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Productivity Growth and Sustainability in Post–Green Revolution Agriculture: The Case of the Indian and Pakistan Punjabs

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This article attempts to determine the long-term productivity and sustainability of irrigated agriculture in the Indian and Pakistan Punjabs by measuring trends in total factor productivity for production systems in both states since the advent of the Green Revolution. These measurements over time and across systems have resulted in three major findings. First, there were wide spatial and temporal variations between the two Punjabs. Although output growth and crop yields were much higher in the Indian Punjab, productivity growth was higher by only a small margin. Moreover, the lowest growth in productivity took place during the initial Green Revolution period (as opposed to the later intensification and post–Green Revolution periods) and in the wheat-rice system in both states. The time lag between adoption of Green Revolution technologies and realization of productivity gains is related to learning-induced efficiency gains, better utilization of capital investments over time, and problems with the standard methods of productivity measurement that downwardly bias estimates, particularly during the Green Revolution period. Second, input growth accounted for most of the output growth in both Punjabs during the period under study. Third, intensification, especially in the wheat-rice system, resulted in resource degradation in both Punjabs. Data from Pakistan show that resource degradation reduced overall productivity growth from technical change and from education and infrastructure investment by one-third. These findings imply the need for policies that promote agricultural productivity and sustainability through public investments in education, roads, and research and extension; and that reduce resource degradation by decreasing or eliminating subsidies that encourage intensification of inputs.

The Indo-Gangetic Plain of northern India and Pakistan has one of the largest concentrations of poor people in the world. The agricultural sector, which employs more than half the area's 500 million inhabitants, has long been considered key to food

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security and poverty alleviation for this population. Beginning in the mid-1960s, Green Revolution technologies were introduced in the area, including high-yielding modern varieties of rice and wheat, the area's two major crops. This change was supported by investment in irrigation and market infrastructure. As a result, the area experienced a dramatic increase in agricultural production, especially in India's Punjab State and Pakistan's Punjab Province.

But despite this promising beginning, the further intensification of input use since the adoption of Green Revolution technologies has provided lower marginal returns (Byerlee 1992); and the continued intensification of cropping has sometimes caused degradation of the resource base in the form of salinization, overexploitation of groundwater, physical and chemical deterioration of the soil, and pest and disease problems (Fujisaka and others 1994; Siddiq 1994). Consequently, there is now great concern about the potential for productivity growth in irrigated Green Revolution systems and their sustainability over the longer term.

The Debate about Agricultural Performance

Despite the evidence of sharply lower growth rates for food grain yields, there is considerable controversy about aggregate performance of the agricultural sector. In particular, good performance in nonfood crops—such as cotton in Pakistan; oilseeds, fruits, and vegetables in northwest India; and livestock in both countries—may have offset the slowdown in food grains.

Moreover, crop yields are only a measure of partial factor productivity, whereas overall agriculture sector performance is generally measured by total factor productivity (TFP). The TFP approach compares an index of output changes with an index of input changes, thus making it possible to attribute residual output growth to technical progress, changes in input quality, and changes in the physical and economic environment. Experience from industrialized countries suggests that, over the longer run, TFP in the agriculture sector should grow at 1.5 to 2 percent a year, and that one- to two-thirds of that growth will be due to investment in research and extension.

Recent estimates of TFP for agriculture in Pakistan and northwestern India provide conflicting conclusions. For Pakistan, two studies indicate negative TFP growth in the post–Green Revolution period, especially in the Punjab (Azam and others 1991; Ali and Velasco 1994). By contrast, another study (Khan 1994) concludes that TFP in Pakistan grew sharply in the period 1980–92, at an annual rate of 2.1 percent, suggesting that the agricultural sector in that country performed well in recent years. For northwest India, there is little recent evidence on aggregate TFP growth, although the few available studies generally indicate that it was positive (Kaur 1991; Sidhu and Byerlee 1991; Kumar and Rosegrant 1994; Evenson and others 1999). These conflicting results are due in part to the studies' widely varying coverage of inputs and outputs, methods of valuing inputs, index procedures used to estimate TFP, and levels of disaggregation.

In addition, there is little quantitative evidence of the impact of resource degradation on productivity growth. Thus, with the body of information that now exists, it is difficult to accurately assess productivity growth and sustainability under intensification, and to reach definite policy conclusions about how best to ensure food security and alleviate poverty in the Indo-Gangetic Plain.

Objectives of the Study

The main objectives of this study are, first, to provide comparable estimates of TFP growth in the Indian and Pakistan Punjabs since the advent of the Green Revolution and, second, to relate productivity trends to changes in resource quality. The article is organized as follows. The next section outlines the methodology. We then describe major trends in the agriculture sector, especially those related to production performance, input use, and resource degradation. We then present estimates of TFP at the state level and by cropping system. In each case, we decompose output growth into the contributions from growth in input use and growth in TFP. In the subsequent section, we use detailed data on resource degradation in Pakistan to further decompose productivity trends into the effects of technology, resource degradation, human resources, and infrastructure. The final two sections discuss policy implications and summarize our main findings.

