POLICY RESEARCH WORKING PAPER 2480

Productivity Growth and Resource Degradation in Pakistan's Punjab

A Decomposition Analysis

Mubarik Ali
Derek Byerlee

The introduction of green revolution technologies in wheat and rice production in Pakistan's Punjab province reversed the country's food crisis and stimulated rapid agricultural and economic growth. But resource degradation through intensification, monocropping, and mismanagement of water resources has offset much of the productivity effect of technological change.

The World Bank
Rural Development Department
November 2000

Summary findings

The introduction of green revolution technologies in wheat and rice production in Asia in the mid-1960s reversed the food crisis and stimulated rapid agricultural and economic growth. But the sustainability of this intensification strategy is being questioned in light of the heavy use of external inputs and growing evidence of a slowdown in productivity growth and degradation of the resource base.

Ali and Byerlee address the critical issue of long-term productivity and the sustainability of Pakistan's irrigated agriculture. To estimate changes in total factor productivity in four production systems of Punjab province, they assemble district-level data on 33 crops, 8 livestock products, and 17 input categories.

They find that average annual growth in total factor productivity was moderately high (1.26 percent) for both crops and livestock for the period 1966–94, but observe wide variation in productivity growth by cropping system.

A second, disaggregated data set on soil and water quality reveals significant resource degradation. The authors use the two data sets to decompose the effects of technical change and resource degradation through application of a cost function.

They find that continuous and widespread resource degradation (as measured by soil and water quality variables) has had a significant negative effect on productivity, especially in the wheat-rice system, where resource degradation has more than offset the productivity effects of technological change.

Degradation of the health of the agro-ecosystem was related in part to modern technologies, monocropping, and mismanagement of water resources.

The results call for urgent analysis of technology and policy options to arrest the degradation of resources.

This paper—a joint product of the Rural Development Department and the Asian Vegetable Research and Development Center—is part of a larger effort to support the development of sustainable intensification of irrigated agricultural systems. The study was funded by the Bank's Research Support Budget under the research project "Total Factor Productivity Growth in Post-Green Revolution Agriculture of Pakistan and Northwest India." Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Derek Byerlee, room MC5-759, telephone 202-458-7287, fax 202-614-0065, email address dbyerlee@worldbank.org. Policy Research Working Papers are also posted on the Web at www.worldbank.org/research/workingpapers. Mubarik Ali may be contacted at mubarik@netra.avrdc.org.tw. November 2000. (30 pages)

Productivity Growth and Resource Degradation in Pakistan's Punjab: A Decomposition Analysis

Mubarik Ali

Asian Vegetable Research and Development Center, Taiwan, China

and

Derek Byerlee

Rural Development Department, World Bank

Contents

List of Tables

List of Boxes

List of Figures

Introduction

The introduction of Green Revolution technologies in wheat and rice in Asia in the mid-1960s produced impressive results in reversing the food crisis and stimulating agricultural and economic growth. However, questions are now being asked about the sustainability of this intensification strategy, in light of high use of external inputs and growing evidence of a slow down in productivity growth and degradation of the resource base (Byerlee, 1992; Pingali and Heisey, 1996; Huang and Rozelle, 1995; Pagiola, 1995).

These concerns were initially based on declining yields observed in long-term experiments (Flinn and De Datta, 1994). Scientists later observed stagnating yields in farmers' fields despite growing input use, especially where intensive cereal mono-cropping had been continuously practiced (Cassman and Pingali, 1995; Ali, 1996; Byerlee and Siddiq, 1994). These problems were considered especially important in the wheat-rice belt, the breadbasket of northern India and Pakistan which covers over 12 million ha and provides food security for some 500 million people (Hobbs and Morris, 1996).

Nonetheless, to date, there is little quantitative evidence of the lack of sustainability of current intensification strategies. Part of the problem has been the difficulty of agreeing on useful measures of sustainability. Lynam and Herdt (1989) proposed a non-positive trend in total factor productivity (TFP) as a good indicator of lack of sustainability of a production system. This measure raises several practical issues, such as the level of aggregation (e.g. crop or system) at which TFP should be measured, whether inputs should include changes in resource quality, and if so, how are those changes to be measured and valued? Recent evidence of changes in TFP in Pakistan, for example, provides inconsistent results from negative trends (Ali and Valesco, 1993) to significantly positive (Khan, 1994). Moreover, it is not necessary (and perhaps not possible) to maintain resource quality for all components in a system in all locations (Lynam and Herdt, 1989). In particular, farmers may avoid or mitigate resource degradation by exploiting substitution possibilities among inputs and crops.

In addition, TFP alone is a relatively blunt instrument for tracking sustainability over the long-term. A positive trend in TFP does not necessarily imply a sustainable system since rapid productivity gains from new technologies may mask the effects of serious resource degradation caused by technology-led intensification, at least in the short to medium-term. In order to overcome this problem as well as to interpret trends in TFP, it is necessary to track indicators of agro-ecosystem health, especially measures of soil and water quality (Herdt and Lynam, 1989). Few studies have attempted to relate productivity trends to such indicators (Lindert, 1996; Huang and Rozelle, 1995).[1]

---

[1] Some studies have estimated the effect of environmental variables, such as pollution, on productivity (Ball *et al., 1994* and Pittman, 1981,) A recent study by Gollop and Swinand (1998) develops an approach to account for externalities in productivity measures but the theoretical basis is questionable (Smith, 1998; Weaver, 1998). Others have related agriculture production to externalities caused by the use of modern technologies (Antle and Pingali, 1995). However, measurement of pollution was indirect

The main objectives of this study are first, to estimate total factor productivity at the production system level in the period since the advent of the Green Revolution in Pakistan's Punjab Province, and second, to relate productivity trends to changes in resource quality. Earlier studies have estimated resource productivity at the national or state level (e.g., Rosegrant and Evenson, 1992), or have been restricted to one crop in a region (e.g., Cassman and Pingali, 1995). Since sustainability is likely to relate to underlying agronomic and socioeconomic characteristics of the farming or production system, such as crop rotation, an important contribution of this study is to quantify productivity trends at the production system level defined in terms of the dominant cropping pattern. Considerable resources were invested in collecting the large amount of data on individual crop and livestock products, inputs, and prices that are required for the system-level analysis.

Further, a major contribution of the study is to quantify trends in resource quality and then to econometrically relate trends in productivity to indicators of resource quality. To do this, we establish a second comprehensive data set on soil and water quality variables based on records of tests in farmers' fields. This enables us to at least partially decompose productivity trends into the effects of technological change, improvements in human resources and infrastructure, and natural resource degradation.[2]

This study focuses on the measurement of agricultural productivity change in the irrigated agriculture of Pakistan's Punjab province which is the agriculturally dominant province in the country, with a farming population of over 60 million people, and often described as Pakistan's bread basket. Over 80% of the cropped area of the province is irrigated. The Punjab was one of the earliest beneficiaries of the Green Revolution with the introduction of modern varieties of wheat and rice in the 1960s. However, recent studies have questioned the sustainability of current intensification strategies (Byerlee and Siddiq, 1994). In light of recent record imports of wheat, the staple food, the issue is clearly critical to agricultural development strategies and food security in Pakistan, as well as in neighboring areas of India.

The paper is developed as follows. The next two sections outline the analytical approach and the major data sources. This is followed by a description of major trends in the agricultural sector, especially those related to technical change and resource quality. Estimates of TFP growth are then presented and productivity growth decomposed into the effects of technology, resource degradation, human resources, and infrastructure through estimation of a cost function. The last section summarizes the main policy implications.

Analytical Approach

Following Lynam and Herdt, a non-positive trend in TFP has been widely accepted, at least by economists, as an indicator of unsustainable resource management (e.g., Cassman and Pingali, 1995; Ehui and Spencer, 1993). However, many practical problems are encountered in choosing an acceptable measure of TFP apart from the fact that positive TFP growth by itself does not

---

[2] Huang and Rozelle (1995) estimated the effects of technological change and environmental degradation using secondary statistics, such as area of land eroded. Preliminary work by Lindert (1996) has used soil testing data although he does not decompose the effects of technological change and resource degradation.

necessarily indicate sustainable resource management. For example, Squires included conventional inputs only, while the resource stock, such as soil nutrient content, was considered as a technical constraint that influences trends in TFP. In contrast, Herdt and Lynam and Alston, Anderson, and Pardey have proposed a measure of Total Social Factor Productivity (TSFP) that incorporates changes in resource quality as well as externalities.[3]

We prefer Squires's approach in the TFP estimation on both conceptual and empirical grounds. Conceptually estimates of TFP are based on the assumption of profit maximization, which is violated by attempts to account for market failure in TSFP measures.[4] In practice, it is difficult to value changes in resource quality and externalities, even where these changes can be physically quantified. Also, in the short to medium term covered by this paper, farmers may not be able to observe resource degradation and therefore it is exogenous to decision making rather than endogenous. The direct estimates of TFP using only conventional inputs and outputs is then the sum of i) technological progress, ii) changes in resource quality, and iii) improvement in technical and allocative efficiency due to investments in human capital and infrastructure. We then use a cost-function to decompose productivity growth into each of these effects. This provides a production system-specific estimate of the effects of changes in resource quality on productivity.

