WPS 2234

POLICY RESEARCH WORKING PAPER 2234

The Green Revolution and the Productivity Paradox

Evidence from the Indian Punjab

Rinku Murgai

In assessing new technologies, policymakers should allow time between the adoption of the technologies and the realization of productivity gains attributable to them. Productivity growth was much lower than might be expected during the green revolution in the Indian Punjab but improved as learning processes took effect and resource management and the use of inputs became more efficient.

The World Bank
Development Research Group
Rural Development
November 1999

Summary findings

Murgai provides district-level estimates of the contribution of technical change to agricultural output growth in the Indian Punjab from 1960 to 1993.

Contrary to widespread belief, productivity growth in the Punjab was surprisingly low during the green revolution (in the mid-1960s), when modern hybrid seed varieties were being adopted. It improved later, after adoption of the new varieties was essentially complete.

Murgai proposes three reasons for this pattern:

- The standard measure of total factor productivity overstates the contribution of capital to output growth at the expense of the productivity residual. High-yielding varieties introduced in the 1960s helped spur output growth by making crops responsive to water and fertilizer, which not only allowed but indeed encouraged far greater use of capital inputs. This increase in the elasticity of the output response to capital inputs is incorporated into the index of factor accumulation and therefore excluded from the measure of total factor productivity growth. As a result, the contribution of technical change to growth in Punjab's agriculture during the green revolution is probably underestimated.
- The overstatement of the capital contribution during the green revolution is exacerbated by indivisibilities in capital inputs.
- Productivity growth did not come from the adoption of modern varieties alone. Improved resource management and public investment in infrastructure also helped improve productivity.

This paper — a product of Rural Development, Development Research Group — is part of a larger effort in the group to study the determinants and impact of technology adoption and productivity growth in agriculture. The study was funded by the Bank's Research Support Budget under the research project "Productivity and Sustainability of Irrigated Systems in South Asia" (RPO 680-34). Copies of this paper are available free from the World Bank, 1818 H Street, NW, Washington, DC 20433. Please contact Maria Fernandez, room MC3-508, telephone 202-473-3766, fax 202-522-1151, email address mfernandez2@worldbank.org. Policy Research Working Papers are also posted on the Web at www.worldbank.org/research/workingpapers. The author may be contacted at rmurgai@worldbank.org. November 1999. (25 pages)

Produced by the Policy Research Dissemination Center

THE GREEN REVOLUTION AND THE PRODUCTIVITY PARADOX:

EVIDENCE FROM THE INDIAN PUNJAB

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(Development Research Group, The World Bank)

This paper provides district-level estimates of the contribution of technical change to output growth for the agricultural sector in the Indian Punjab from 1960 to 1993. Contrary to most views, productivity growth was surprisingly low during the green revolution years, when modern hybrid seed varieties were adopted, and increased in later years, after adoption was essentially complete. Three reasons are proposed for this pattern. First, the standard measure of total factor productivity (TFP) overstates the contribution by capital to output growth at the expense of the productivity residual. The green revolution technologies increased the elasticity of output response to capital inputs, a factor that is excluded from the measure of TFP growth. Second, overstating the capital contribution during the green revolution is exacerbated by indivisibilities in capital inputs. Third, productivity growth did not come from the adoption of modern varieties alone. Improved resource management and public investment in infrastructure were also responsible for raising productivity.

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[1] I gratefully acknowledge the help provided by Dr. M.S. Bhatia at the Directorate of Economics and Statistics, India, in making the data available for this study. I would like to thank Derek Byerlee, Alain de Janvry, Elisabeth Sadoulet, Paul Winters, and seminar participants at the University of California–Berkeley and The World Bank for their valuable comments.

CONTENTS

INTRODUCTION

The green revolution led to dramatic increases in agricultural production and radically transformed the course of Indian agriculture. Nowhere was this more true than in the state of Punjab, where the new high-yielding varieties (HYVs) of wheat and rice were first and most intensively adopted. From 1965 to 1973, production of wheat, the primary winter (*rabi*) crop, increased at an annual rate in excess of 7 percent. Rice, which was not widely grown prior to the green revolution, grew at a remarkable rate of 18 percent during this period. Overall agricultural production increased at a rate of 6 percent.

This record of growth in production has led many economists to believe that productivity growth must have also been high in Punjab's agricultural sector. More recently, in the years following the green revolution, there has been growing concern that high rates of productivity growth have not been sustained, in light of heavy water and fertilizer inputs, diminishing growth in yields of the major crops, and degradation of the water and land resource base.

This paper examines the empirical justification for the perception that productivity growth was high during the green revolution and has subsequently faltered. I have assembled detailed data for estimating and interpreting trends in total factor productivity (TFP), disaggregated by districts and cropping systems, from 1960 to 1993. The results are surprising. Productivity growth in Punjab was lowest during the green revolution years, even as farmers switched from traditional varieties of wheat and rice to modern hybrid seed varieties and the agricultural sector experienced stellar growth rates in production. TFP growth increased during a phase of rapid factor accumulation that immediately followed the green revolution, after adoption of HYVs was essentially complete.

I propose a solution to the puzzle in two parts. The first part lies in exposing the limitations of the commonly used growth accounting method of measuring productivity growth. The standard approach of computing a divisia TFP index and equating TFP growth with technical change yields biased estimates of productivity growth when technological change is not Hicks neutral. In the Punjab case, the standard approach biases the estimates of productivity growth during the green revolution downward.

The other part of the solution to the puzzle has to do with processes, such as indivisibilities in capital inputs and processes of learning (by both the suppliers and the adopters of technology), that create a lag between technology adoption and the realization of productivity gains. Evidence of a time lag highlights the danger of reading too much into the adjustment problems that often emerge during the early stages of technology adoption.

