaneously with the area allocation and yield equations.

The results are summarized by deriving both short-run and long-run elasticities. The specification of the model implies that the size of both the short-run and long-run elasticities depends on the productivity of the implemented technology; the more productive the implemented technology, the greater are the elasticities (in absolute value).

The short-run area elasticities by technique indicate that changes in the availability of quasi-fixed inputs have very significant intertechnique effects. In particular, the pace of the transition to the MVs of both wheat and rice is positively influenced by the availability of all quasi-fixed inputs. Further, given fixed levels of the quasi-fixed inputs, changes in incentives lead to important changes in the composition of techniques. Increases in the expected revenue of the superior varieties of all crops, whether due to an increase in expected price or yield, encourage the adoption of these varieties. This finding suggests that if the real price of wheat and rice had not been declining over the period of study (see Chapter 3), the transition to the MVs would have been even more rapid.

Even though the response to incentives was important, the magnitude of the elasticities suggests that intertechnique effects due to changes in the availability of quasi-fixed inputs are often severalfold larger than the same elasticities due to changes in the incentives (in absolute value). The availability of private irrigation and roads appears to have been particularly important in the transition process. The area allocation results also indicate that the competition between techniques as the availability of resources and incentives changed differed by crop and season.

The importance of the intertechnique results is reinforced by the yield results, which indicate that the choice of implemented techniques largely determines overall yield by crop. In addition, the (fixed) local environment has a significant influence on yield levels.

For the most part, the short-run output elasticities reiterate the area results in indicating that the availability of quasi-fixed inputs played a major role in the determination of the growth of output; the magnitude of the output elasticities with respect to the quasi-fixed inputs is large relative to their price counterparts.

The short-run aggregate output elasticity with respect to a change in all (real) prices increased from nearly zero before the onset of the green revolution to a high of 0.18 in 1979, when the transition to the MVs of wheat and rice was largely complete. Thus, conditional on the availability of quasi-fixed inputs, aggregate agricultural output does not respond much to a change in price.

The results from the quasi-fixed input equations suggest that the decisions made by farmers regarding irrigation, and indirectly regarding net cropped area, were responsive to the increase in profitability spurred by the introduction of the

MVs. The long-run elasticities of area irrigated by private resources with respect to prices and the availability of roads and fertilizers were particularly large.

Although similar responses were not obtained in the government investment equations as specified, the observed increases in the provision of electricity and the availability of fertilizers and roads suggest that the government has responded to economic incentives.

The long-run output elasticities with respect to prices are all large relative to their short-run counterparts. These elasticities reflect the strong response of private irrigation and the somewhat more moderate response of net cropped area and fertilizers as incentives changed. The long-run aggregate supply elasticity, although negligible before the onset of the green revolution, reached a high between 1.3 and 1.5 in the late 1970s. Although these aggregate supply elasticities are large relative to those obtained in other studies that do not model explicitly the choice of technique and change in the availability of resources, they make sense given the conceptual framework of this study.

Given the results of this study, one can conclude that as long as expansions in irrigation facilities and fertilizers are possible and lead to further adoption of the more productive techniques, aggregate agricultural output will continue to respond significantly to changes in economic incentives. However, once the transition to the new varieties is fully played out, stagnation will occur. Once stagnation occurs, further substantial growth in agricultural output will require the introduction of new higher-valued techniques and products. If these new techniques are more capital-intensive than the previously implemented techniques, the rate of capital accumulation will continue to play a critical role in the growth of agriculture.

APPENDIX 1: ADJUSTMENTS FOR BOUNDARY CHANGES

Based on data published in the *Statistical Abstracts of Punjab*, the total area in each of the various districts of Punjab has changed continually over time. Although most changes have been negligible, substantial changes occurred in the districts of Hoshiarpur, Sangrur, Ferozepore, and Bhatinda during the sample period.