It should be noted that this measure overestimates TFP to the extent that resource degradation is internally induced—for example, depletion of soil nutrients to maintain current production levels. Also as a measure of sustainability, it ignores externalities such as effects on human and environmental health, which may be the major sustainability issues in some systems. However, in addition to practical difficulties, the theoretical case for including such externalities in agricultural productivity measures is questionable (Smith, 1998; Weaver, 1998).

The chain-linked Tornqvist-Theil indexing procedure is commonly used to measure TFP because it is exact for a flexible linear homogeneous translog aggregate production function (Diewert, 1976, and Hulten, 1986). The index is estimated as follows.[5]

$$TFP = \ln(Q_t / Q_{t-1}) = 1/2\sum_{i=1}^{m} (s_{it} + s_{it-1})\ln(q_t / q_{t-1}) \tag{1a}$$

[3] For empirical efforts to apply this approach see Ehui and Spencer (1993), Antle and McGuckin (1993), Oskam (1991), Archibald (1988) and Barnett, Payne and Steiner. (1995)

[4] See Murgai (1999) and the recent exchange in American Journal of Agricultural Economics (Gollop and Swinand (1998); Weaver (1998) ; Smith (1998).

[5] The measures of productivity growth will be biased if firms are in a temporary equilibrium rather than the long-run equilibrium, implicitly assumed by this estimation method (Berndt and Fuss (1986) and Hulten (1973)). This situation may arise, for example, with underutilized capital and labor capacity. We have no reason to expect this is the case in this study. Moreover, even if there is under utilization we have estimated values of the quasi-fixed inputs using the method specified in Berndt and Fuss (1986). That is, we computed the *value* of services from stocks of quasi-fixed inputs, rather than using the *quantity* of these stocks. For example, we took area planted (i.e., total capacity), not harvested area (utilized capacity) multiplied by the market rental rate of land. In the case of tractors and labor, we employed an annual utilization rate

$$\ln(X_t / X_{t-1}) = 1/2\sum_{z=1}^{m} (s_{zt} + s_{zt-1})\ln(x_{zt} / x_{zt-1}), \text{ and} \quad (1b)$$

$$\ln(TFP_t / TFP_{t-1}) = \ln(Q_t / Q_{t-1}) - \ln(X_t / X_{t-1}) \quad (1c)$$

where q_{it} is the quantity of the *i*th output (*i*=1,2,...,*m* number of product types) in the *t*th period (*t*=1,2,...,*T* number of years); x_{zt} is the quantity of the *z*th input (*z*=1,2,...,*n* number of inputs) in the *t*th period; $\ln(Q_t / Q_{t-1})$ and $\ln(X_t / X_{t-1})$ are the weighted rate of change in all outputs and inputs, respectively; and s_{zt} and s_{it} are the respectively share of the *z*th input in total costs and of the *i*th output in total value of production. This study estimated TFP for crops, livestock, and all agriculture. The partial factor productivities (PFPs) for important inputs (labor, water, and land) were also estimated, in order to help understand underlying trends in TFP.[6]

The decomposition of productivity changes can be econometrically estimated through a production function, profit function, or a cost function. We selected the cost function which has a number of advantages over the primal approach. The cost function in translog form[7] can be expressed as:

$$\begin{aligned}\ln C =& \alpha + \sum_{i=1}^{m}\alpha_i \ln q_i + \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m}\beta_{ij}\ln q_i \ln q_j + \sum_{z=1}^{n}\rho_z \ln w_z \\ &+ \frac{1}{2}\sum_{z=1}^{n}\sum_{u=1}^{n}\chi_{zu}\ln w_z.\ln w_u + 1/2\sum_{i=1}^{m}\sum_{z=1}^{n}\delta_{iz}\ln q_i.\ln w_z + \sum_{c=1}^{p}\mu_c \ln I_c \\ &+ \sum_{o=1}^{r}\phi_o \ln S_o + \sum_{f=1}^{q}\gamma_f \ln H_f + \sum_{r=1}^{k}\lambda_r T_r + \sum_{d=1}^{l}v_d D_d \\ &+ \sum_{o=1}^{r}\sum_{z=1}^{n}\Theta_{oz}\ln w_z \ln S_o + \sum_{i=1}^{m}\sum_{o=1}^{r}\Omega_{io}\ln q_i \ln S_o + \sum_{c=1}^{p}\sum_{o=1}^{r}\Psi_{co}\ln I_c \ln S_o \\ &+ \sum_{z=1}^{n}\upsilon_z \ln w_z T + \sum_{j=1}^{m}\theta_j \ln q_j T\end{aligned} \quad (2)$$

[6] To estimate PFPs the summation sign in (1b) is removed to estimate the input index, and the input share is set to one. The output index remains unchanged.

[7] The translog form is preferred because specific features of technology (like returns to scale or homotheticity) may be tested by examining the estimated model parameters. Specifically, if the technology is homothetic, the dual cost function is multiplicatively separable in output quantities and input prices. However, the function does not allow the possibility of weak input-output separability. The approximation potential of the translog and other locally flexible forms has been called into questions in a number of studies (Chalfant , 1984; Thompson, 1988).

where C is total cost, q_i is output, w_z is the price of the zth input, I_c are variables related to technological innovations (such as proportion of modern variety area), S_o are resource quality-related variables (such as organic matter content in soils), H_f are human and infrastructure-related variables (such as literacy rate, and distance from road), T_r is an annual index of time for production system r, and D_d is a dummy variable for district d. The effect of technological change on cost is controlled through the coefficient μ (expected to be negative), and the effect of changes in resource quality are measured through ϕ plus the coefficients of the interaction terms between resource quality and other variables evaluated at the mean value of these variables (the sign will be positive or negative depending on a negative or positive definition of resource quality). The effect of improvements in human resource and infrastructure variables on productivity is estimated through γ (expected to be negative). The system-specific trends in technology, resource quality or efficiency, not captured by the above variables are estimated through λ_r.

In addition to the traditional interaction terms of the translog function between input prices and outputs, selected other interaction terms were also included to keep the number of estimated coefficients manageable. The effects of variable inputs, output level, and technological change on production may depend upon the resource stock variables. To capture these effects, the interaction between each of input prices, output, and technology variables with resource stock variables were introduced. Moreover, as the study covers a relatively long period of time, expected overtime changes in input and output elasticities are captured by including the interaction between input prices and outputs with the trend variable.[8]

For the cost function in (2) to be homogenous of degree 1 in input prices requires:

$$\sum_{z=1}^{n} \rho_z = 1, \sum_{u \neq z=1}^{n-1} \chi_{uz} = 0, \sum_{z=1}^{n} \Theta_z = 0, \sum_{i=1}^{m} \delta_{iz} = 0 (z = 1, ..., n) \quad (3)$$

From the translog cost function, we derive input share equations using the Shephard's lemma and assuming the profit maximization behavior as follows:

$$s_z = w_z x_z / C = \rho_z + \sum_{u \neq z=1}^{n-1} \chi_{uz} \ln w_u + \sum_{i=1}^{m} \delta_{i1} \ln q_i + \upsilon_z T + \sum_{o=1}^{r} \Theta_z \ln S_o, \text{ (for each input } z = 1, \cdots, n) \quad (4)$$

[8] Technological change is assumed to be Hick's neutral, therefore interactions of technological change variables with input prices and output levels are not included. The same is true for the infrastructure variables. Likewise, resource stock and infrastructure variables can safely be assumed to independently affect productivity, and their interactions are excluded. The resource stock, infrastructure, and technology variables are assumed to affect productivity linearly, thus the square terms for these variables are not included. The exclusion of these variables keeps the number of estimated parameters manageable, and reduces multicollinearity

where s_z are input share in the total cost as defined before. The condition that all factor shares add up to one requires to impose the same restrictions on the parameters of the factor share equation as in (3).

Additionally assuming marginal cost pricing for the outputs, we obtain the "revenue share" equations, as follows:

$$R_i = p_i q_i / C = a_i + \sum_{i=1}^{m} \beta_i \ln q_i + \sum_{z=1}^{n} \delta_i \ln w_z + \upsilon_z T + \sum_{o=1}^{r} \Omega_o \ln S_o (i = 1,...,m) \quad (5)$$

Estimating the full dual system (i.e., cost and share equations together) results in much higher efficiency. Therefore, in this analysis equations (2), (4), and 5) were estimated simultaneously, along with the restriction specified in equation (3). Including the revenue share equation and equating its coefficients with the respective coefficients in the cost function, has the advantage of relaxing the assumption of fixed output(s), usually associated with application of the cost function.