Although no claim is made that the Punjab case 'represents' South Asia or even India, this paper illustrates processes and factors that are likely relevant elsewhere. By taking these processes and factors into account, policy makers can more readily devise alternative prescriptions for realizing productivity gains more rapidly in regions that lag behind Punjab.

THEORETICAL FRAMEWORK AND DATA

The Tornqvist–Theil Index of TFP[1]

Consider an input-output separable production function:

$$(1)\quad Q_t = f\left(X_t, t\right)$$

where X denotes a vector of m conventional inputs, such as labor, land, and capital; and t denotes the technology (assumed to be equal to an index of time). The primal rate of technical change is given by the rate of growth in output controlling for the weighted growth in input use, where the weights are provided by the elasticity of output with respect to inputs:

$$(2)\quad \frac{\partial \ln f}{\partial t} = \frac{d \ln Q}{dt} - \left(\sum_{j=1}^{m} \frac{d \ln f}{d \ln x_j} \frac{d \ln x_j}{dt} \right)$$

Under the assumptions of profit maximization (inputs are paid their marginal products) and competitive output markets (output price equals marginal cost), we have:

$$(3)\quad \frac{\partial \ln f}{\partial t} = \frac{d \ln Q}{dt} - \left(\sum_{j=1}^{m} S_{jt} \frac{d \ln x_j}{dt} \right) E_{Q,C}$$

where $E_{Q,C}$ is the elasticity of output with respect to cost (a measure of the returns to scale), and S_{jt} is the share of input j in total cost at time t. The bracketed term is the continuous time divisia input index.

Under constant returns to scale technology, if divisia indices are used to aggregate inputs and outputs, the rate of growth of TFP (the ratio of aggregate output to aggregate input) equals the measure of technical change. A discrete time approximation provides an expression of technical change, which can be estimated with observable price and quantity data without estimating the cost or production functions. Several discrete approximations to the divisia index exist; the Tornqvist–Theil approximation is preferred since it yields an exact measure of technical change for the linear homogenous translog production function with Hicks-neutral technical change. The chain-linked Tornqvist–Theil index of TFP for a system with *n* outputs and *m* inputs is defined as:

$$(4)\quad TFP_t = \frac{QI_t}{XI_t} = \frac{\left(QI_{t-1}\right)\prod_{i=1}^{n}\left(Q_{it}/Q_{it-1}\right)^{\frac{1}{2}\left(R_{it}+R_{it-1}\right)}}{\left(XI_{t-1}\right)\prod_{j=1}^{m}\left(X_{jt}/X_{jt-1}\right)^{\frac{1}{2}\left(S_{jt}+S_{jt-1}\right)}}$$

where R_{it} and S_{jt} are the revenue share of output *i* and the cost share of input *j* at time *t*, respectively. Rolling weights in the index accommodate any substantial drift in relative prices of inputs and outputs. Consequently, the rate of change in the TFP index represents changes ensuing from technological change rather than changes in relative prices.

In this study, I estimate the partial factor productivity for important inputs (labor, land, capital, and fertilizer), as well as the TFP for the agricultural sector, by districts and cropping systems.

Model Assumptions and Potential Biases

The divisia TFP index as an appropriate measure of technical change has been criticized for the restrictive assumptions outlined above.[2] For a divisia index to provide an unbiased estimate of productivity growth, a critical assumption—and one that is typically ignored—is that technical change is Hicks neutral. In other words, TFP growth (for a linearly homogenous production function) provides a correct measure of technical change *if and only if* technical change is Hicks neutral. To see this, consider a translog production function with one output and multiple inputs:

$$(5)\ \ln Q = \alpha_0 + \sum_i \alpha_i \ln X_i + \frac{1}{2} \sum_i \sum_j \alpha_{ij} \ln X_i \ln X_j + \beta_0 t + \frac{1}{2} \beta_1 t^2 + t \sum_i \gamma_i \ln X_i \,.$$

With biased technological progress $(\gamma_i \neq 0)$, the rate of growth of output is:

$$(6)\ \dot{Q} = \sum_i \left(\alpha_i + \sum_j \alpha_{ij} \ln X_j + \gamma_i t \right) \frac{d \ln X_i}{dt} + \beta_0 + \beta_1 t + \sum_i \gamma_i \ln X_i$$

where the term in brackets is the elasticity of output with respect to input *i*, or its factor share under profit maximization, perfect competition, and constant returns to scale. As equation 6 shows, when technical change is not Hicks neutral, observed factor shares are not independent of technical progress. Thus, a divisia input index that is computed with observed factor shares conflates the contribution of factor accumulation to output growth with that of technological progress.

Antle and McGuckin (1993) propose that the residual computed by the specification in equation 5 provides an alternative, but appropriate, measure of TFP growth that allows for nonneutral technological change. However, in this case, the contribution of technological progress to output growth comes from two quarters—change in the elasticity of output with respect to input use, and change in TFP.

Data

All input, output, and price data used to compute TFP were collected at the district level from 1960 to 1993.[3] During this period, there were numerous adjustments in district boundaries; district definitions used in this study preserve the classification existing in 1966, when the state of Haryana was created from Punjab. Districts were aggregated into three distinct cropping systems—rice–wheat, cotton–wheat, and maize–wheat—on the basis of cropping intensity and the major summer (*kharif*) crop. Wheat is the dominant *rabi* crop everywhere.