Although it is unclear exactly when the division occurred, the districts of Ferozepore and Bhatinda were split into the three districts of Ferozepore, Bhatinda, and Faridkot. Data for both Ferozepore and Bhatinda before 1971 include the data for area that is now in Faridkot. Rather than disentangle these data and try to recover the data for Faridkot, the data published for Faridkot in years after 1971 are divided between Ferozepore and Bhatinda according to the area in Faridkot that originated in each of these districts. That is, approximately 70 percent of the area in the new district of Faridkot was originally in the district of Ferozepore; thus, 70 percent of each area series reported for Faridkot is added to the same area series in Ferozepore, while the remainder (30 percent) is added to the Bhatinda data, as approximately 30 percent of the area in the present district of Faridkot originated from the old district of Bhatinda.

The area of Hoshiarpur and Sangrur decreased 32 and 34 percent, respectively, during the division of erstwhile Punjab into present-day Punjab and Haryana in 1966. For the purpose of this study, the present-day districts of Hoshiarpur and Sangrur are analyzed. Thus the pre-1965 data are adjusted to make the older data series consistent with the more recent data. For the most part, the data obtained were already adjusted for the changes that occurred. For Sangrur, for example, all data appeared to be adjusted, and thus consistent with the present-day data series, with the exception of data on area sown to wheat. To determine how to adjust these data, an adjusted series and an "old" series of gross cropped area available for the years 1960-64 were compared. Based on these comparisons, it appeared that an adjustment factor of 0.65 was used to make the pre-1966 data consistent with the more recent data. The remaining unadjusted data for Sangrur were adjusted using this adjustment factor. Similarly, all unadjusted data for Hoshiarpur in the pre-1966 years were adjusted using an adjustment factor of 0.77, calculated in a manner identical to that described above for Sangrur. Unfortunately, further checks of the data for Hoshiarpur indicated problems in the irrigation data for the years 1968-1972. In particular, unreasonable numbers were obtained for irrigation intensity (gross irrigated area divided by net irrigated area). Thus the data for this district were ultimately dropped from the analysis.

APPENDIX 2: DERIVATION OF AREA AND EXPECTED YIELDS BY TECHNIQUE

Derivation of Area

Over the period of the study, new varieties were introduced for many of the crops. The most significant changes occurred in both rice and wheat and to a smaller extent in maize. Information is available on area planted to these new varieties.

For the purpose of this model, the assumption is made that there are three techniques of production for wheat and rice. The three techniques include an irrigated modern variety (MV) and two traditional varieties (irrigated and dry). Given the assumption that all MVs in Punjab are irrigated, the disaggregation of wheat and rice into these three varieties is straightforward. That is, data are available for the total area planted to each crop, total area irrigated for each crop, and area planted to MVs for each crop. Using this information and the assumption that all MVs are irrigated, area allocated to each technique of wheat is calculated as follows:

$$\text{MV Wheat Area} = \text{MV Wheat Area (Given)}, \tag{32}$$

$$\text{Irrigated Traditional Wheat Area} = \text{Total Irrigated Wheat Area} - \text{MV Wheat Area, and} \tag{33}$$

$$\text{Dry Traditional Wheat Area} = \text{Total Wheat Area} - \text{Total Irrigated Wheat Area.} \tag{34}$$

Similar calculations are made to disaggregate rice area by variety. With the exception of a few negative numbers obtained for irrigated traditional wheat and rice area (equation [33]), the data derived as the result of this disaggregation process indicate that the assumption is reasonable. It is assumed that the negative numbers indicate that some MVs are also planted on dry land. (Alternatively, the negative numbers may be indicating problems with the data.) Because the negative numbers were generally small—relative to the total area sown to wheat (rice)—rather than disaggregating the MV wheat (rice) area into two activities (irrigated MV and dry MV), the assumption that all MVs are grown on irrigated land is maintained; irrigated traditional wheat (rice) area is set equal to zero, and the amount of dry traditional wheat (rice) calculated by equation (34) is reduced by the amount of dry land presumed to be planted to dry MVs.

For the remaining crops (maize, cotton, and gram), the assumption is made that there are only two techniques of production, irrigated and dry traditional varieties. Area allocated to the dry traditional varieties is derived as in equation (34), and total area irrigated by crop is given in the original data.