Methodology

Our approach is to estimate growth in TFP for three periods corresponding to different phases of technical change: (1) The Green Revolution period itself (1966–74), when input-responsive modern varieties of wheat and rice were widely adopted, leading to an immediate and dramatic increase in production; (2) the input intensification period (1975–85 in India, 1975–84 in Pakistan), when the use of fertilizers and capital inputs increased rapidly; and (3) the post–Green Revolution period (1986–94 in India, 1985–94 in Pakistan), when input use leveled off (Byerlee 1992).

We base our calculations (box 1) on district-level data on all inputs, outputs, and prices, collected from statistical agencies and secondary sources in both states. The data cover the period 1961–94 in India and 1966–94 in Pakistan. Input categories include land, labor, water, machinery, draught animals, fertilizer, and pesticide costs. To minimize aggregation bias in TFP, inputs of different qualities are valued by the price of each quality type. Land is divided into irrigated and unirrigated, labor into skilled and unskilled (based on the rural literacy rate in each district), water into canal

Box 1. Calculating Change in Total Factor Productivity as a Result of the Green Revolution

Of the several ways to measure TFP using different rules for aggregating outputs and inputs (Alston and others 1995), we use the chain-linked Tornqvist-Theil index, because it provides an exact measure of technical change for the linear homogenous translog production function with Hicks-neutral technical change (Diewert 1976). TFP is obtained by taking the difference between the growth rates of the aggregate output and input indices:

$$TFP \approx \ln(TFP_t \,/\, TFP_{t-1}) = [\ln(QI_t/QI_{t-1}) - \ln(XI_t/XI_{t-1})] = \Sigma_t\ 1/2\ (R_{it} + R_{it-1})\ln(Q_{it} \,/\, Q_{it-1}) - \Sigma_j\ 1/2\ (S_{jt} + S_{jt-1})\ \ln(X_{jt} \,/\, X_{jt-1})]$$

where QI_t is the aggregate output index, XI_t is the aggregate input index, and R_{it} and S_{jt} are the revenue share of output i and cost share of input j at time t, respectively.

and tubewell, and fertilizer into individual nutrient sources (nitrogen, phosphorous, and potassium).

Outputs are aggregated into an output index using district-specific farm harvest prices for crops and market center–specific prices for livestock products.

These data are used to estimate TFP separately for different agro-ecological zones, defined in terms of cropping systems, to avoid the problem of aggregation across heterogeneous regions. This approach enables direct comparison of productivity trends and helps determine whether productivity slowdown and environmental degradation are associated with particular cropping systems and ecologies. In India, the districts are divided into three cropping systems: wheat-rice, wheat-cotton, and wheat-maize. In Pakistan, they are divided into wheat-rice, wheat-cotton, wheat–mixed summer crops (often maize or sugarcane), and wheat-mungbean (or wheat-fallow). The district-level data are then aggregated to quantify TFP growth in terms of the dominant cropping pattern. For Pakistan, where we collected test results from 1971–94 on the quality of groundwater and soil (organic matter, phosphorous content, and soluble salts), productivity growth is also econometrically decomposed into the effects of technology, resource degradation, human resources, and infrastructure. Disaggregated data on resource quality for the Indian Punjab and for the pre-1971 years in Pakistan were not available.

Trends in Production, Input Use, and Resource Degradation

Table 1 describes the production record in the two Punjabs for the three major crops—wheat, rice, and cotton—during the Green Revolution, intensification, and post–Green Revolution periods. During the first period, modern wheat and rice varieties were widely and rapidly adopted in both states. Wheat production increased by more than 7 percent annually, with yield increases accounting for slightly more than half

Table 1. Yield Performance of Major Crops, Indian and Pakistan Punjabs

	Indian Punjab	*Pakistan Punjab*
Growth rate in yields (%)		
Wheat	[3.6]	[2.2]
Green Revolution	4.7	5.1
Intensification	2.6	1.1
Post–Green Revolution	2.5	2.1
Rice	[4.1]	[-0.3^{ns}]
Green Revolution	9.4	4.2
Intensification	2.3	–1.6
Post–Green Revolution	0.7^{ns}	–1.4
Cotton	[1.6]	[3.6]
Green Revolution	0.4^{ns}	-0.6^{ns}
Intensification	0.1^{ns}	2.8^{ns}
Post–Green Revolution	7.3	8.0
Average yields (kg/ha)		
Wheat		
Green Revolution	2,004	1,246
Intensification	2,750	1,605
Post–Green Revolution	3,643	1,902
Rice		
Green Revolution	1,609	1,320
Intensification	2,777	1,366
Post–Green Revolution	3,246	1,215
Cotton		
Green Revolution	347	288
Intensification	316	267
Post–Green Revolution	504	601

Note: The figures in brackets [ ] indicate growth rate in the parameter value during overall study period.

ns = not significantly different from zero at 10 percent.