One of the main objectives of this study is to decompose productivity growth. This can be done using the cost function coefficients and respective growth rates of the variables causing growth. The growth rates due to technological change (G_I), human and physical infrastructure development (G_H), and changes in resource stock (G_S) can be estimated as:

$$G_H = -\partial \ln C / \partial \ln H * \partial \ln H / \partial T = -\sum_{f=1}^{q} \gamma_f * \partial \ln H_f / \partial T$$

$$G_I = -\partial \ln C / \partial \ln I * \partial \ln I / \partial T = -\sum_{c=1}^{p} [(\mu_c + \sum_{o=1}^{r} \Psi_o \ln S_o) * \partial \ln I_c / \partial T] \quad (6)$$

$$G_S = -\partial \ln C / \partial \ln S * \partial \ln S / \partial T = -\sum_{o=1}^{r} [(\phi_o + \sum_{z=1}^{n} \Theta_z \ln w_z + \sum_{i=1}^{m} \Omega_i \ln q_i + \sum_{c=1}^{p} \Psi_c \ln I_c) * \partial \ln S_o / \partial T]$$

where $\partial \ln S_o / \partial T$, $\partial \ln I_o / \partial T$, and $\partial \ln H_o / \partial T$ are the percentage growth rates during the study period in resource stock, technology, and infrastructure variables, respectively. Apart from these, there may be some unidentified sources of productivity and degradation sources due to, for example, change in pest complex, or deterioration in the genetic potential of varieties.. These are captured through regional trend coefficient λ . Total productivity growth due to all these factors (parallel to the TFP estimated with the index number approach) will be . $G_H + G_I + G_S + \lambda$.

Data Sources

We used district-level data for all 16 irrigated districts of Punjab, defined as those having at least 50% irrigated area. Together they account for over 90% of agricultural production in the Punjab. The district level data were then aggregated to the production system level for purposes of computing TFP. Production systems were defined based on: i) cropping intensity, and ii) the major summer (or kharif) crop during 1980-81. Wheat is the dominant winter (or rabi) crop everywhere, accounting for over 80% of cropped area. Thus the districts of the province were divided into four commonly recognized systems based on the dominant summer (kharif) crop: 1) wheat-mixed summer crops (often maize or sugarcane), 2) wheat-cotton, 3) wheat-rice, and 4) wheat-mungbean (or wheat-fallow).[9] These systems represent quite different agronomic types from a cereal-legume or fallow system (more likely to be sustainable) to a continuous cereal cropping system (likely to be less sustainable—Hobbs and Morris, 1996). Livestock are important in all systems, especially cows and buffaloes for milk and meat.

District level annual data were collected from secondary sources and the Statistical Division of the Federal Ministry of Food and Agriculture, at a high level of detail for the period 1966-94. The study includes 33 crops, 8 livestock products, six crop by-products, and 17 input categories. Inputs and outputs were valued at farmgate harvest prices, also collected or estimated at the district level.

Input categories for the crop sector included land, labor, water, machinery (separately for tractor, thresher, and harvester), draught animals, fertilizer (separately for nitrogen, phosphorus, and potash), and pesticide costs (separately for aerial and ground spray), and for the livestock sector, labor, fodder and feed, and interest and maintenance costs (shed, veterinary supplies, and other cost).[10] The annual use of these inputs for 19 districts over a period of 1966-94 was estimated. All stock values were converted to flow values. Land was evaluated at its rental value, and family labor at its opportunity cost of unskilled labor. Labor stocks were multiplied by a year- and gender-specific participation rate (number of days labor used in agriculture in a year), based on household survey data collected annually by the Punjab Economic Research Institute (PERI). Similarly, machinery service price include interest and depreciation on capital, and operation cost which includes labor, fuel, shed and maintenance costs based on annual utilization rates.

Changes in the quality of conventional inputs are often confounded with changes in TFP (Alston, Norton, and Pardey, 1995). To avoid this problem i) labor was disaggregated into skilled and unskilled labor based on the rural literacy rate in each district; ii) land was divided into irrigated and unirrigated land; and iii) water into canal and tubewell water. The price of each input-quality type were separately estimated based on annual surveys by PERI. This high level of disaggregation resulted in a much richer data set than previously employed for analysis of productivity trends in the Punjab.

---

[9] District boundaries define these systems reasonably well. In three of the systems there is one dominant crop rotation. Only in the wheat-mixed system is there a much variation in crop rotation. In the wheat-mungbean system the majority of the land is fallowed in the summer season due to water scarcity. See Byerlee and Hussain (1992) for details.

[10] Depreciation cost was not included in livestock as appreciation of the younger stock was assumed to cancel the depreciation of older stock.

Finally, district-level data for the variables on resource quality based on soil and water testing were collected from the Punjab Soil Fertility Department. These variables represent values, averaged by district and year, from thousands of soil tests (organic matter, phosphorus content, pH, and soluble salts) conducted by the department for scientists and farmers. While not strictly a random sample, we have no reason to believe there will be systematic biases by district or over time. There has also been considerable concern about secondary salinity and sodicity caused by use of low quality tubewell water (Siddiq, 1994; Byerlee and Siddiq, 1994). This was captured by a similar data set on tubewell water test values (residual carbonate and electroconductivity) by district and year.

Growth in TFP was analyzed for three periods corresponding to different phases of Green Revolution technical change (Byerlee, 1992): the Green Revolution period, 1966-74, when modern varieties were widely adopted with associated inputs, the input-intensification period, 1975-84, when input use increased rapidly, and a post-Green Revolution period, 1985-94, when input use leveled off. However, the cost function analysis was restricted to the whole period, 1971-94, because of the non-availability of resource quality data prior to 1971.

Major Trends in Punjab's Agriculture

The major characteristics of Punjab agriculture are described in table 1. Farm size which now averages 3.9 ha has continuously declined over the past three decades, with a decreasing share of that land farmed by the tenant. At the same time, human resource investments and infrastructure have steadily improved over this period; however, rural literacy remains very low.

Table 1. Physical and human resource base, size of holding, and land ownership type in the irrigated Pakistan's Punjab

By region and period (1966-94)

	Period	*Wheat-mixed*	*Wheat-rice*	*Wheat-cotton*	*Wheat-mungbean*	*All Punjab*
Farm size (ha)	Green Revolution	4.9	4.4	5.3	7.0	5.3
	Intensification	4.5	4.0	4.9	6.5	4.8
	Post Green Revolution	3.7	3.2	4.0	5.2	3.9
Rented land (%)	Green Revolution	45.6	43.5	49.5	43.7	44.4
	Intensification	36.8	38.3	42.2	37.4	37.3
	Post Green Revolution	28.9	28.9	33.5	29.8	29.1
Literacy (%)	Green Revolution	21.9	21.3	15.8	16.1	18.8
	Intensification	28.9	28.6	22.1	22.1	25.4
	Post Green Revolution	33.9	32.5	25.1	22.2	28.7
Distance from paved road (km)	Green Revolution	6.0	6.5	7.6	9.2	7.2
	Intensification	4.0	4.4	4.8	9.5	5.4
	Post Green Revolution	2.1	2.5	2.2	3.8	2.5

Green Revolution =1966-74; Intensification = 1975-84; Post Green Revolution, =1985-94.

Source: Pakistan Agriculture Census reports data on these parameters for the period 1971, 1981, and 1991. The values for other ye extrapolated using a constant growth rate in between the two periods. The values reported here are the average for the study period.

Changes in the crop subsector

Crop growth in the Punjab has largely been through intensification. Land area has increased at only 0.7% annually since 1966. Technological change in Pakistani Punjab's agriculture was triggered by the introduction of modern varieties (MVs) of wheat in 1967 which covered almost all wheat area by 1983. MVs of rice were also adopted but were limited by farmers' specialization in high-valued aromatic Basmati rice varieties produced largely for the export market. However, an improved high value rice variety (Basmati 385) was released in 1985 and rapidly adopted (Sharif et al., 1992). Similarly new high-yielding cotton varieties were widely adopted in the post-Green Revolution period.

Use of modern varieties stimulated rapid input intensification (table 2). Fertilizer use jumped from an average of 14 kg of nutrient per ha of cropped area in the Green Revolution period to an average of 86 kg per ha in the post-Green Revolution period. Pesticide use also increased rapidly, especially for cotton in the post-Green Revolution period. Finally, total supply of water and its timely availability have been greatly improved through investment (largely private) in tubewells, especially during the Green Revolution and intensification periods. The wheat-rice system is most dependent on tubewell water.

The Green Revolution technology increased the demand for labor so that average labor use for crops increased from 85 person-days per ha in the Green Revolution period to 99 days per ha in the intensification period (a 15% increase) (see table 2). However, the additional labor demand together with off-farm demands, notably from the Middle East, pushed the wage rate up and induced the adoption of mechanical technology. This decreased labor use for crops to 71 days/ha in the post-Green Revolution period. Meanwhile, mechanical power (tractor, harvester, and thresher) increased from 1.5 hr per ha in the first period to 14.8 hr per ha in the most recent period replacing draft power use which decreased dramatically from 79.6 days to 8.5 days per ha over the same period. Considerable across region variation in input intensification can be seen from table 2.