Data were collected at a high level of detail from secondary sources and the Indian Directorate of Economics and Statistics. Major farm outputs—twenty crops, fruits, and livestock products—were aggregated into a divisia output index using district-specific farm harvest prices for the crops and state-level prices for livestock and fruits. The input aggregate included land, animal power, labor, canal water, fertilizer (separately for nitrogen, phosphorous, and potash), pesticides, and capital (separately for tractors, diesel tubewells, and electric tubewells).[4] Land was valued at the average costs incurred per hectare, which include the rental value of owned land; rent paid for leased-in land; and land revenues, cesses, and taxes. Costs of animal labor were computed from the cost of maintenance, which includes the cost of fodder and concentrates, the depreciation on animals and cattle sheds, upkeep labor charges, and other expenses. Labor stocks were converted to the appropriate flow variable (number of person-days per year) by multiplying by a year-specific participation rate. In Punjab, canal water is provided according to a fixed rotation schedule for a monthly per-hectare payment that depends on the crop portfolio for each farmer. Costs of canal water were computed by multiplying an average monthly cost by the quantity of canal-irrigated area.[5] Capital inputs were valued in terms of their operational cost (labor and fuel), their maintenance and repair costs, and the depreciation and opportunity cost of investment.

The analysis was conducted for four periods corresponding to different phases of technical change:

- *Pre-green revolution* (1960–64)—The period leading up to the introduction of HYVs of wheat.[6]
- *Green revolution* (1965–73)—The period beginning with the introduction of HYVs and ending with their widespread adoption, when approximately 85 percent of the wheat area was planted to HYVs. Because modern varieties are thought to have provided the primary impetus for output growth, the contribution of productivity growth to output might be expected to have been high during this period.
- *Input intensification* (1974–84)—The period marked by a rapid increase in fertilizer use. Because the adoption of HYVs was nearly complete and input use was steadily increasing during this period, productivity growth might be expected to have been lower than during the green revolution.
- *Post-green revolution* (1985–93)—A period when fertilizer use leveled off as diminishing returns set in (Sidhu and Byerlee, 1992). The slowing rate of growth in fertilizer use does not necessarily mean that overall input use was lower during this period. An

accumulation of other factors, such as investment in capital, might have continued at a rapid pace. A priori, if concerns about diminishing marginal productivity of inputs and rampant resource degradation are legitimate, then both productivity and output growth should have been lower during this period than during the previous period. However, improved input use efficiency might have counteracted these effects.

Patterns of Production, Input Use, and Prices

To place productivity estimates in appropriate perspective, major characteristics of the agricultural sector from 1960 to 1993 are summarized in table 1.[7] Punjab experienced high rates of crop production growth during the green revolution. Mexican-based dwarf wheat varieties first tested at the Punjab Agricultural University in 1964 were released in 1966. By 1968, the modern varieties of rice, maize, and bajra had also been introduced. Since then, the initial HYVs have been continually modified to meet demand. New HYVs of cotton were widely adopted in the post-green revolution period.

Output growth during the green revolution can be attributed largely to dramatic improvements in the yields of wheat and rice, and to expansion of area under wheat and rice HYVs. The introduction of short-duration modern varieties also allowed for multiple cropping, thereby increasing cropping intensity. In the post-green revolution period, both these sources of output growth (area expansion and yield) declined. However, cultivation broadened for previously minor high-value crops, such as sunflower and vegetables; and high-yielding cotton spread to large parts of Punjab. As a result, the rate of growth of aggregate output outpaced the production performance of wheat and rice during the post-green revolution period.

The adoption of new varieties initiated a period of rapid expansion at both the extensive and intensive margins. Over time, the role of area expansion declined as increasingly marginal lands needed to be brought into cultivation. However, growth at the intensive margin continued to be important in the post-green revolution period. The consumption of chemical fertilizer in Punjab increased from 4 kilograms of nutrient per hectare of cropped area at the onset of the green revolution to 156 kilograms per hectare in the post-green revolution period. The number of mechanized wells (particularly electric tubewells) increased tenfold, from 8 to 80 wells per 1,000 hectares of cropped area. In addition, the use of tractors expanded greatly at the expense of animal labor. Mechanization was stimulated by declining prices for capital inputs and an increase in real wages through the 1980s. Finally, intensification of capital inputs and fertilizer use was accompanied by declining labor utilization rates, which fell from 210 person-days during the green revolution to 155 person-days in the post-green revolution period.[8]

TRENDS IN TFP

Table 2 summarizes various measures of productivity at the state level. Punjab sustained productivity growth rates of 1.3 percent or more in each of the four periods, averaging 1.9 percent from 1960 to 1993. These estimates are comparable to long-term productivity growth estimates reported for Punjab and at the higher end of those reported for All-India.[9] The productivity gains explain approximately 39 percent of the 5-percent growth rate in aggregate output from 1960 to 1993; factor accumulation contributed the remainder to output growth.

There are striking contrasts in the contribution of productivity gains to growth in output across the different periods. First, contrary to expectations, TFP growth was slowest during the green revolution. During this period, output grew at a rapid rate of nearly 6 percent per year, leading economists to believe that productivity growth must have been extraordinarily high. However, factor accumulation shows an equally remarkable upsurge during the green revolution, as evidenced by a growth rate in input use of more than 4.6 percent. Surprisingly low rates of TFP growth during the green revolution are reflected in the trends in partial factor productivity. Productivity growth during this period can be attributed to labor- and land-saving components of technical change, whereas much of the output growth was due to rapid and sustained investments in tubewells and tractors, as well as increased fertilizer and pesticide use.

Second, TFP growth increased to 1.8 percent per year in the input intensification period but slowed in the post-green revolution years to 1.5 percent. As a result, the main source of growth in the later years continued to be factor accumulation and deepening, not TFP gains.

There were also sharp differences in productivity growth across cropping systems and districts (table 3). Districts such as Kapurthala and Ludhiana in the rice–wheat system of central Punjab showed decreases in productivity from 1960 to 1993, whereas districts such as

Bhatinda and Ferozepur in the cotton–wheat system of southwestern Punjab experienced productivity growth in excess of 2.5 percent per year. The rather low productivity residual in the two central districts was accompanied by extremely high growth rates in factor accumulation (particularly capital deepening). By contrast, the maize–wheat system, where the role of inputs was relatively modest, had a more satisfactory rate of technical change (2.4 percent), despite a low output growth.