Sources: Ali and Byerlee (forthcoming) and Murgai (forthcoming).

that growth; rice production also grew rapidly, especially in the Indian Punjab. In the post–Green Revolution period, however, yield growth rates in both states decreased to an average of 2 percent a year for wheat and became stagnant or negative for rice, creating concerns that the Green Revolution may not be sustainable.

Adding to these concerns, the gap between yields in the two states widened over time, even though the two states had similar cropping patterns and ecologies. Wheat yields in India during the post–Green Revolution period were nearly double those in Pakistan, although they share similar agro-climatic conditions. Rice yields in India were also much higher during the post–Green Revolution period, although this was known to be partly due to Pakistan's specialization in low-yielding, highly valued Basmati rice. However, cotton yields in Pakistan were higher in both level and growth rate.

The data indicate that the differences between the states in production performance are associated with differences in input use and cropping intensity (table 2). In the first period, the adoption of modern varieties stimulated rapid input intensification in both Punjabs. In India, fertilizer use jumped from 33 to 156 kg of nutrients per hectare of cropped area between the first and third periods; labor use gradually declined; and the use of mechanical power (tractors, harvesters, and threshers) increased from 4.3 to 41 hours per hectare. Pakistan followed the same patterns, although cropping intensities and the use of fertilizer and machinery were considerably lower in all periods.

The data also show considerable degradation of the water and soil resource base in both states. There are indications that the wheat-rice cropping system in the Indian

Table 2. Changes in Cropping Intensity, Irrigated Area, and Input Use, Indian and Pakistan Punjabs

	Indian Punjab	*Pakistan Punjab*
Cropping intensity (%)	[1.0]	[0.8]
Green Revolution	138.0	117.0
Intensification	158.0	126.0
Post–Green Revolution	174.0	136.0
Irrigated area (%)	[1.7]	[0.3]
Green Revolution	68.6	81.9
Intensification	81.9	85.1
Post–Green Revolution	90.8	86.3
Fertilizer (kg/ha)	[13.1]	[12.6]
Green Revolution	33.0	14.1
Intensification	99.2	48.3
Post–Green Revolution	155.9	86.1
Machines (hrs/ha)	[12.8]	[12.0]
Green Revolution	4.3	1.5
Intensification	15.3	5.7
Post–Green Revolution	41.0	14.8
Tubewells (#/1,000ha)[a]	[11.5]	[3.9]
Green Revolution	27.3	8.2
Intensification	80.6	16.2
Post–Green Revolution	104.4	26.0
Labor (days/ha)	[–1.4]	[–0.9]
Green Revolution	84.2	85.0
Intensification	75.9	98.7
Post–Green Revolution	64.6	71.1

Note: The figures in brackets [ ] indicate growth rate in the parameter value during overall study period.

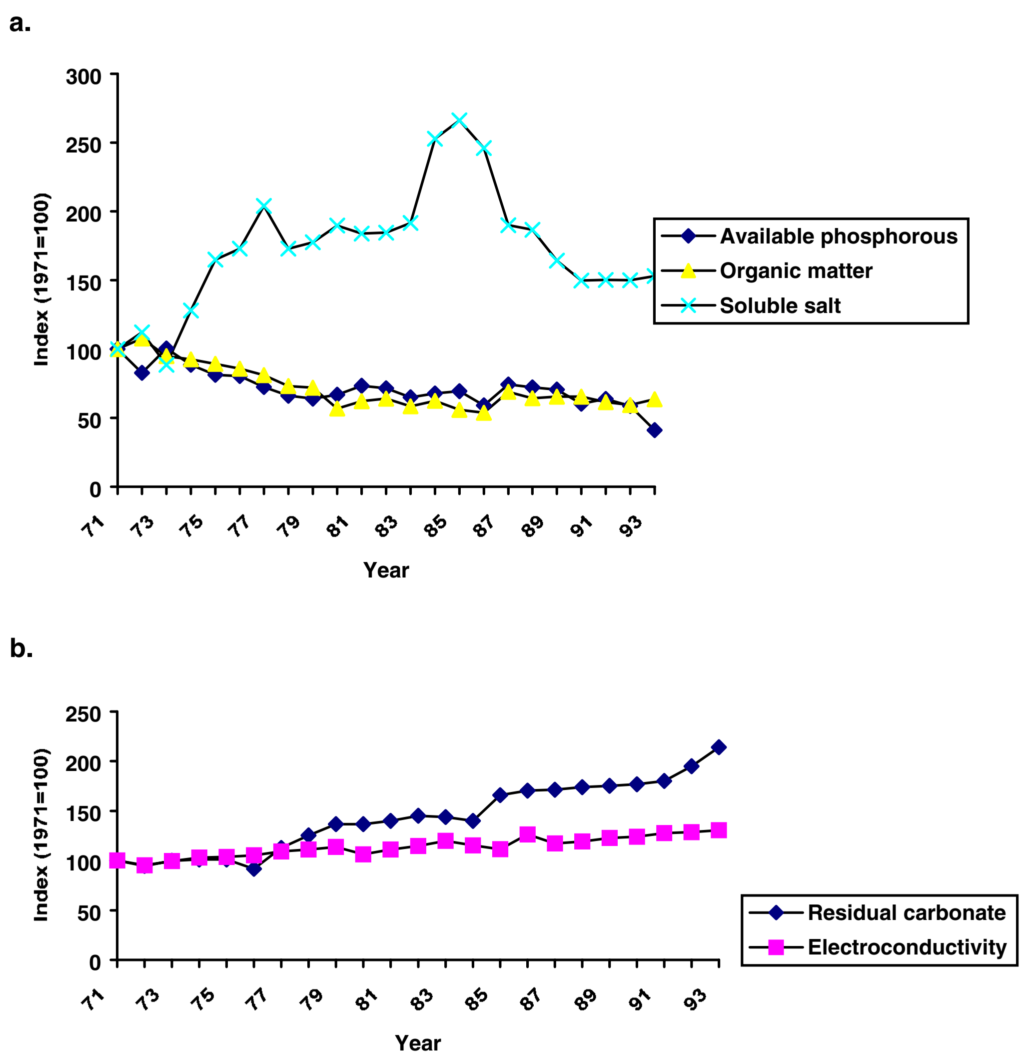
ns = not significantly different from zero at 10 percent.