Table 2. Input use in the crop and livestock sectors in Pakistan

By cropping region and period, 1966-94

Sector	*Crop System by Period*[a] *Wheat-mixed*			*Wheat-rice*			*Wheat-cotton*			*Wheat-Mungbean*			*All Punjab*		
	1	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
Crop (ha^{-1})															
Fertilizer (kg)	14.1	46	76	12.3	44.8	64.7	18.5	62.3	120.3	6.1	26	49.1	14.1	48.3	86.1
Plant protection (%)	18.2	24.6	23.9	18.9	28.3	13.4	21.3	35.6	70.2	11.1	16.6	25.3	18.3	27.9	40.1
Labor (days)	89.5	108.4	84.6	73.6	88.7	69.4	87.2	100.7	65.8	82.4	86.4	62.6	85	98.7	71.1
Bullock (days)	74.4	45.6	10.8	72.9	38.1	6.5	85.4	49.6	7.7	83.8	45.8	8	79.6	45.8	8.5
Machine (hr)	1.4	6	14.7	1.6	7.1	15.7	1.7	6.4	17.3	0.8	2.6	9.1	1.5	5.7	14.8
Water (acre ft)															
Tubewell	1.1	1.9	2.5	2.8	5	6	1.5	2.4	2.6	0.6	1.4	2	1.4	2.5	3
Canal	4.9	4.6	4.2	2.6	2.5	2.1	5.9	5.4	4.8	3.5	3.2	2.9	4.7	4.3	3.9
Irrigated area (%)	81	85.2	84.7	74	85.2	88.6	97.2	98.1	98.4	59.7	61.5	67	81.9	85.1	86.3
Crop intensity (%)	113	130	132	132	139	147	121	128	147	104	109	118	117	126	136
Livestock (SAU^{-1})[b]															
Labor (days)	35.8	41.5	42.5	32.6	37.8	40.3	33.6	35.6	34.5	30.2	35.2	30.5	33.8	37.9	37.4
Feed & fodder (t)	3.19	3.87	4.11	3.5	3.8	4.13	4.07	3.91	3.66	2.07	2.42	2.51	3.4	3.7	3.7
Others (Rs)	50.9	60.4	61.9	52.5	62.4	63.3	49.6	58.6	61.9	45.9	54.3	59.5	50	59.1	61.7

[a] 1 = Green Revolution 1966-74, 2 = Intensification 1975-84, 3 = Post Green Revolution, 1985-94

[b] Standard Animal Unit

Source: Authors' own calculation

The yield of all crops in the province increased at an average rate of 1.8% per annum led by wheat and cotton. The highest yield gain occurred in the Green Revolution period. The introduction of short-duration varieties of major crops, supported by increased water availability triggered double-crop cultivation on the same land. Overall, the cropping intensity rose about 30% during 1966-94.

The production of all crops in the province increased at the rate of 3.3% per annum during the study period, slightly higher than the rate of population growth. The rate of growth was highest in the Green Revolution period at 3.8% per annum, and then declined to about 3% as yield growth in wheat slowed sharply. Production growth rates were maintained in the post-Green Revolution period due to rapid increases in cotton yields and release of new early maturing mungbean varieties. There were also significant differences in performance by system. Production growth in the wheat-cotton and wheat-mungbean systems was double that of the wheat-rice system.

Changes in the livestock subsector

Livestock production increased at about the same rate as for crops (3.4%), although causes of this increase are less apparent than in the crop sector. The growth rate in all livestock outputs jumped sharply in the post-Green Revolution period. The major jump occurred in milk production which is due in part to the substitution of bullocks by milking cows and buffaloes. The high growth in meat production during the later periods was mainly because of the slaughtering of bullocks due to tractorization. Changes in the livestock sector across region were not uniform, although they varied less than in the crop sector.

Trends in resource quality

There are strong indications that soil and water quality in the province has deteriorated (table 3 and figures 1a and 1b). For example, average soil organic matter was already lower than 1% during the early 1970s, and this has further deteriorated in all production systems at an average annual rate of 2.3%, or a decline of over 33% over the study period. The rate of decrease was highest in the wheat-rice system. Available phosphorus has also decreased in all systems at about the same rate. Total soluble salts increased significantly in all the systems, while an increase in pH occurred in two of the four systems.

Similarly, the data confirm the deterioration in tubewell water quality, reflected in a significant increase in residual carbonate and electroconductivity of tubewell water in all production systems. Residual carbonate almost doubled during the study period, reflecting the common observation that farmers are increasingly tapping poorer quality groundwater.

Table 3. Average values of selected water and soil quality parameters in Punjab

By period and region, 1971-94

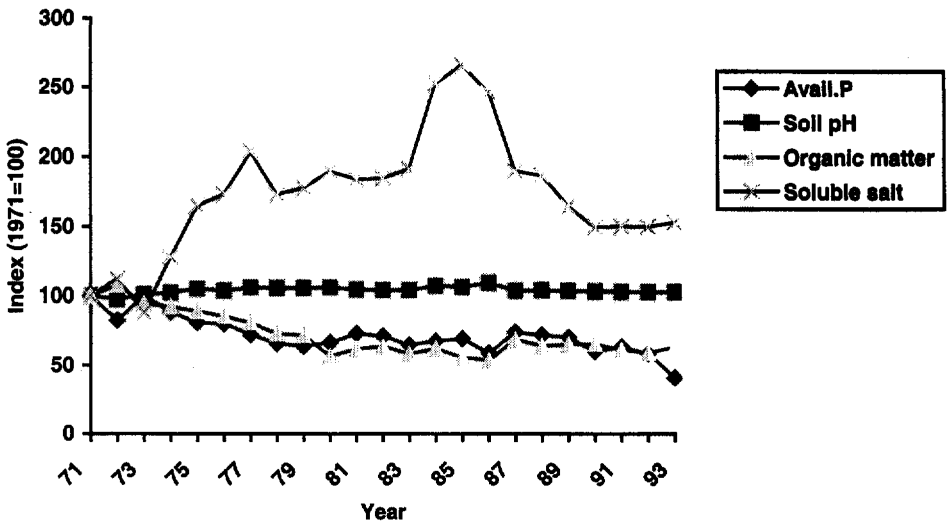
System	Period[a]	Soil				Water	
		Organic matter (%)	Available phosphorus (ppm)	Soil pH	Soluble salts (%)	Residual carbonate (me/l)	Electrocon -ductivity
Wheat-mixed	1	0.85	5.94	8.01	0.28	1.35	848
	2	0.68	5.00	8.33	0.34	1.83	943
	3	0.57	5.01	8.39	0.45	2.66	1172
Wheat-rice	1	1.02	7.42	7.74	0.12	1.20	743
	2	0.72	6.23	8.26	0.33	1.72	800
	3	0.59	4.60	8.50	0.42	2.78	874
Wheat-cotton	1	0.86	5.94	8.30	0.20	2.16	1010
	2	0.62	5.00	8.63	0.44	2.41	1099
	3	0.54	5.01	8.41	0.41	3.03	1214
Wheat-mungbean	1	0.90	7.53	8.08	0.27	1.18	939
	2	0.62	5.17	8.61	0.42	1.37	1006
	3	0.53	4.83	8.50	0.38	2.00	1141
Punjab	1	0.89	7.04	8.06	0.22	1.54	896
	2	0.66	5.46	8.46	0.39	1.90	993
	3	0.56	4.83	8.44	0.42	2.67	1123

[a]1 = Green Revolution 1966-74 (In this table, however, the mean is only for 1971-74 as data for earlier years are not available) , 2 = Intensification 1975-84, 3 = Post Green Revolution, 1985-94

Source: Authors' own calculation

Figure 1a.

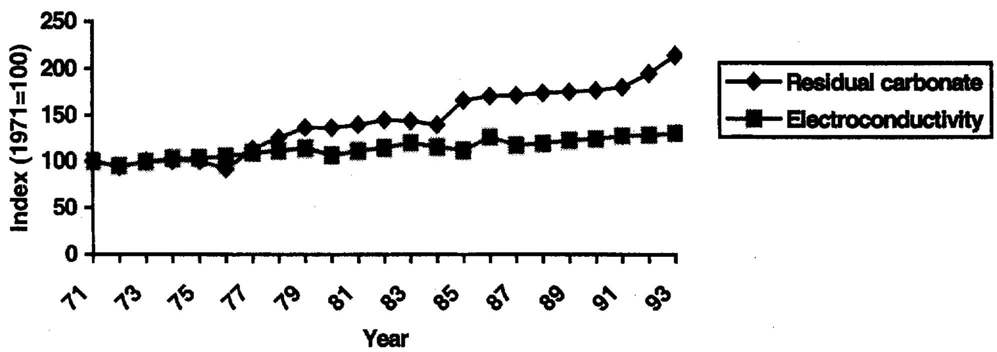
Figure 1a: Indices of trends in soil quality



Source: Authors' own calculation

Figure 1b.

Figure 1b: Indices of trends in tubewell water quality



Source: *Authors' own calculation*

Trends in productivity

Table 4 summarizes various measures of productivity. Both land and labor productivity have increased at about 2.5% annually. Land productivity has risen more slowly since the boost during the Green Revolution period, while labor productivity has generally increased in successive periods due to rapid mechanization. An important result is the overall decline in water productivity, which reflects inefficient use of irrigation water in part due to subsidies on canal water prices and fixed rates on electricity used for tubewells (Faruqee, 1995).

The overall growth in TFP for the crop sector was 1.26% per annum. Contrary to most views, TFP increased little in the Green Revolution period due to high investment costs, especially in tubewells, and was most rapid in the post-Green Revolution period.[11] There have also been sharp differences by system with the highest rate of growth in TFP in the wheat-cotton and wheat-mungbean systems (Figure 2). Both systems experienced rapid growth in the post-Green Revolution period due to successful technological innovations (especially new cotton and mungbean varieties).