Patterns of productivity growth across cropping systems do not conform to the state-level trend. Unlike the state-level trend, the cotton–wheat system experienced its highest rates of productivity growth during the green revolution. And despite a state-level productivity slowdown, TFP grew at a faster rate in the post-green revolution period in both the rice–wheat and maize–wheat cropping systems than in the input intensification period.

I propose several hypotheses to explain the diverse patterns of growth experiences across space and over time:

- The contribution of capital accumulation to productivity growth has been overstated by standard growth accounting.
- The time lag between HYV adoption and productivity gains might be partly due to the rate of adopting new varieties.
- The availability of a complementary infrastructure for HYV adoption, particularly irrigation systems, might have influenced productivity growth.
- Recent productivity declines in some areas might be due to resource degradation.

Each hypothesis is separately evaluated below.

Overstating the Contribution of Capital Accumulation

Low levels of TFP growth during the green revolution can be explained in various ways. First, the standard growth accounting approach yields biased estimates of productivity growth if technical change is not Hicks neutral. In the Punjab context, the direction of bias overstates the contribution of capital accumulation to growth and understates the role of technical change. Adoption of wheat and rice HYVs during the green revolution spurred a rapid increase in investment in modern inputs, especially tubewells. During this period, the number of diesel and electric tubewells per hectare grew by more than 20 percent, and their productivity declined by more than 15 percent. By contrast, labor productivity increased by 5.4 percent. As Hsieh (1997) argues, standard measures of TFP in regions where the capital–labor ratio has risen rapidly will substantially understate true productivity growth if the elasticity of substitution between inputs is less than 1 and there is labor augmenting technical change. The reason is that the standard approach weights the growth of inputs with observed shares of inputs in cost. However, if the new labor-augmenting technologies are more responsive to capital inputs, the share of capital inputs in costs increases more than it would without technical change. Therefore, part of the benefits of technology adoption are captured in the index of capital accumulation, at the expense of the productivity residual.

Second, indivisibility of capital inputs can exacerbate the tendency to overstate the contribution of capital accumulation. As investment patterns across cropping systems in Punjab show, adoption of HYVs was accompanied by significant capital accumulation (table 3). Input use (particularly investment in tubewells) grew by 6.6 percent per year in the rice–wheat system during the green revolution; and by 5.3 percent per year in the cotton–wheat system during the post-green revolution period, when HYV cotton was adopted. Incentives for private investment in tubewells were strengthened by favorable prices for machinery, fixed rates for electricity used for tubewells, and unregulated access to groundwater by well owners.

Lumpiness of capital inputs, especially when farm sizes are as small as in Punjab, leads to their underutilization.[10] As a result, the adoption period shows low measured rates of productivity growth. As excess capacity is absorbed over time, output gains can be realized with limited input investment, and TFP growth increases. Furthermore, as new improved varieties are introduced, they can be adopted without substantial increase in factor accumulation, so productivity growth improves over time. In the rice–wheat zone, this might be the mechanism for the time lag between HYV adoption and the realization of productivity gains.

Learning by Doing and Learning From Others

The time lag between the adoption of modern varieties and the realization of productivity gains might also be due to a process of learning by doing that gradually leads to greater efficiency in input use and improved management. If learning by doing is important, then we would expect to find that early adopters have a productivity advantage over regions that adopted later, because they have had time to develop more efficient input use practices. But skills are not only learned by doing, but also acquired from others' experiences. If learning from others is important, then we would expect to see higher productivity growth in regions that adopted modern varieties later than others, because adopting later allows varieties to be tested by time and refined by researchers to better suit local conditions. Even though no further breakthroughs in yield potential have been achieved since the green revolution, the cumulative importance of incremental gains in yields in newer varieties and resource management practices has been an important source of productivity growth in the post-green revolution period (Byerlee, 1996).

To assess whether the pattern of productivity growth was correlated with the pace of HYV adoption in Punjab, I computed TFP for each district according to its relative speed of adopting wheat HYVs (table 4). The observed patterns are more complicated than we would expect to find from either a learning-from-others or a learning-by-doing hypothesis alone. In reality, both factors likely played a role.

Fast adopters had low rates of productivity growth in comparison to slower adopters during the green revolution, but developed a productivity advantage in the later periods. This pattern suggests that learning-by-doing gains were small in the short run, overshadowed by rapid factor accumulation to facilitate adoption. Late adopters gained from the experience of early adopters but did not have localized learning experiences from their own cultivation. Over time, early adopters perhaps had a slight advantage, once productivity gains became more location specific and initial investment costs had been borne.

Observed correlation between the pace of adoption and productivity growth begs the question of why some districts adopted HYVs faster than others. Although the answer is beyond the scope of these data, one possible explanation might be the presence of Punjab Agricultural University in Ludhiana and associated extension programs in the central districts. Differences in human capital might also drive the pace of adoption, although this seems an unlikely explanation in Punjab, where rural literacy has proceeded at comparable rates in most regions. Also, as stressed by McGuirk and Mundlak (1991), it is unlikely that the availability of human capital could have changed enough during the green revolution to significantly affect the pace of adoption.

Complementary Infrastructure

The availability of complementary infrastructure, particularly canal irrigation systems, is another factor that should be considered in explaining the pace of adoption and, in turn, productivity growth (Kumar and Rosegrant, 1994). To assess the role of public irrigation systems in inducing TFP gains, I compared trends in input use across districts (table 5).