Although information regarding adoption of maize MVs is available, production of maize is only disaggregated into irrigated and dry techniques because the extent to which these new varieties have been accepted has been relatively minor and has fluctuated over time. A large part of this varied success is explained by the unreliable yields of the newer varieties and the problems some of these varieties have experienced with disease and drought. Because the data required to study the effect of these problems on the rate of adoption of the new varieties are not available in the data base, the distinction between irrigated varieties is not made.

Expected Yields: Traditional Varieties

A full series of data on yield by variety is not available for the traditional varieties. Data from *Farm Accounts in Punjab* are used to construct these variables. The data provided in this series are the result of a survey of 32 nonmechanized holdings throughout Punjab. Although the sample is notably small and the holdings surveyed have changed over the years, this study relies on the assumption that the data "indicate, within reasonable limits, trends or relative changes that take place from year to year in the financial position of the farmers" (*Farm Accounts in Punjab, 1975/76*, p.6). Data are available from *Farm Accounts in Punjab* for the following years: 1960-69, 1972, 1975, and 1979, by geographical region.[32] Separate yields for each crop are given for irrigated and unirrigated areas. Because the series is not complete, the construction of the yield variables from these data involved manipulation of the available data and several assumptions.

In general, expected yields for each traditional variety (irrigated and dry) for all years and all districts were obtained by regressing the available or relevant data on regional intercept shifters and a time trend. Regional intercept shifters are incorporated to allow expected yields to vary across regions, and a time trend is incorporated to allow for the possible improvement over time of the different techniques of production. The significance of the fixed regional effects and the time trend was assessed using an F-test or a t-test. With the exception of the irrigated maize yield, the regression results suggest that the yields of the traditional varieties have not changed significantly over time. The increase in irrigated maize yield undoubtedly reflects the introduction of improved varieties of maize during the period of study. The fixed regional effects were significant in every equation except irrigated gram and irrigated traditional wheat. Thus, for all varieties except irrigated gram, irrigated traditional wheat, and maize, the average regional yield of each traditional variety is used as an indication of the expected yield. The expected irrigated maize yields were calculated by taking into account the significant regional effects and the significant trend variable. Given the lack of significant regional effects and time trend, the expected irrigated gram and traditional wheat yields were calculated by averaging the available data over time and across all districts. The expected yields calculated for each variety are detailed below.

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[32]In *Farm Accounts in Punjab*, Punjab is divided into three physical regions closely corresponding to those discussed in Chapter 3. Region 1 corresponds to the hilly area and includes the districts of Hoshiarpur and Gurdaspur; region 2 is the central plains area and includes the districts of Amritsar, Jullundur, Kapurthala, Ludhiana, and Patiala; and region 3 comprises the southwestern districts of Ferozepore, Bhatinda, and Sangrur.

Wheat: Dry Traditional Yield

The available regional yield data for unirrigated wheat (1960-66) were used to calculate the following expected yields (tons per hectare):

Region 1: 0.884 Region 2: 0.711 Region 3: 0.541

Wheat: Irrigated Traditional Yield

Regional yield data for irrigated wheat (1960-66) were used to calculate the following expected yields (tons per hectare):[33]

Region 1: 1.249 Region 2: 1.249 Region 3: 1.249

Rice: Dry Traditional Yield

Dry rice yields are available only for region 1 (the area with the highest rainfall) in *Farm Accounts in Punjab*, yet some rice is grown in other regions. To calculate a yield for the other two regions the average (dry) yield from region 1 (1960-66) is used as a base, and the region 2 and region 3 yields are calculated using the regional effects obtained from the dry gram results (see below). The gram regional effects are used rather than the more likely choice of maize, as the gram calculations are based on a larger number of observations.[34] Thus the expected yields (tons per hectare) are

Region 1: 1.09 Region 2: 0.606 Region 3: 0.594

Rice: Irrigated Traditional Yield

As with irrigated traditional wheat, only regional yield data for 1960-66 were used to calculate the following expected yields (tons per hectare):