[11] Similar results have been observed in a recent study of the Indian Punjab (Murgai, 1999). The reason for this decline may be high investment on tubewells which enters TFP as a capital flow cost. As most of tubewells are not utilized to their full capacity, the cost does not fully reflect their contribution in productivity. In particular, installation of tubewells is probably a risk reducing strategy, due to uncertain water supply from the canal system.

Table 4. Growth rate of partial factor productivity, input, output, and TFP indices

By production system, percent per year

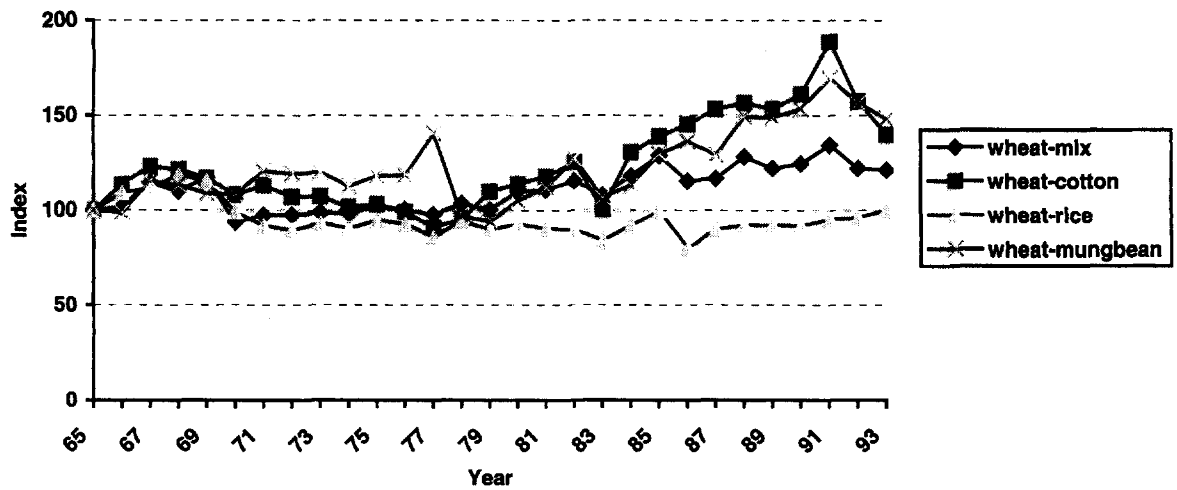
System	*Period*[a]	*Partial productivity*			*Crop*			*Livestock*			*Overall TFP*
		water	*land*	*labor*	*output*	*input*	*TFP*	*output*	*input*	*TFP*	
Wheat- mixed	All	-1.90	2.09		2.29	1.42	0.87	2.79	2.01	0.78	1.00
	1	-3.08	2.54	-5.09	3.35	4.46	-1.12^{ns}	2.77	3.57	-0.80^{ns}	-0.90^{ns}
	2	-1.50	3.51	1.67	2.25	0.75	1.50	1.47	1.46	0.01^{ns}	1.10
	3	-0.90	0.02	2.66	1.87	1.40	0.46^{ns}	4.80	2.66	2.14	1.28
Wheat-rice	All	-3.03	0.89	1.03	1.79	2.30	-0.50	2.70	2.00	0.70	0.11
	1	-7.31	0.76	-2.11	3.44	5.88	-2.43	2.86	3.59	-0.72^{ns}	-1.77
	2	-3.65	0.88	0.80	1.24	1.84	-0.60	1.19	1.07	0.12^{ns}	-0.37^{ns}
	3	0.14	1.85	3.01	2.04	1.17	0.88	5.17	3.04	2.13	1.87
Wheat-cotton	All	-0.25	2.98	3.44	3.65	2.08	1.57	3.75	1.92	1.82	1.94
	1	-4.99	3.18	-1.81	3.66	3.96	-0.30	3.10	1.72	1.38	0.09^{ns}
	2	0.10	2.32	3.48	3.55	1.77	1.79	3.06	2.20	0.87	1.87
	3	1.96	2.90	4.30	2.70	0.92	1.77	5.36	2.55	2.81	2.32
Wheat-mungbean	All	-3.49	1.89	3.08	3.68	2.36	1.32	4.40	2.46	1.93	1.98
	1	-7.85	4.36	0.95	6.79	4.55	2.24	1.50	3.08	-1.59	1.61
	2	-2.81	-1.26	0.70	1.31^{ns}	2.02	-0.70	4.73	3.08	1.64	0.46^{ns}
	3	-0.48	3.68	7.70	4.80	1.56	3.24	5.46	1.66	3.80	4.03
All Punjab	All	-1.41	2.43	2.51	3.23	1.97	1.26	3.30	2.05	1.25	1.51
	1	-5.14	2.75	-2.85	4.00	4.49	-0.49^{ns}	2.75	2.82	-0.07^{ns}	-0.17^{ns}
	2	-1.29	2.22	2.33	2.77	1.50	1.27	2.39	1.92	0.47^{ns}	1.21
	3	0.61	1.96	4.14	2.85	1.25	1.60	5.15	2.53	2.62	2.25

Note: All the coefficients, except those bearing ^{ns} sign, are statistically significant at least at the 10% level

[a] 1 = Green Revolution 1966-74, 2 = Intensification 1975-84, 3 = Post-Green Revolution, 1985-94; ALL = 1966-94.

Figure 2.

Figure 2: Trends in TFP by Production System



Source: Authors' own calculation

By contrast, the wheat-rice system experienced a significant negative growth in TFP over the study period. These results confirm widespread concerns that continuous double cropping of cereals, especially rice and wheat which require very different soil and water management practices, is an unsustainable cropping pattern (Hobbs and Morris, 1996). Deterioration in soil and water quality, discussed earlier, seems to be especially serious in this system.

Growth in TFP for livestock was similar to the crop sector (1.25% per annum) but almost all of this productivity growth occurred in the post-Green Revolution period. There were no significant technological innovations in livestock but improved fodder supply, substitution of milk animals for draft animals, and the one-time slaughter of draft animals, explain this jump in TFP. However, these sources of livestock productivity may not be available in the future. Combined crop and livestock TFP grew at 1.51% per annum, higher than for the crop or livestock sector alone.

Decomposition of Productivity Growth

As concern related to resource productivity is usually directed to the crop sector, which is directly affected by soil and water quality, we estimated the cost function for the crop sector only. One problem with multi-output, multi-input cost functions is that, even for a few outputs and inputs, the number of parameters to be estimated is large (Ray, 1982). This problem is greater when many soil and water quality parameters and their interaction with input price, output level, and technology variables are also included in the function. However, this is less a problem in our case because of the large number of data points available from combining time-series and cross-sectional data and by estimating the cost function, and factor- and revenue-share equations simultaneously. One output (Divisia Index of all 33 crop outputs) and six inputs (chemicals, water, labor, land, machinery, and animal/bullock cost) were included in the function for the crop sector. In the cost function, as in any other dual function, input prices rather than physical quantities were used.

Aggregation bias can occur with group (district-level) data as used in this study. However, use of district and regional trends, infrastructure, and resource quality variables can account for differences in the cost structure across districts. Tests for heteroskedasticity and first order autocorrelation were conducted using Langrange multiplier tests (Jarque and Bera, 1980), and the presence of these effects was rejected at the 10% significance level.

The definition of the variables in the cost function are given in box 1. The effect of technological change was imperfectly proxied by two variables (i) the proportion of area sown to modern wheat varieties, and (ii) cropping intensity. Cropping intensity is a proxy for adoption of MVs in summer crops (for which varietal adoption data were not available), since one of the major impacts of MVs of cotton and rice was to shorten the growing period, and thus to resolve the conflict between harvesting of the summer crop and planting of the following wheat crop (Byerlee et al., 1987.; Sharif et al., 1992; Ali et al., 1997). The effect of resource degradation was estimated through the soil and water quality variables described above. The adult literacy rate was used to capture the effect of changes in labor quality. The inverse of the distance of a village from the nearest metal road was used to quantify the effect of improvement in physical infrastructure. Region-specific time-trend dummies were included to capture the remaining unspecified effects of technological change, resource degradation, or change in resource productivity not included in the function.

The cost function in equation (2) along with the factor- and revenue-shares equations in (4) and (5) and cross equation restrictions in (3) were simultaneously estimated using the seemingly unrelated regression (SUR) procedure. In view of the adding-up requirement of the input share, one equation (for draft animal) was deleted. The interactions of one input price with all other prices and resource stock variables, as a group, were tested. Similarly, interactions of output with all input prices and resource stock variables as a group were tested. The trend variables for input and output prices were also validated. All these interactions as a group, except those of water with resource quality variables which were subsequently excluded, were significant at least at the 10% level. The results of the cost function estimates are reported in the Appendix.

The production elasticities, estimated at the mean level of prices and output and resource stock in the middle of the study period, are positive for all inputs, except for machinery. The respective elasticities for fertilizer, water, labor, land, machinery, and draft power are 0.03, 0.17, 0.61, 0.58, -0.15, and 0.07. The negative elasticity for machinery can be explained by the lumpy nature of investment in tractors, introduced at a subsidized rate in the country. The elasticities of all inputs except labor are increasing as indicated by positive trend coefficients. The return to scale (the inverse of the output elasticity) is 1.10 and increasing.