There is little disparity in the extent of irrigation in the districts. From 1960 to 1993, 75 percent or more of the sown area was irrigated in all but the sub-montainous districts of the north. However, the sources of irrigation are radically different across districts. Kapurthala and Ludhiana, where the rates of productivity growth were lowest, had, on average, more than 38 diesel wells per 1,000 hectares of gross cropped area from 1960 to 1993. The corresponding investment in electric tubewells was more than 60 units. This stands in contrast to much lower intensities of input use (less than 23 diesel wells per 1,000 hectares) in Bhatinda and Ferozepur. The relative paucity of tubewells in the southwestern districts is compensated for by extensive surface irrigation networks, most of which were built several decades ago. In 1988, the irrigated area serviced by canals in Bhatinda and Ferozepur was approximately 80 percent and 60 percent, respectively. By contrast, canal irrigation accounted for less than 10 percent of the irrigated area in Ludhiana and Kapurthala.

It is not surprising to find a positive correlation between the availability of canal irrigation and productivity growth during the green revolution and its reversal by the post-green revolution. When the green revolution introduced new water-sensitive and water-intensive crop varieties, districts with canal irrigation had to invest less to usefully apply the new technologies. That is, comparable rates of growth in output were achieved in most districts, but with vastly different rates of growth in input use. The disparity was aggravated by negligible growth rates in surface water costs to the farmer, starting from an already low marginal cost of canal water use. However, there were drawbacks to using canal water instead of relying on tubewells for access to water. As discussed by Bogess, Lacewell, and Zilberman (1993), modern irrigation technologies (such as tubewells) typically have higher irrigation efficiency, improve the uniformity of water distribution, permit greater frequency of water application (thereby reducing losses from runoff and deep percolation), and allow timely irrigation. By contrast, the usefulness of surface water is legally limited by its distribution according to a fixed rotation rule, regardless of crop water needs. Therefore, one finds a more rapid transition to HYVs in areas where new irrigation technologies were simultaneously introduced and adopted, but one that was more costly in terms of productivity growth. Over time, areas traditionally reliant on canal water increased their pace of HYV adoption and investment in modern irrigation technologies as well; the consequences are apparent in a marked productivity slowdown in these districts during the post-green revolution period.

The complementarity of investment in infrastructure, such as canal irrigation systems, with investment in agricultural research bears further scrutiny. The pros and cons of subsidizing canal water have long been debated among policy makers and researchers. One argument is that the productivity advantage of the surface water districts was due to a highly subsidized price for canal water. The reasoning is that some part of output growth resulted from an increase in canal irrigation, which appears in the residual since canal water was underpriced. However, surface irrigation systems were by and large in place by the time of the green revolution. The amount of area irrigated by government canals increased from 1,173,000 hectares in 1960 to 1,537,000 hectares in 1993. The increase pales in comparison to the increase in area irrigated with tubewells, which expanded from 829,000 hectares in 1960 to 3,927,000 hectares in 1993. Therefore, high TFP growth rates induced by surface irrigation are indeed true productivity gains, and not a result of underpricing.

On the other hand, massive subsidization programs for electricity, combined with cheap credit, might in fact have encouraged overcapitalization of regions where groundwater quality is good. Overcapitalization in tubewells would result in low productivity estimates if farmers were not able to fully utilize the existing capacity. Thus, government subsidization programs might have been a mixed blessing, permitting smaller farmers to adopt HYVs but raising efficiency costs at the regional level.

Resource Degradation

Evidence is accumulating of a slowdown in the growth rates of major crop yields since the end of the green revolution and of limited expansion possibilities at the extensive margins, making sustainable productivity growth an immediate policy concern and objective. Adding to the concern is the fact that many of the gains in production in Punjab have come from increased use of fertilizers and energy, which in turn rely heavily on the intensive use of land and groundwater resources. Degradation of land and water resources could seriously limit future production increases through fertilizer and energy inputs and agricultural research.

How has land and water degradation contributed to poor production performance in some Punjab districts in recent years? Conversely, have changes in the quality of the resource base in other districts helped to spur productivity? These questions are of central importance for the sustainability of growth, since resource degradation in many cases might be practically irreversible.

Table 6 shows changes in groundwater availability and land quality indicators at the district level. There is considerable diversity in the quality and availability of groundwater resources in Punjab. Gurdaspur and Hoshiarpur in the northern sub-mountainous regions have good-quality groundwater, but the water level is often too deep to be exploited with shallow tubewells. By contrast, in the southwestern districts such as Ferozepur and Bhatinda, groundwater is brackish. The central districts of Ludhiana, Amritsar, Kapurthala, Jalandher, and Patiala, along with parts of Sangrur, have good-quality water that has been exploited by widespread investment in shallow tubewells.

Water use patterns have had diametrically opposite results in the central and southwestern parts of Punjab. Since 1979, the water table has fallen by more than 3 meters in large parts of the central districts, ranging from 25 percent of Ludhiana to 90 percent of Patiala. By contrast, the water table rose in most parts of Bhatinda and Ferozepur from 1979 to 1993. Although there are pockets in Gurdaspur and Hoshiarpur where the water table has been rising, more than 75 percent of both districts has witnessed a decline in the aquifer over the period studied.

The data on land quality are relatively scanty. The available information suggests that from 1972 to 1984, areas that were severely salt affected (uncultivable) and salt affected (though still cultivable) decreased in all districts, with the exception of Ferozepur and Bhatinda. In these districts, waterlogging is severe, creating large areas of marginal lands and even forcing some land out of cultivation.

Based on these patterns, it is likely that the recent productivity decline in Ferozepur and Bhatinda is in part due to the waterlogging and salinity problems. Moreover, resource degradation, if continued at the same pace, will certainly impose the need for painful reclamation strategies on farmers if productivity growth is to be maintained. With a pronounced recent trend in both districts towards cultivating water-intensive rice, the waterlogging problem is likely to worsen over time if nothing is done to change current patterns of resource use. Pumping groundwater is an obvious solution to the problem of waterlogging, but the groundwater is brackish and unfit for use without mixing with canal water. Although canal water provision in these areas spurred high rates of productivity growth in the 1960s and 1970s, it might have worsened long-term growth prospects by exacerbating waterlogging and encouraging the cultivation of water-intensive rice.