a. Tubewell numbers are not directly comparable. Tubewells in Pakistan are much larger.

Sources: Ali and Byerlee (forthcoming) and Murgai (forthcoming).

Punjab was hurt by a steep decline in the water table, while rising water levels in the wheat-cotton zone led to severe waterlogging in the wheat-cotton zone. Data from the Pakistan Punjab also confirm a serious problem of waterlogging and salinity, due in part to deterioration in the quality of tubewell water (reflected in a significant increase in residual carbonate and electroconductivity of groundwater). Soil quality in Pakistan (in terms of available soil organic matter and phosphorus) also deteriorated, particularly in the wheat-rice zone (figures 1a and 1b).

Figure 1. a. Indices of Trends in Soil Quality; **b.** Indices of Trends in Tubewell Water Quality



Source: Ali and Byerlee (forthcoming).

Trend in TFP

Our analysis shows that the Indian Punjab experienced a better overall growth rate than Pakistan, with the states having, respectively, 5 and 3.2 percent annual growth rates in output and 1.9 and 1.5 percent annual growth rates in TFP. But despite these different growth rates, both states experienced similar lags between the adoption of modern varieties and the realization of TFP gains. Contrary to expectations, our evidence shows that TFP in both states barely increased during the Green Revolution period itself, when output growth was most rapid. Instead, TFP gains accelerated during the input intensification period, after the adoption of modern varieties had essentially been completed. Table 3 summarizes state-level trends in aggregated output and input use, and TFP growth in both Punjabs.

We propose three possible reasons for this lag.

- First, empirical evidence from areas of Asia that experienced rapid Green Revolution-induced change suggests that when new technologies were first adopted, inefficiency was fairly high (about 30 percent). In general, high levels of technical inefficiency are due mainly to deficiencies in information and technical skills (Ali and Byerlee 1991), and these were probably serious factors in both Punjabs, where poorly educated farmers switched, in a single generation, from traditional agriculture to complex multiple cropping systems dependent on significant levels of modern inputs.

  The increase in technical efficiency a few years later, during the second period, can be attributed to learning by doing, as farmers gained experience using the

Table 3. Growth Rate of Partial Factor Productivity and TFP Indices, Indian and Pakistan Punjabs

	Partial Factor Productivity			*Total Factor Productivity*		
	Land (%)	*Labor (%)*	*Water (%)*	*Output (%)*	*Input (%)*	TFP *(%)*
Indian Punjab	[4.4]	[4.9]	[–8.1]	[5.0]	[3.0]	[1.9]
Green Revolution	4.9	5.4	–22.1	5.9	4.6	1.3
Intensification	4.5	3.8	0.6^{ns}	4.3	2.4	1.8
Post–Green Revolution	2.9	5.6	0.6^{ns}	4.5	3.0	1.5
Pakistan Punjab	[2.4]	[2.5]	[–1.4]	[3.2]	[1.9]	[1.5]
Green Revolution	2.0	–3.9	–5.9	3.2	4.6	-1.4^{ns}
Intensification	2.3	3.0	–1.3	2.8	1.4	1.4
Post–Green Revolution	2.9	6.2	1.5	3.9	1.0	2.9

Note: The figures in brackets [ ] indicate values during overall study period.
ns = not significantly different from zero at 10 percent.
Sources: Ali and Byerlee (forthcoming) and Murgai (forthcoming).

new technologies; and also to an increase in human capital as education levels rose in both states. Indeed, evidence from India suggests that Green Revolution technological change directly increased the returns to education by spurring greater private investment in schooling, particularly in states such as the Punjab (Foster and Rosenzweig 1996).