The elasticities of soil quality parameters were estimated at the regional mean values of input prices, output level, and technology variables. They are as expected. For example, organic matter and phosphorus have negative elasticities in all the systems, while total soluble salts, an indication of salinity, has a positive sign in the wheat-rice and wheat-mixed systems, confirming results of a recent farm-level study, that soil salinity is an important constraint on crop yields in northern Punjab (Siddiq, 1994). Of the two water-quality variables only electroconductivity produced a consistent and significant coefficient, indicating that soil salinity is in part due to the application of poor quality tubewell water.[12]

[12] The residual sodium carbonate of tubewell water was found to be highly correlated with electroconductivity and was deleted from the final equation.

Box 1. Variable definitions used in the translog cost function for Punjab agriculture, 1971-94

Independent variables

q_1 = output = Crop output measured in divisia index number of production [1965=100]

w_1 = fertilizer =Divisia index of N, P, and K prices of nutrient and spray prices

w_2 = water = Index of tubewell water price

w_3 =labor = Index of wage rate of labor

w_4 =land = Divisia index of annual rent of irrigated and unirrigated land

w_5 = machine = Index of tractor prices

w_6 = animal = Index of feed, fodder, interest, and miscellaneous animal costs per standard animal unit

S_1 = soil organic matter = Index of organic matter content in the soils (average of all the observations in a district)

S_2 = soil phosphorus = Index of available phosphorus in the soils (average of all the observations in a district)

S_3 = salts in soil = Index of total soluble salts in the soils (average of all the observations in a district)

S_4 = electroconductivity = Index of electroconductivity of water (average of all the observations in a district)

I_1 = modern variety = Index of proportion of the total wheat area under modern wheat varieties

I_2 = cropping intensity = Index of cropping intensity defined as total cropped area divided by net sown area

L_1 = education = Index of percentage of farmers who can read and write

L_2 = road = Index of the inverse of the average distance of a village from a road.

T = trend at the cropping system level = Regional time trend variable. Its value for a specific region was equal to trend (0,1,2,...for 1965,1966,1967....), and zero otherwise

D =district dummy = Set of district dummy variables having a value of one for a district, and zero otherwise.

Dependent variables

s_1 = fertilizer factor share = is (total cost of all types of fertilizer nutrients and spray cost)÷(total farm production expenditure)

s_2 = water factor share = (total cost of tubewell operating cost and canal water cost)÷(total farm production expenditure)

s_3 = labor factor share = (total cost of labor including family labor evaluated at the unskill wage rate)÷(total farm production expenditure)

s_4 = land factor share = (rent of irrigated and unirrigated land)÷(total farm production expenditure)

s_5 = machine factor share = (total operating cost of tractor, harvester, threshing, and bullock)÷(total farm production expenditure)

s_6 = animal factor share = (interest and miscellaneous animal cost)÷(total farm production expenditure)

y_1 = revenue share = (marketing revenue from all crops)÷(total farm production expenditure)

C = total cost = Index of farm production expenses (1965=100), which includes total chemicals, water, labor, land, machinery, and draft power.

The technological variables had the expected effects of lowering costs with the greatest effect for cropping intensity, reflecting success in developing short-duration modern varieties . Finally, the quality of human and physical resources plays a critical role in improving agriculture productivity, especially in a dynamic agriculture, like that of the irrigated Punjab. A 1% increase in the human and physical infrastructure variables is estimated to increase crop sector productivity by 0.01% and 0.07%, respectively, confirming other evidence of high returns to these investments in post-Green Revolution agriculture (e.g., Hussain and Byerlee, 1995; Ali and Flinn, 1989).

Using coefficients of the cost function and formulation in (6), productivity growth was decomposed into three effects: i) technological change, ii) degradation of soil and water quality, and iii) improvement in human and physical infrastructure (table 5), all evaluated at the system-specific mean rate for each variable included in the cost function.[13] Technological changes and improvements in human and physical infrastructure combined produced a growth of 0.94% per annum with each accounting for about half the total. Resource degradation in aggregate lowered growth by 0.53% per annum. The combined effect of technological change, resource degradation, and improvement in human and physical infrastructure was negative in the wheat-rice system (overall increase in unit cost). The contribution of technological change was highest in the wheat-cotton and wheat-mungbean systems.

Soil and water degradation reduced productivity in all regions, highlighting the role of natural resource variables on productivity. In the wheat-rice system, resource degradation more than cancelled the effects of technological change, and improvements in 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 environmental and management-related factors may include development of insect-pest complex (e.g., increased intensity of *Phalaris minor* in the rice-wheat system) due to inappropriate use of pesticides and monocropping of cereals, depletion of water aquifers, and development of a hard plow pan due to inappropriate mechanization (Byerlee, 1992; Hobbs and Morris, 1996). More research is needed to identify the management practices causing such a decline. As massive public investment to control water logging and salinity is not included in the cost function which relates to private costs and returns only, the effect of these other factors is probably under estimated.

[13] Total annual productivity growth estimated through the econometric analysis is 0.41% for 1971-94, lower than the 1.30% estimated through the index number approach for the corresponding period , but with the same ranking by production system. The difference in productivity growth obtained using index number or econometric approaches may be due to many reasons; (i) 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, 1995, p. 182), (ii) the productivity measure obtained from the cost function is net of factor substitution, while the index number approach includes the substitution effect (Ray, 1982, p. 496), (iii) TFP growth in the index number includes changes in resource quality and infrastructure, whereas the econometric approach has controlled for these variables, and (iv) not all the variables related to technological change could be included in the cost function which might have under estimated technological progress

Table 5. Decomposition of the total change in the crop sector productivity in Punjab during 1971-94

percent per year

	System				
	Wheat-mixed	*Wheat-cotton*	*Wheat-rice*	*Wheat-mungbean*	*Overall Punjab*
Soil and water quality deterioration					
Water electroconductivity	-0.0241	0.0033	-0.0109	0.0013	-0.0073
Soil phosphorous	-0.0268	-0.0642	-0.0868	-0.0043	-0.0487
Soil organic matter	-0.1547	-0.109	-0.2123	-0.0655	-0.1374
Total soil soluble salts	-0.0567	0.0009	-0.0583	0.0001	-0.0265
Other factors[a]	-0.3060	0.4670	-0.9250	-0.5570	-0.3140
Total	-0.5682	0.2982	-1.2929	-0.6257	-0.5343
Technological Change					
CI & MV[b]	0.3499	0.7268	0.3394	0.5271	0.4970
Public investment					
Roads and literacy	0.4176	0.4984	0.3714	0.4643	0.4434
Net effects	0.1992	1.5234	-0.5821	0.3658	0.4061

Note: The rate of productivity change in each production system was evaluated by multiplying the negative of the coefficient with the system-level rate of per annum change (in percentage) in each factor.

[a] Based on the system-specific trend coefficients evaluated at regional mean values of the other variables used in the cost function.

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

Source: Authors' own calculation

The deterioration in agro-ecosystem health, depicted by the declining trend in the resource stock variables discussed earlier, is in itself a cause for concern. This is more so when at least some of this deterioration seems to relate to intensification, especially increased use of fertilizer and water (table 6).[14] We also estimated the long-term negative effect of modern inputs on productivity through their effect on degradation of the resource stock. On average, a 1% increase in tubewell water and fertilizer reduced productivity over the period by 0.011 and 0.021% through their effects on the quality of the resource stock, offsetting some of their positive production effects.

[14] Some of these effects may be indirect. For example, use of fertilizer and water may deplete soil phosphorous and organic matter by encouraging higher cropping intensity.

Table 6. Effect of modern technology inputs on productivity through depletion of the resource stock

Resource quality parameter	*Production elasticity (%)*[1]	*Effect of 1% increase in technology inputs on resource stock (%)*[2]		*Effect of 1% increase in technology inputs on productivity (%)*[3]	
		Water	*Fertilizer*	*Water*	*Fertilizer*
Available soil organic matter	0.060	-0.053	-0.265	-0.003	-0.016
Available soil phosphorus	0.024	-0.159	-0.136	-0.004	-0.003
Total soluble salts in soils	-0.015	0.224	0.103	-0.003	-0.002
Electroconductivity	-0.006	0.077	0.095	-0.000	-0.001
Total				**-0.011**	**-0.021**

[1]The production elasticities of resource stock variables ($\partial lnP/\partial lnS$, where P represent productivity, and S a stock variable) were obtained from the cost function coefficients by evaluating them at the mean values of all other variables involved, and then inverting their signs, i.e. $\partial lnP/\partial lnS=-\partial lnC/lnS$

[2]The percentage effect of a technology variables on a resource stock variable ($\partial lnS/\partial lnI$, where I represents a technology variable) was obtained by regressing the logarithm of each resource stock variables on the logarithm of technology inputs (i.e., fertilizer and water).

[3]The effect of technology variables on productivity ($\partial lnP/\partial lnI$) was estimated by multiplying the production elasticity of a resource stock variable with the effect of technology variable on the resource stock, i.e. $(\partial lnP/\partial lnI) = (\partial lnP/\partial lnS)* (\partial lnS/\partial lnI)$.