Clearly, the effects of aquifer depletion in arresting productivity growth have not been substantial enough to outweigh productivity gains from other sources in the central districts. But sustained water use (spurred by cheap rates of extraction) will raise the cost of input investment and encourage the overcapitalization of increasingly fragmented farms as larger wells are dug to reach lower aquifers. Even if potentially higher costs are ignored, current trends in water use are not sustainable, because the rate of extraction remains far above the rates of recharge.

Though not a cause for alarm, the trends in Punjab might be an early warning that the types of input-intensive technologies fostered by the green revolution might slow down or preclude growth possibilities in the long run. Research and development might have to be redirected toward work designed to maintain the yield gains from past research.

CONCLUSIONS

India's Punjab exemplifies the green revolution of the mid-1960s, when it achieved dramatically high rates of growth in agricultural output. Growth during the green revolution can be attributed largely to improvements in the overall yields of wheat and rice and to the expansion of area under wheat and rice HYVs. However, most yield improvements resulted from rapid factor accumulation, especially in fertilizers and capital inputs. Contrary to widespread belief, productivity growth contributed little to economic growth.

The method of growth accounting helps to explain why productivity growth was actually much lower during the green revolution than might be expected. HYVs introduced in the 1960s were important in spurring output growth by making crops responsive to fertilizer and water, which not only allowed but indeed encouraged far greater capital input use. This increase in the elasticity of output response to modern inputs is incorporated in the index of factor accumulation and is therefore excluded from the TFP residual. The bias likely underestimates the contribution of technical change to growth in Punjab's agriculture during the green revolution. Further research is needed to test this hypothesis and to refine the measurement of TFP. An alternative index is needed for the factor accumulation that would obtain if there were no technological progress.

Comparing growth experiences by districts and cropping systems underscores the importance of estimating TFP disaggregated below the national and state levels. To explain district-level growth experiences, I propose that the impetus for TFP growth did not come from the adoption of modern varieties alone, but also from the indirect effects of the modern technologies—resource management and input use efficiency. The indirect effects can be spread in a variety of ways, including learning by doing and learning from others.

Furthermore, the availability of infrastructure, particularly surface irrigation systems, promoted TFP gains. Existing canal irrigation systems allowed a period of learning without massive investment in private inputs and diminished overcapitalization in indivisible capital inputs. Taken together, learning processes and input indivisibilities created a time lag between the adoption of new technologies and the realization of productivity gains. For policy makers, this suggests the importance of carefully considering the time period over which new technologies are assessed to give them a fair chance.

Finally, cross-district comparisons suggest that fears about unchecked reductions in productivity growth are exaggerated. The evidence for a recent productivity slowdown does not apply to all districts in Punjab. However, extensive groundwater mining in some regions and severe waterlogging and salinization in others might be early signs of a decline to come.

In Punjab, the large variety of cropping systems, climatic conditions, infrastructure, and socioeconomic characteristics necessitate more than a single explanation for the tremendous diversity in patterns of productivity growth across districts. Several complementary hypotheses are needed to explain the diverse growth experiences in Punjab. Further analysis is required to assess the relative significance of these sources of growth. Certainly, a much clearer understanding of the alternative sources of growth is needed to help decision makers better allocate investments between agricultural research and infrastructure expansion.

NOTES

[1] This section relies primarily on Antle and Capalbo (1988). See also Alston, Norton, and Pardey (1995).

[2] For a detailed discussion of these assumptions as they apply to the Punjab case, see Murgai (1997). Barrow (1998) provides a more general discussion of the growth accounting and production function methods of productivity measurement.

[3] A full description of data sources, variable definitions, and construction of input and output indices can be obtained from the author upon request.

[4] Inputs that are intermediate farm outputs channeled back into production, such as seeds and organic manure, were excluded from both the input and the output index.

[5] Since annual data on the area irrigated by canals were not available, canal water costs were computed by assuming that a constant percentage of irrigated area (1984 value) has been irrigated by canals each year. Since the percentage of area irrigated by canals has been decreasing over time in all districts, this method underestimates canal irrigation costs in the early years. However, the resulting bias in TFP estimates is likely to be small since canal water costs are typically less than 1 percent of total factor payments.

[6] We rely primarily on wheat rather than on rice due to a recent reversion towards traditional but superior quality basmati rice.

[7] All reported growth rates are computed with semilog regressions. Growth rates for the pre-green revolution period are not reported since the period lasts for only 5 years. Years prior to 1960 could not be included in the analysis because of missing data and consistency problems in the data that were available.

[8] Hazell and Ramaswamy (1991) found a similar decrease in labor utilization rates in a study of the effects of the green revolution in South India. They attribute the change to increased mechanization of irrigation and paddy threshing.

[9] See, for example, Desai (1994), Kumar and Rosegrant (1994), Sidhu and Byerlee (1992), and Dholakia and Dholakia (1993)—summarized in Ahluwhalia (1996).

[10] Conditions of indivisibility in the case of tubewells are elaborated in Dubash (1998). The degree of indivisibility depends on the technology of groundwater withdrawal, characteristics of the aquifer, farm sizes, and groundwater markets.

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TABLES

Table 1. Output and input use characteristics.