- A second reason for the lag in realizing TFP gains is that the introduction of modern varieties was accompanied by significant capital investment by small farmers, particularly in tubewells, during the Green Revolution period. The tubewells are likely to have been underutilized in the short run, until the newly created capacity could be exploited. Such underutilization of quasi-fixed inputs generally leads to an underestimation of TFP gains during the period when investment costs are incurred, but TFP gains become observable as excess capacity is absorbed (Berndt and Fuss 1986).
- Third, low TFP growth during the Green Revolution relates in part to limitations of the conventional method of productivity measurement when technical change is biased toward saving one or more factors (Murgai forthcoming). When technical change is biased in this sense, it is impossible to separate the contribution of technical change from that of factor accumulation, because part of the contribution of technical change is captured in changes in the factor shares used to aggregate inputs. In the case of land- and labor-saving technologies, conventional TFP calculations underestimate the contribution of technical change to growth, particularly during the Green Revolution period.

In contrast to the first two periods, TFP growth slowed slightly in India—from 1.9 to 1.5 percent—during the third period, while in Pakistan it rose sharply, to 2.9 percent, due partly to Pakistan's gains in the livestock sector and partly to its large increase in cotton yields (from 267 kg/ha during intensification to 601 kg/ha during the post–Green Revolution period) and mungbean production. The strong performance of cotton and mungbean followed the introduction of modern varieties of both crops and a sharp increase in pesticide use, although the latter has proven technically and environmentally unsustainable in recent years.

In India, by comparison, irrigated cotton was a much less important crop (Chanmugam 1994; Kurosaki 1999). Until the reforms of 1994, quantity restrictions on cotton kept India's domestic price below world prices, and nontariff barriers restricted cotton imports (World Bank 1996). Varietal research for irrigated cotton in India consequently lagged, although rain-fed cotton has been very successful in the central part of the country. In addition, because of price policies favoring production for the domestic market, the Indian Punjab produced only short-staple cotton for local consumption, and the long-staple varieties produced by Pakistan for export were never adapted to Indian conditions.

Growth performance varied not only between the states but within each state as well, with the performance of different cropping systems varying widely (table 4). The wheat-rice systems, which benefited from the development of modern semi-dwarf crop varieties, had the lowest rates of TFP growth. In the Indian and Pakistan wheat-rice zones, TFP grew at 1.4 and 0.1 percent a year, respectively. These results confirm widespread concerns that continuous double cropping of cereals, especially wheat and rice, which require very different soil and water management practices, is an unsustainable cropping pattern (Pingali and Rosegrant 1994; Byerlee and Siddiq 1994; Cassman and Pingali 1995; Ali 1996). Deterioration in soil and water quality seemed especially serious in the wheat-rice system, as evidenced by indicators of soil and water quality disaggregated by system in Pakistan (Ali and Byerlee forthcoming). The better performance of this system in the Indian Punjab reflects, in part, the focus on early maturing coarse rice for local consumption, as well as concerted efforts to arrest resource degradation (e.g., through widespread use of gypsum to combat secondary salinity from tubewells).

The wheat-cotton systems in both states, by contrast, had much higher rates of TFP growth. However, the high pesticide use in this system has led to environmental and health damage, which is not taken into account in the growth-accounting method using for estimating TFP.

TFP growth was also relatively high in Pakistan's wheat-mungbean system, where production growth rates were maintained in the post–Green Revolution period due to the release of early maturing mungbean varieties, which allowed a more sustainable cereal-legume rotation. In the wheat-mungbean zone, yield growth rates for wheat were among the highest in the state.

Table 4. Growth Rate of Output, Input, and TFP indices, by Cropping Systems

	Output (%)	*Input* (%)	TFP (%)
Indian Punjab			
Wheat-rice	5.1	3.7	1.4
Wheat-cotton	5.0	2.5	2.5
Wheat-maize	3.6	1.2	2.4
Overall	5.5	3.0	1.9
Pakistan Punjab			
Wheat-rice	2.4	2.3	0.1
Wheat-cotton	4.1	2.1	1.9
Wheat-mungbean	4.3	2.3	2.0
Wheat-mix	2.6	1.6	1.0
Overall	3.2	1.9	1.5

Sources: Ali and Byerlee (forthcoming) and Murgai (forthcoming).

Decomposition of Productivity Growth

Temporal and spatial differences in productivity growth, taken together, highlight the potential roles of technological change, infrastructure and human capital, and resource degradation in determining TFP growth. Indeed, previous studies have related TFP growth in the Indian and Pakistan agricultural sectors to technological change (tied explicitly or implicitly to research investments), extension systems, infrastructure investments, human capital endowments, and policy reform (Rosegrant and Evenson 1992; Kumar and Mruthyunjaya 1992; Fan and others 2000; Pingali and Heisey 2001). However, there has, until now, been little effort to determine the quantitative impact of resource degradation on productivity growth.