Source: Authors' own calculation

Conclusions

Although results achieved in Pakistan with Green Revolution technologies are impressive, the results of this study raise important questions about the sustainability of those gains, especially in light of growing evidence of degradation of land and water resources. In this study, the assembly and analysis of a very comprehensive data set on both crop and livestock production, as well as a number of soil and water-quality variables, provided the opportunity to understand some of the underlying trends in major production systems of Pakistan's irrigated Punjab.

On the surface, overall output growth in the sector of over 3% annually for nearly three decades, and TFP growth of 1.26% per year, suggest a fairly dynamic sector backed by significant technical change. However, growth in land productivity has slowed since the Green Revolution while labor productivity has jumped with acceleration of tractorization so that much of the recent growth in TFP is due to adoption of labor-saving technologies. A closer examination also shows considerable variation in productivity growth by production system. Crop sector TFP growth was relatively high in two production systems (wheat-cotton and wheat mungbean), modest in one system (wheat-mixed), and negative in the wheat-rice system.

TFP is a composite measure of the effects of changes in technology, resource quality, and improvements in human and physical infrastructure. As such a positive trend in TFP as observed in most production systems in this paper, is not a good measure of long-term sustainability. The one system (wheat-rice) with negative TFP growth almost certainly suggests problems of sustainability. The data assembled for this paper suggests considerable evidence of degradation in soil and water quality throughout the province and there is some evidence that part of this depletion is related to the use of inputs considered to be important ingredients of growth in modern agriculture. The estimation of a cost function across districts and over time including several variables for resource quality and variables for technical change suggests that resource degradation had important negative effects on productivity in all systems, and especially in the wheat-rice system. On average, this deterioration in resource quality lowered annual productivity growth by 0.53% in the province. Other unmeasured factors, such as development of insect-pest complexes, were also responsible for a further reduction in resource productivity. Externalities, such as the effects of pesticide use on human health in the wheat-cotton system could not be analyzed in this study but may also be important. Thus TFP growth would have been much higher in the absence of resource degradation.

These results combined with the stagnation of output in recent years, reflected in large-scale imports of wheat, underline growing concerns about degradation in Pakistan's most valuable asset--its irrigated land base. Resource degradation in itself is not a reason for policy intervention if it is internalized into producer decision making. However, in this case, there are several reasons to believe that this is not the case. First, some of the problem arises from distorted policies that lead to divergence in private and social costs. In particular, several of the modern inputs analyzed in this study have been subsidized for much of the period of analysis. Even now electricity for tubewell operation is priced at a fixed annual rate leading to overuse of poor quality tubewell water which is a major contributor to soil salinity (Siddiq, 1994). Second, the information base on which farmers make decisions is inadequate with respect to internalizing rapid changes in soil and water quality variables by moving to more sustainable practices such as integrated nutrient and pest management, more diversified crop rotations, and incorporation of legumes into the system. Third, public sector research has undoubtedly been biased toward development of technologies based on packages of modern inputs, and has neglected research on public goods such as integrated crop management and crops such as legumes that enhance diversification and sustainability of production systems. Indeed, until recently, very little research addressed efficient use of inputs, and the balancing of external input use and internal sources of nutrients. Thus from a policy perspective, there is a case for public and private initiative on several fronts--increased investment in resource management research and extension, research to develop diversified and more sustainable cropping patterns and rotations, removal of price distortions on key inputs, especially water, and special incentives to invest in inputs such as gypsum that can counteract the problem of poor quality tubewell water. Although, this paper contends that such policy interventions may be rewarding if they can reverse the trend in resource degradation, costs of such interventions have to be considered against potential benefits, before making definite policy prescriptions.

Appendix

Estimated coefficient of the translog cost function for the crop sector of irrigated Punjab, 1971-94 dependent variable = log of the index of total cost

Variable	*Coefficient*	*t-value*
Intercept	0.1245	4.55
Output	0.8506	36.22
Output^2	0.4071	11.18
Fertilizer	0.0265	7.00
Water	0.1319	14.70
Labor	0.3998	43.59
Land	0.4018	32.51
Machine	-0.0060	-1.62
Animal	0.0460	15.96
Fertilizer * output	0.0692	12.60
Water * output	0.0127	0.95
Labor * output	-0.0657	-4.82
Land * output	-0.0472	-2.60
Machine * output	0.0353	6.91
Animal * output	-0.0044	-1.20
Fertilizer^2	0.0583	11.65
Water^2	-0.0358	-2.41
Labor^2	0.2570	14.82
Land^2	0.0052	0.22
Machine^2	-0.0712	-6.75
Animal^2	-0.1000	-3.06
Fertilizer * water	-0.0428	-7.50
Fertilizer * labor	-0.0039	-0.65
Fertilizer * land	0.0269	5.00
Fertilizer * machine	-0.0350	-7.12
Fertilizer * animal	-0.0258	-10.72
Water * labor	-0.0491	-4.05
Water * land	0.0825	5.57
Water * machine	0.0511	7.40
Water * animal	0.0258	1.63
Labor * land	-0.1419	-9.18
Labor * machine	-0.0319	-4.27
Labor * animal	0.0759	3.41
Land * machine	0.0397	6.85
Land * animal	0.1226	9.01

Appendix

Estimated coefficient of the translog cost function for the crop sector of irrigated Punjab, 1971-94
dependent variable = log of the index of total cost

Variable	*Coefficient*	*t-value*
Machine * animal	-0.0753	-2.56
Output * trend	-0.0137	-7.77
Fertilizer * trend	0.0001	0.17
Water * trend	0.0019	2.99
Labor * trend	-0.0064	-8.73
Land * trend	0.0010	1.14
Machine * trend	0.0045	13.05
Animal * trend	0.0060	3.30
Soil organic matter	-0.0673	-4.52
Soil phosphorus	-0.0338	-2.89
Salts in soil	0.0236	3.79
Electroconductivity	0.0151	0.50
Education	-0.0095	-0.28
Road	-0.0661	-3.15
Cropping intensity	-0.5719	-12.15
Modern variety	-0.0366	-1.88
Cropping intensity * soil organic mater	-0.4685	-7.44
Cropping intensity * soil phosphorus	-0.2528	-3.96
Cropping intensity * salts in soil	-0.0469	-1.67
Cropping intensity *electroconductivity	-0.0994	-0.85
Modern variety * soil organic matter	0.0352	2.43
Modern variety * soil phosphorus	0.0149	1.33
Modern variety * salts in soil	-0.0058	-0.80
Modern variety * electroconductivity	-0.0236	-1.21
Fertilizer * soil organic matter	0.0075	1.81
Fertilizer * soil phosphorus	-0.0024	-0.66
Fertilizer * salts in soil	0.0041	2.78
Fertilizer * electroconductivity	0.0030	0.52
Labor * soil organic matter	-0.0269	-2.44
Labor * soil phosphorus	0.0442	4.73
Labor * salts in soil	-0.0188	-4.93
Labor * electroconductivity	0.0390	2.57
Land * soil organic matter	0.0269	2.18
Land * soil phosphorus	-0.0376	-3.59
Land * salts in soil	0.0090	2.12

Appendix

Estimated coefficient of the translog cost function for the crop sector of irrigated Punjab, 1971-94 dependent variable = log of the index of total cost

Variable	*Coefficient*	*t-value*
Land * electroconductivity	-0.0555	-3.27
Machine * soil organic matter	-0.0118	-3.01
Machine * soil phosphorus	0.0027	0.81
Machine * salts in soil	0.0067	4.94
Machine * electroconductivity	0.0128	2.41
Animal * soil organic matter	-0.0069	-2.90
Animal * phosphorous	0.0042	1.50
Animal * salts in soil	-0.0009	-0.97
Animal * electroconductivity	0.0006	0.15
Output * soil organic matter	0.1763	6.89
Output * soil phosphorus	-0.0084	-0.37
Output * salts in soil	0.0214	2.23
Output * electroconductivity	-0.0195	-0.50
Trend in the wheat-mixed system	0.0010	0.31
Trend in the wheat-cotton system	-0.0053	-1.43
Trend in the wheat-rice system	0.0068	2.12
Trend in the wheat-mungbean system	0.0029	2.41
Trend in overall Punjab [a]	0.0014	1.75
Weighted average R^2	0.988	
Number of observations	368	

Note: The coefficients on district dummies are not reported here. Due to various restrictions, the coefficients of the factor and revenue share equations are equal to the respective coefficients in the cost function. Thus the coefficients in the former equations are not reported here.

[a] The trend and t-values for the overall Punjab were estimated as the weighted average of the regional trend. The weights are relative average cost shares of each region in the total production cost of the whole Punjab during the whole study period.

Source: Authors' own calculation

References

Ali, M. 1996. "Quantifying the Socioeconomic Determinants of Sustainable Crop Production: An Application to Wheat Cultivation in the Tarai of Nepal", *Ag. Econ*, 14: 45-60.

Ali, M. and J.C. Flinn, 1989. "Profit efficiency among Basmati rice producers in Pakistan Punjab, *Am. J. Ag. Econ.* 71(2): 303-310.