	Entire Period 1960-93	Green Revolution 1965-73	Input Intensification 1974-84	Post-Green Revolution 1985-93
Output Characteristics				
Growth rate in aggregate output (%)	3.4	3.7	1.0	6.3
Growth rate in cultivated area (%)				
Wheat	2.5	4.4	1.2	1.8
Rice	7.8	8.9	9.6	2.6
Cotton	0.8	2.4	-1.4^{ns}	7.2
Growth rate in yields (%)				
Wheat	3.6	4.7	2.6	2.5
Rice	4.1	9.4	2.3	0.7^{ns}
Cotton	1.6	0.4^{ns}	0.1^{ns}	7.3
Input Characteristics				
Cropping intensity (%)	153.7	138.0	157.7	174.3
Irrigated area (%)	77.0	68.6	81.9	90.8
Units Per 1000 hectare				
Labor (number)	398.4	399.9	394.2	417.4
Bullocks (number)	170.6	229.7	153.6	91.3
Fertilizer (tonnes)	82.7	33.0	99.2	155.9
Tractors (number)	17.1	4.3	15.3	41.0
Diesel Tubewells (number)	25.9	19.2	43.4	24.8
Electric Tubewells (number)	35.5	8.1	37.2	79.7
Labor utilization (days/year/person)	196.2	210.5	192.3	154.7

Note: ^{ns} = not significantly different from zero at 10%; growth rates computed using semi-log regressions.

Table 2. Growth rates of TFP, output, input, and partial factor productivity indices.

	Entire Period 1960-93	Green Revolution 1965-73	Input Intensification 1974-84	Post-Green Revolution 1985-93
I. *Total Factor Productivity* (%)				
TFP	1.92	1.32	1.84	1.49
Output	4.95	5.92	4.28	4.45
Input	3.03	4.61	2.44	2.96
II. % Contribution of TFP to Output Growth				
Punjab	38.8	22.3	43.0	33.5
III. Partial Factor Productivity (%)				
Labor	4.9	5.4	3.8	5.6
Land	4.4	4.9	4.5	2.9
Diesel Tubewells	-4.8	-26.4	9.2	6.8
Electric Tubewells	-10.4	-16.5	-8.7	-0.4^{ns}
Tractors	-9.4	-13.6	-7.2	-6.8
Fertilizers	-9.7	-14.2	-5.1	1.9^{ns}

Note: ^{ns} = not significantly different from zero at 10%; growth rates computed using semi-log regressions.

Table 3. Growth rates of TFP, output, and input indices, by cropping systems and districts.

	Entire Period 1960-93	Green Revolution 1965-73	Input Intensification 1974-84	Post-Green Revolution 1985-93
Total Factor Productivity (%)				
Rice-Wheat System	**1.4**	**-0.6^{ns}**	**2.0**	**2.2**
Kapurthala	-0.7	-6.8	2.5	1.5
Ludhiana	-0.0^{ns}	-4.4	1.9	2.3
Sangrur	1.1	-0.9^{ns}	2.3	3.2
Jalandher	1.3	-0.1^{ns}	1.9	1.6
Amritsar	1.5	-0.6^{ns}	1.4	3.0
Gurdaspur	2.3	2.4	1.5	2.6
Maize-Wheat System	**2.4**	**1.7**	**2.4**	**3.0**
Hoshiarpur	2.4	1.7	2.4	3.0
Cotton-Wheat System	**2.5**	**3.2**	**1.9**	**0.8^{ns}**
Patiala	2.4	1.8	2.8	1.7
Bhatinda	2.6	4.2	0.8	1.7
Ferozepur	3.0	5.7	1.5	-1.2
Output (%)				
Rice-Wheat	**5.1**	**5.9**	**4.7**	**3.4**
Kapurthala	5.2	5.1	5.4	2.6
Ludhiana	4.7	4.4	4.1	2.9
Sangrur	4.7	6.0	4.7	3.7
Jalandher	5.0	7.4	4.2	2.7
Amritsar	5.2	5.4	4.5	4.5
Gurdaspur	5.1	5.8	4.8	3.5
Maize-Wheat	**3.6**	**6.6**	**3.2**	**3.0**
Hoshiarpur	3.6	6.6	3.2	3.0
Cotton-Wheat	**5.0**	**5.7**	**4.0**	**6.1**
Patiala	5.6	7.3	5.5	3.3
Bhatinda	4.6	5.0	3.1	7.2
Ferozepur	5.0	6.1	3.2	7.1
Input (%)				
Rice-Wheat	**3.7**	**6.6**	**2.7**	**1.2**
Kapurthala	5.9	11.9	2.9	1.1
Ludhiana	4.8	8.8	2.2	0.6^{ns}
Sangrur	3.6	6.9	2.4	0.5^{ns}
Jalandher	3.8	7.5	2.3	1.0
Amritsar	3.7	6.0	3.0	1.6
Gurdaspur	2.9	3.4	3.4	1.0
Maize-Wheat	**1.2**	**4.9**	**0.8**	**0.0^{ns}**
Hoshiarpur	1.2	4.9	0.8	0.0^{ns}
Cotton-Wheat	**2.5**	**2.5**	**2.2**	**5.3**
Patiala	3.2	5.5	2.7	1.6
Bhatinda	2.0	0.8^{ns}	2.3	5.5
Ferozepur	2.0	0.4^{ns}	1.7	8.3

Note: ^{ns} = not significantly different from zero at 10%; growth rates computed using semi-log regressions.

Table 4. District-level growth rates of TFP, output, and input indices, by pace of district adoption of wheat HYVs.