Part of the problem has been the difficulty of agreeing on how to measure the impact of resource degradation on TFP. Some have argued that TFP measurement should incorporate changes in resource quality and externalities, such as water pollution (Herdt and Lynam 1992), while others measure TFP only with conventional inputs and consider resource stocks as a technical constraint that influences trends in TFP (Squires 1992). We prefer the second approach, for three reasons. First, attempts to account for market failure and social costs, such as resource degradation, in estimates of TFP violate the theoretical basis of those estimates (Byerlee and Murgai forthcoming). Second, it is difficult, in practice, to value changes in resource quality, even where these changes can be physically quantified. Finally, in the medium term covered by this article, farmers may not be able to observe resource degradation, and therefore it is exogenous rather than endogenous to decisionmaking (see Policy Discussion). Keeping these considerations in mind, we assess resource degradation concerns in detail by estimating a cost function for Pakistan that relates costs of production to human and physical infrastructure development, technological change, and resource quality.[1] (As noted above, disaggregated data on resource quality for the Indian Punjab were not available.) We use the adult literacy rate to capture the effect of changes in labor quality, and the inverse of the distance of a village from the nearest metal road to quantify the effect of improvement in physical infrastructure. The effect of technological change is proxied by two variables: (1) the proportion of area sown to modern wheat varieties, and (2) cropping intensity, which is a proxy for adoption of modern summer crop varieties that shorten the growing period and thus allow for early planting of winter crops. The effect of resource degradation is estimated through measures of soil and water quality (phosphorus, organic matter, and soluble salts for soil or electroconductivity for water). Region-specific time-trend dummies are included to capture the remaining unspecified effects of technological change, resource degradation, and change in resource productivity not included in the function.

The coefficients estimated in the cost function are used to decompose productivity trends into the effects of technological change, improvements in human resources and infrastructure, and natural resource degradation. The decomposition was performed by multiplying the negative of the coefficient in the cost function by the system-level rate of change (in percent) per year for each variable included in the cost function.

Based on this analysis, we found that, for the Pakistan Punjab, technological change and improvements in human and physical infrastructure together produced an average growth of 0.94 percent per year, with each accounting for about half the total—and that resource degradation, in aggregate, lowered growth by 0.53 percent per year (table 5).[2] The combined effect of technological change, improvements in human and physical infrastructure, and resource degradation was negative in the wheat-rice system (i.e., there was an overall increase in unit cost), and the contribution of technological change was highest in the wheat-cotton and wheat-mungbean systems. These results confirm the pattern found in the TFP estimates reported in the previous sections.

Soil and water degradation reduced productivity in all regions, highlighting the effect of natural resource variables on productivity. In the wheat-rice system, resource degradation more than canceled the productivity-enhancing contributions of technological change, education, and infrastructure. The unspecified "other factors" captured by coefficients on the regional time-trend variable also reduced productivity quite strongly in all but the wheat-cotton system. These omitted variables include resource degradation factors that were not measured, such as the development of pest complexes due to inappropriate use of pesticides and to monocropping of cereals. More research is needed to identify the management practices causing such a decline. Moreover, as massive public investment to control waterlogging and salinity is not included in the cost function, which relates only to private costs and returns, the effect of these factors is probably underestimated.

Policy Discussion

Concerns about food security following the food crisis of the mid-1960s led the governments of India and Pakistan to concentrate resources in irrigated areas, such as the Punjabs, which held promise for the greatest crop yield increases (Sims 1993). The subsequent gap in agricultural performance and in sources of growth between the two states, despite quite similar agro-ecological potential, seems to relate to differences in nonprice policies toward agriculture, since price incentives, a major policy instrument in both countries, were fairly similar.

At the core of the price policies was a strategy of massive subsidization of fertilizer, credit, power, and irrigation inputs. In India, subsidies on the four major inputs grew at 9 to 12 percent a year in real terms between 1981 and 1993, accounting for between 2.2 and 2.7 percent of gross domestic product by the end of that period (Gulati

Table 5. Decomposition of Total Change in Crop Sector Productivity in Pakistan's Punjab, 1971–94
(percent per year)

	Soil and water quality deterioration								
Region	*Water electro-conductivity*	*Soil phosphorous*	*Soil organic matter*	*Total soil-soluble salts*	*Other factors*[a]	*Total*	*Technological change (CI and MV*[b]*)*	*Public investment (roads and literacy)*	*Net effects*
Overall Punjab	–0.007	–0.049	–0.137	–0.027	–0.314	–0.534	0.497	0.443	0.406
Wheat-rice	–0.011	–0.087	–0.212	–0.058	–0.925	–1.293	0.339	0.371	–0.582
Wheat-mung	0.001	–0.004	–0.066	0.000	–0.557	–0.626	0.527	0.464	0.366
Wheat-cotton	0.003	–0.064	–0.109	0.001	0.467	0.298	0.727	0.498	1.523
Wheat-mixed	–0.024	–0.027	–0.155	–0.057	–0.306	–0.568	0.350	0.418	0.199

Note: The rate of productivity growth in each production system was evaluated by multiplying the negative of the coefficient in the cost function with the system level rate of change per annum in each factor.

a. Based on the system-specific trend coefficients (converted to percentage terms) in the cost function.

b. CI = cropping intensity, MV = percent area in modern varieties of wheat

Source: Ali and Byerlee (forthcoming).

and Sharma 1995). Subsidies were also an important element of public spending in Pakistan, but with a stronger bias toward large farmers (Sims 1986, 1993). Inputs subsidies in both countries were maintained well beyond an initial period when they might have been economically justified to overcome farmers' risk aversion and to support learning by doing. This was because once established, they were politically difficult to remove. In the Indian Punjab, where small and medium farmers who dominate the electorate were major beneficiaries, the subsidies became even more entrenched than in Pakistan.