Region 1: 1.49 Region 2: 1.24 Region 3: 1.29

Maize: Dry Traditional Yield

A full series of data required for this calculation is available for regions 1 and 2. Data for region 3 are available only for two years. The average yields for regions 1 and 2 are used as the expected yield for these regions. The two data points available for region 3 are compared with the average yield over the same years for region 1. The average yield of region 3 is 0.92 times that of region 1. This figure (0.92) is used to adjust the average yield of region 1 for the whole sample (1960-66) to obtain a yield for region 3. The resulting expected yields (tons per hectare) are

[33]Other data were available but not used, as it is assumed that after 1966 the irrigated wheat yields reflect a mix of both traditional varieties and MVs.

[34]Maize is a better choice, as it is grown in the same season; however, the region 3 effect may not be reliable, as data available are sparse. Further, the regional effects for gram and maize (dry) yields are very similar for regions 1 and 2, where data are more abundant. Thus, the more reliable region 3 effect for gram is used.

Region 1: 1.26 Region 2: 0.68 Region 3: 1.16

Maize: Irrigated Yield

Because the irrigated maize category includes a combination of both traditional varieties and MVs, the calculation of expected yield is not limited to pre-1967 years. However, the availability of data does limit the analysis to the years 1960-69, 1972, 1975, and 1979. The results from the regression of all the available yield data on the regional intercept shifters and time trend indicate that both effects are significantly different than zero. Based on the results obtained, the expected yields (tons per hectare) are (1960, t =1)

Region 1: 0.919 + .036t Region 2: 1.17 + .036t Region 3: 0.58 + .036t

Cotton Yields

Expected yields are calculated separately for each variety of cotton. The final expected irrigated and dry cotton yields are calculated by weighting the yields described below by the proportion of cotton acreage planted to each variety.

Desi Cotton: Dry Yield

A full data series on unirrigated Desi cotton yields are available only for region 1 (1960-69, 1972, 1975, and 1979). The regression of these yields on a time trend indicates that the time trend is not important. Region 2 yield data are available for four years only and data for region 3 exist for only three years. Expected yields for these regions are calculated using an approach identical to that used to calculate dry maize yield for region 3. Based on the results obtained, the expected yields (tons per hectare) are

Region 1: 0.445 Region 2: 0.383 Region 3: 0.435

Desi Cotton: Irrigated Yield

Yield data from all three regions over the years 1960-69, 1972, 1975, and 1979 were used to obtain the following expected yields (tons per hectare):

Region 1: 0.485 Region 2: 0.592 Region 3: 0.596

American Cotton: Dry Yield

As with dry Desi cotton, a full yield series is available only for region 1. No yield data are available for the other two regions. The regression of yield data from region 1 on a time trend indicates that the yields do not change significantly over time. The regional effects for the Desi dry yields are used to obtain expected yields for the other two regions using the calculated yield for region 1 as a base. The resulting expected yields (tons per hectare) are

Region 1: 0.539 Region 2: 0.464 Region 3: 0.527

American Cotton: Irrigated Yield

Irrigated American cotton yields are available only for region 2 and region 3. Regression results suggest that only the regional effect is significant. Using the regional effects obtained in the analysis of Desi cotton (irrigated) yields and the expected American cotton (irrigated) yield for region 2 as a base, a yield for region 1 is derived. The resulting expected yields (tons per hectare) are

Region 1: 0.546 Region 2: 0.666 Region 3: 0.823

Gram: Dry Yield

Data are available for dry gram yield in all regions for the following years: 1960-69, 1975, and 1979. Based on these data the expected yields (tons per hectare) are

Region 1: 0.910 Region 2: 0.506 Region 3: 0.496

Gram: Irrigated Yield

Data are available only for regions 2 and 3 for the years 1960-69, 1975, and 1979. Given that both the time trend and the regional fixed effects were insignificant, the expected irrigated gram yield is assumed to be the same in all regions. The expected irrigated gram yield is 0.645 tons per hectare.

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