	Entire Period 1960-93	Green Revolution	Input Intensification	Post-Green Revolution
			Total Factor Productivity (%)	
Fast Adopters				
Ludhiana	-0.04^{ns}	-5.17	-0.77	2.77
Jalandher	1.26	-2.41	1.94	1.56
Kapurthala	-0.69	-8.7	1.38	1.95
Amritsar	1.45	-0.53^{ns}	1.02	2.80
Sangrur	1.12	-0.98^{ns}	1.99	3.37
Medium Adopters				
Patiala	2.36	1.84	2.83	1.65
Bhatinda	2.62	3.60	1.06	-
Ferozepur	3.01	5.14	1.60	-0.98^{ns}
Slow Adopters				
Gurdaspur	2.26	1.97	1.41	2.53
Hoshiarpur	2.40	1.83	2.83	2.83
			Output (%)	
Fast Adopters				
Ludhiana	4.74	6.26	3.83	3.58
Jalandher	5.04	6.97	6.10	2.75
Kapurthala	5.18	5.02	5.84	3.40
Amritsar	5.16	5.85	4.22	4.74
Sangrur	4.71	6.41	4.60	3.77
Medium Adopters				
Patiala	5.55	7.15	5.35	3.33
Bhatinda	4.63	3.94	4.59	-
Ferozepur	4.95	5.83	3.05	6.56
Slow Adopters				
Gurdaspur	5.13	5.18	5.28	3.23
Hoshiarpur	3.64	5.55	1.74	3.42
			Input (%)	
Fast Adopters				
Ludhiana	4.78	11.43	4.59	0.81
Jalandher	3.79	9.37	4.17	1.19
Kapurthala	5.87	13.72	4.46	1.45
Amritsar	3.71	6.38	3.20	1.94
Sangrur	3.59	7.38	2.62	0.40^{ns}
Medium Adopters				
Patiala	3.19	5.31	2.52	1.68
Bhatinda	2.01	0.34^{ns}	3.53	-
Ferozepur	1.95	0.70^{ns}	1.44	7.54
Slow Adopters				
Gurdaspur	2.87	3.22	3.87	0.70
Hoshiarpur	1.24	3.72	-1.08	0.60^{ns}

Note: ^{ns} = not significantly different from zero at 10%; growth rates computed using semi-log regressions.

Table 5. District-level input use characteristics.

	Punjab	Kapurthala	Ludhiana	Sangrur	Jalandher	Amritsar	Gurdaspur	Patiala	Hoshiarpur	Bhatinda	Ferozepur
Cropping Intensity	153.7	138.7	162.3	172.2	151.9	160.6	155.2	159.4	148.4	143.8	146.6
% Irrigated Sown Area	77.0	83.3	83.9	79.2	84.6	94.4	61.5	72.2	34.8	74.9	82.4
% Irrigated by Canals*	-	5.9	4.4	35.9	11.4	50.9	28.7	15.2	9.9	80.3	59.5
Input use (per 1000 ha GCA)											
Fertilizer (tons)	82.7	106.4	127.2	71.9	93.9	86.1	93.1	87.5	53.8	59.5	78.7
Labor	398.4	388.9	398.5	345.8	451.8	469.1	502.1	378.3	473.6	353.2	376.1
Diesel Tubewells	25.9	45.2	38.4	32.6	35.5	13.1	11.1	32.7	27.1	20.6	22.5
Electric Tubewells	35.5	60.2	64.7	29.6	57.3	49.9	47.1	35.8	34.2	7.9	23.4
Animal Power	170.6	217.3	196.7	169.4	210.5	185.6	184.5	200.2	288.3	110.1	127.0
Tractors	17.1	17.4	23.4	13.9	21.4	14.7	11.6	18.2	12.8	16.1	19.5
Growth in input intensity (%)											
Fertilizer (tons)	13.1	13.4	11.2	14.4	10.5	14.3	14.6	14.9	10.1	14.1	13.4
Labor	0.3	-0.5	0.04^{ns}	1.1	-0.03^{ns}	0.2	0.4	0.09^{ns}	0.2	0.5	-0.04^{ns}
Diesel Tubewells	8.2	9.8	4.6	8.6	7.7	-0.4^{ns}	8.4	7.7	4.1	12.3	13.0
Electric Tubewells	13.8	14.3	14.7	19.2	10.6	14.2	14.0	14.6	11.4	20.9	13.8
Animal Power	-4.0	-6.9	-4.2	-2.7	-6.4	-3.9	-5.3	-4.7	-2.9	-2.3	-4.5
Tractors	12.8	14.6	12.5	14.6	12.7	14.7	14.8	12.7	13.7	12.1	11.8

^{ns}=Not significantly different from zero at 10%; growth rates computed using semi-log regressions; * 1988 data

Districts have been arranged from left to right, in ascending order of productivity growth

Table 6. Changes in groundwater availability and land quality at the district level.

Districts	Change in Water Table between 1973 and 1993 (as a % of geographical area)						Land Quality Indicators				
	Fall			Rise			Severely salt-affected area		Salt-affected in patches		Salt-affected & waterlogged
	0-3 m	3-5 m	>5 m	0-3 m	3-5 m	>5 m	1972 (1000 ha)	1984 as a % of 1972	1972 (1000 ha)	1984 as a % of 1972	1984 (1000 ha)
Kapurthala	40.0	49.0	11.0	0.0	0.0	0.0	25.0	64.0	23.0	56.5	-
Ludhiana	75.0	17.0	8.0	0.0	0.0	0.0	**	**	**	**	**
Sangrur	12.0	54.0	34.0	0.0	0.0	0.0	41.0	29.3	29.0	44.8	12.0
Jalandher	13.0	47.0	39.0	0.8	0.2	0.0	15.0	66.7	42.0	21.4	-
Amritsar	59.0	28.0	13.0	0.0	0.0	0.0	61.0	37.7	209.0	27.8	4.0
Gurdaspur	79.0	6.0	2.0	12.0	0.0	0.0	23.0	56.5	46.0	30.4	3.0
Patiala	10.0	81.0	9.0	0.0	0.0	0.0	6.0	66.7	40.0	45.0	4.0
Hoshiarpur	78.0	14.0	1.0	7.0	0.0	0.0	**	**	**	**	**
Bhatinda	35.0	9.0	0.0	24.0	7.0	25.0	1.0	300.0	7.0	71.4	6.0
Ferozepur	64.0	3.0	0.5	8.5	7.0	17.0	39.0	35.9	58.0	93.1	43.0
Faridkot	37.0	15.0	15.0	7.0	4.0	22.0	1.0	2000.0	18.0	344.4	47.0

Note: Faridkot originated from Bhatinda and Ferozepur but has not been aggregated in order to show the diversity within the district; **: data not available

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12 - 1