At the same time, however, output prices on basic food grains were taxed to maintain low food prices. These controls on food marketing kept grain prices below world prices—a problem compounded by overvalued exchange rates and tariff protection of the nonagricultural sector in both states. Thus, despite the high subsidies, there was a large net transfer of resources out of agriculture. Effective protection rates for food grains over much of this period averaged between −33 and −50 percent (Faruqee 1995; Gulati and Kelley 1999).

In any case, similar pricing strategies in the two states, along with empirical evidence on agricultural supply response and input elasticities from the Asian context, suggest that the differential performance between the states is more likely the result of nonprice factors. This view is supported by other studies showing that investments in rural infrastructure, human capital, and research and extension play a dominant role in influencing supply and productivity growth (Binswanger and others 1993; Fan and others 1999; Rao 1989).

Based on comparisons of public expenditures in agriculture in the two states and on the importance to growth of education and infrastructure, as evident from the cost function analysis, India would be expected to have more rapid input use and productivity growth than Pakistan, where the share of public resources allocated to agriculture was lower (Choudhry and Faruqee 1995). Indeed, India did have more rapid productivity growth, due to massive public investment in rural infrastructure, human capital, and research and extension, and to the subsequent better quality of those factors. India's greater investment in rural infrastructure meant, in particular, that by the mid-1980s, all rural villages in the Indian Punjab were electrified, the density of the road network was well above that of the Pakistan Punjab, and more than 90 percent of the cropped area was irrigated (Fan and others 1999). In Pakistan, by comparison, investment in education and rural infrastructure was much lower (Mujahid-Mukhtar 1991; Rosegrant and Evenson 1992; Faruqee 1995). India also had a relatively better developed network of agricultural research centers and universities, especially in the northwest (Mruthyunjaya and Ranjitha 1998).

Given the relative importance, however, of nonprice incentives for growth, the trend of expanding subsidies at the expense of productivity-enhancing investments raises concerns about the sustainability of growth over the long term if current price-based policies continue (Fan and others 1999). In Pakistan, the total share of public resources allocated to agriculture has been declining, and irrigation-related expenditures have been particularly impaired, with a 4 percent annual rate of decrease (Ahmad and Kutcher 1992). In particular, continuous underinvestment in operational and management costs has seriously reduced the efficiency of the irrigation system (Chaudhry and Ali 1989), resulting in such problems as regular breaches, excessive seepage, and limited water supplies for the tail reaches of distributaries. Research spending also fell in real terms in the 1990s and accounts for a falling share of the agriculture budget (Choudhry and Faruqee 1995). Across the border in India, even though the share of public resources devoted to agriculture has risen steadily since the early 1980s, subsidies to agriculture have increased three times faster than other expenditures (World Bank 1996).

Apart from crowding out productivity-enhancing expenditures, input subsidies have also been a major cause of overcapitalization, inefficient use of inputs, and a shift in cropping patterns toward water- and fertilizer-intensive crops, thus contributing, in India, to soil degradation, salinity problems, and overexploitation of groundwater (Joshi and Tyagi 1994; Vaidyanathan 2000). In Pakistan, the subsidy on canal water prices has led to inefficient use of water and has contributed to the waterlogging and salinity problem (Ahmad and Kutcher 1992). In addition, the flat rate structure of water and electricity prices, together with a subsidy on tubewell drilling without regulation of the number of tubewells, has distorted the efficient use of water (Johnson 1989). Resource degradation is not, in itself, a reason for policy intervention if it is internalized in producer decisionmaking. In this case, however, distorted policies have led private and social costs to diverge.

Removal of price distortions in the form of input subsidies would be a major step toward arresting resource degradation and encouraging more sustainable systems. It would also encourage higher productivity growth by freeing resources for high-priority public investments in rural infrastructure, education, and research and extension. Since the early to mid-1990s, both Pakistan and India have initiated steps to reduce price distortions in the agricultural sector, but these efforts have not yet been accompanied by an increase in public investments in agriculture.[3]

Arresting resource degradation will also require a concerted effort on several other fronts. First, the shortage of public investment funds has led to considerable underinvestment in establishing new drainage systems, which are central to resolving the waterlogging and salinity problems. It may be argued that irrigation is a private good and should gradually be handed over to private markets, but drainage is a public good and will remain so, at least beyond the farmfield—and it is beyond the farmfield that most drainage investments are needed (World Bank 1994). New institutional structures for irrigation are now being piloted in Pakistan; these approaches include the devolution of water management to farmers' organizations, and the establishment of public utilities to operate and price water further up the system (Bandaragoda and Firdousi 1992). These measures, too, may help resolve resource degradation problems.

Second, halting resource degradation will require that research systems, which have been oriented toward developing technologies based on packages of modern inputs, place more emphasis on input-efficient and environmentally friendly practices. This will require considerable location-specific research on such themes as integrated pest and nutrient management and cropping systems. It will also require diversifying rotations to include legumes and the use of conservation tillage. Many such practices are information intensive and will require much greater information dissemination and extension efforts. Research systems in both states have shifted direction toward these new priorities in the 1990s.

Finally, a large number of institutions in the two Punjabs have overlapping mandates to address soil and water management problems in irrigated agriculture, and their efforts are poorly coordinated. In the Pakistan Punjab alone, for example, nearly a dozen institutions are working on salinity problems. Information about land and water problems is also institutionally dispersed, as is policymaking (John Mellor Associates and Asianics Agro-Develoment International 1994). It is important, therefore, to establish a central agency in each Punjab to regularly provide farmers and policymakers with current information on the status of land and water resources in irrigated areas.

Conclusion

In examining the critical issue of long-term productivity and sustainability of irrigated agriculture in the Indian and Pakistan Punjabs, this study confirms previous findings that India experienced much higher and more rapid growth of yields for food crops. However, the results suggest that most of India's higher growth was due to the more rapid growth of inputs. Though overall productivity growth in the Indian Punjab was higher, it was not by a large margin.

The gap in input use and agricultural performance between the two states, despite quite similar agro-ecological potential, seems to relate to differences in nonprice policies that encouraged much faster growth of input use in India than in Pakistan. But while investment (both public and private) plays a central role in productivity growth, there was, in both Punjabs, a considerable lag between investment in infrastructure and Green Revolution inputs and the realization of productivity growth. This seems to relate in part to learning by doing and investment in human capital, which take time to produce improvements in technical efficiency; and in part to the better utilization of lumpy capital investments over time, especially tubewell capacity. For policymakers, this lag suggests that a long-term commitment is needed to realize complementarities between investment in technologies and supporting infrastructure.

The results of this study also raise serious concerns about the long-term sustainability of intensive irrigated Green Revolution systems due to resource degradation. For Pakistan, this study provides the first quantitative evidence of the impact of resource degradation, which is estimated to reduce productivity growth by one-third overall, and in the case of wheat-rice, to practically cancel the effect of technological change. These results, combined with the stagnation of cereal output in recent years, highlight the urgent need for measures that will arrest the problem of resource degradation and maintain the Punjabs' most valuable assets—their irrigated land base.

Notes

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This study summarizes the results of a study sponsored by the World Bank, "Total Factor Productivity Growth in Post–Green Revolution Agriculture of Pakistan and Northwest India." More detailed discussions of the India and Pakistan results can be found in Murgai (1997) and Ali and Byerlee (forthcoming), respectively. The authors thank the Research Support Board for funding and two anonymous reviewers for valuable comments.

1. We selected the dual (cost function) approach over the primal (production function) approach for econometrically decomposing productivity growth, because the former has a number of advantages (Alston and others 1995). The use of factor prices, rather than their quantities, as explanatory variables avoids problems of simultaneity that arise when input choices are endogenous with output. Factor prices are more likely to be behaviorally exogenous to a producer. In addition, the dual approach allows estimation of a system of equations comprising the cost function and the system of factor share equations, which results in greater efficiency.

2. Total annual productivity growth estimated through the econometric analysis is 0.41 percent for 1971–94, lower than the 1.30 percent estimated through the index number approach for the corresponding period, but with the same ranking by production system. There are several possible reasons for the difference in productivity growth obtained using the index number and econometric approaches: (a) the TFP growth rate (primal) is computed with input levels held constant, whereas the cost function rate (dual) is computed with input level adjusted optimally to technological change (Antle and McGuckin 1993); (b) the productivity measure obtained from the cost function is net of factor substitution, whereas the index number estimate includes the substitution effect (Ray 1982); and (c) not all the variables related to technological change could be included in the cost function, which therefore might have underestimated technological progress.

3. Pakistan has eliminated its fertilizer subsidy, and India has removed credit subsidies but has yet to eliminate fertilizer subsidies. In India, as part of a broader liberalization program that started in 1991, the irrigation subsidy has also been marginally reduced, but at the expense of the quality and reliability of water delivery. Efforts to reduce the subsidy on rural power have been unsuccessful; in fact, the subsidy has increased by 14 percent a year in real terms between 1991 and 1995 (World Bank 1996). Output markets for the main crops have also been liberalized in both countries, leading to an increase in the prices of rice and cotton in India, and of food grains in Pakistan.

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