Ali, M. and L. E. Velasco, 1993. "Intensification-Induced Resource Degradation: The Crop Production Sector in Pakistan." Manila; International Rice Research Institute.

Ali, M., I.A. Malik, H.M. Sabir, and B. Ahmad. 1997. *The Mungbean Green Revolution in Pakistan*, Technical Bulletin No. 24, Asian Vegetable Research and Development Center, Tainan, Taiwan.

Alston, J., G. Norton and P. G. Pardey. 1995. *Science Under Scarcity; Priorities and Practices for Agricultural Research Evaluation and Priority Setting,* Ithaca: Cornell University Press, 1995.

Alston, J.M., J. R. Anderson, and P. G. Pardey, 1995. "Perceived Productivity Foregone, Future Farm Fruitfullness, and Rural Research Rationalization," in G.H. Peters and D. Hedley (eds), *Agricultural Competitiveness: Market Forces and Policy Choice. Proceedings of the Twenty-Second International Conference of Agricultural Economists. Harare, Zimbabwe, 22-29 August, 1994.* Aldershot, U.K.: Dartmouth.

Antle, J. M. and P. L. Pingali. 1995. "Pesticide, productivity, and farmer health: A Philippine case study," *Am. J. Ag. Econ.* 76(3):418-430.

Antle, J. M. and T. McGuckin. 1993. Technological Innovation, Agricultural Productivity,and Environmental Quality, "In G.A. Carlson, D. Zilberman and J.A. Miranowski (eds), *Agricultural and Environmental Resource Economics*, New York, Oxford University Press.

Archibald, S.O. 1988. Incorporating Externalities into Agriculture Productivities Analysis." In S.M. Capalbo and J.M. Antle (eds). *Agricultural Productivity:Measurement and Explanation,* Washington, DC: Resource for the Future.

Ball, V.E., C.A.K. Lovell, R.F. Nehring, and A. Somwaru. 1994. "Incorporating Undesirable Outputs into Models of Production: An Application to US Agriculture." *Cahiers d'Economique et Sociologie Rurales* 31:59-73.

Barnett, V., R. Payne and R. Steiner (eds), 1995. *Agricultural Sustainability in Economic, Environmental, and Statistical Terms*. London: John Wiley and Sons, Ltd.

Berndt E.R. and M.A. Fuss. 1986. "Productivity Measurements with Adjustments for Variation in Capacity Equilibrium and Other Farms of Temporary Equilibrium," *J. Econometrics,* 33:7-29.

Byerlee, D. and T. Husain (eds.), 1992. *Farming Systems of Pakistan,* Lahore, Pakistan: Vanguard Books.

Byerlee, D. 1992. "Technical Change, Productivity, and Sustainability in Irrigated Cropping Systems of South Asia: Emerging Issues in the Post-Green Revolution Era." *J. Int. Dev.* 4(5): 477-496.

Byerlee, D., and A. Siddiq. 1994. "Has the Green Revolution been Sustained? The Quantitative Impact of the Seed-Fertilizer Revolution in Pakistan Revisited". *World Dev.* 22(9):1345-1361.

Byerlee, D., M.R. Akhtar, and P.R. Hobbs. 1987. "Reconciling Conflicts in Sequential Cropping Pattern Through plant Breeding: The Example of Cotton-Wheat in Pakistan's Punjab." *Ag. Sys.* 24:291-304.

Chalfant, J.A. 1984. "Comparison of Alternative Functional Forms with Application to Agricultural Input Data," *Am. J. Ag. Econ.* 66(2):216-20.

Cassman, K.G., and P.L. Pingali. 1995. "Extrapolating Trends from Long-Term Experiments to Farmers' Fields: The Case of Irrigated Rice Systems in Asia." In V. Barnett., R. Payne and R. Steiner (eds), *Agricultural Sustainability in Economic, Environmental, and Statistical Terms.* London: John Wiley and Sons, Ltd.

Diewert, W. E. "Exact and Superlative Index Number." *J. Econometrics.* 4(1976):115-45.

Ehui, S. K., and D. S. C. Spencer. 1993. "Measuring the Sustainability and Economic Viability of Tropical Farming Systems: A Model From Sub-Saharan Africa." *Ag. Econ.* 9:279-296.

Faeth, P. 1993. *Agricultural Policy and Sustainability: Case Studies for India, Chile, the Philippines and the United States*, Washington, DC: World Resource Institute.

Faruqee, R., 1995. *Government's role in Pakistan Agriculture: Major Reforms are Needed,* Policy Research Working Paper No 1468, Washington: World Bank.

Flinn, J.C. and S.K. De Datta. 1994. "Trends in Irrigated Rice Yields Under Intensive Cropping at Philippine Research Stations." *Field Crop Research.* 9:1-15.

Gollop, F. M., and G.P. Swinand, 1998. "From Total Factor Productivity to Total Resource Productivity: An Application to Agriculture". *Am. J. Agr. Econ.* 80:577-583.

Herdt, R. W., and J.K. Lynam, 1992. "Sustainable Development and the Changing Needs of International Agricultural Research", in Lee, D. R., S. Kearl, N. Uphoff (eds), *Assessing the*

Importance of International Agricultural Research for Sustainable Development, Ithaca: Cornell University, 1992.

Hobbs, P., and M.L. Morris. 1996. *Meeting South Asia's Future Food Requirements from Rice-Wheat Cropping Systems: Priority Issues Facing Researchers in the Post-Green Revolution Era.* Natural Resources Group Paper 96-01. Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT).

Hulten, C. R. "Divisia Index Number." *Econometrica.* 41(6)(1973):1017-1025.

Huang, J. and S. Rozelle, 1995. "Environmental Stress and Grain Yields in China", *Am. J. Ag. Econ.,* 77: 853-864.

Hussain, S.S., and D. Byerlee. 1995. "Education and Farm Productivity in post-Green Revolution Asia," in G.H. Peters and D. Hedley (eds), *Agricultural Competitiveness: Market Forces and Policy Choice. Proceedings of the Twenty-Second International Conference of Agricultural Economists. Harare, Zimbabwe, 22-29 August, 1994.* Aldershot, U.K.: Dartmouth.

Hulten, C.R., 1986. "Productivity Change, Capacity Utilization, and the Source of Efficiency Growth," *J. Econometrics*, 33:31-50.

Jarque, C. M. and A. K. Bera. 1980. "Efficient Tests for Normality, Homoscedasticity and Cereal Independence of Regression Residuals" *Economic Letters*, Vol. 6, Chapter A:255-259.

Khan, M.H. 1994. The Structural Adjustment Process and Agricultural Change in Pakistan in the 1980s and 1990s, Draft paper, Simon Fraser University, Vancouver.

Lindert, P.H., 1996. "Soil Degradation and Agricultural Change in Two Developing Countries", In *Global Agricultural Science Policy to the 21st Century,* Proceedings of an International Conference, Aug. 22-26, Melbourne.

Lynam, J. K., and R. W. Herdt. 1989. "Sense and Sustainability: Sustainability as an Objective in International Agricultural Research." *Agr. Econ.* 3:381-398.

Mc Fadden, D. 1978. "Cost, Revenue, and Profit Functions", In M.A. Fuss and D. Mc Fadden (ed.) *Production Economics: A Dual Approach to Theory and Applications,* North Holland pp, Vol. 1:3-110).

Murgai, R., 1999. Diversity in Economic Growth and Technical Change: A District-wise Disaggregation of the Punjab and Haryana Growth Experience, Policy Economics Working Paper,, World Bank (forthcoming).

Oskam A. 1991 "Productivity Measurement, Incorporating Environmental Effects of Agricultural Production." In K. Burger *et al.,* (eds). *Agricultural Economics and Policy:*

International Challenges for the Nineties, Amsterdam: Elsevier.

Pagiola, S., 1995. "Environmental and Natural Resource Degradation in Intensive Agriculture in Bangladesh", Environment Department Paper No. 15, Washington: World Bank.

Pingali, P.L, and P.W. Heisey. 1996?. "Cereal Crop Productivity in Developing Countries: Past Trends and Future Prospects", In *Global Agricultural Science Policy to the 21st Century,* Proceedings of an International Conference, Aug. 22-26, Melbourne.

Pingali, P.L., M. Hossain, and R.V. Gerpacio, 1997. *Asian Rice Bowls: The Returning Crisis?* Wallingford: CABI in association with IRRI, Los Banos.

Pittman, R.W. 1981. "Issues in Pollution Control:Interplant Cost Differences and Economies of Scale," *Land Econ.* 57:1-17.

Ray, S.C. 1982. "A Translog Cost Function Analysis of U.S. Agriculture." 1939-77, *Am. J. Agr. Econ.* 64(2):490-498.

Rosegrant, M. W. and R. E. Evenson, 1992, "Agricultural Productivity and Sources of Growth in South Asia," *Am. J. Agr. Econ.,* 74(3): 757-761.

Sharif M., J. Longmire, M. Shafique, and Z. Ahmad, 1992. Adoption of Basmati 385: Implications for Time Conflicts in Rice-Wheat System of Pakistan's Punjab. In *Farming Systems of Pakistan,* D. Byerlee and T. Hussain (eds), Lahore: Vanguard Publishers.

Siddiq, A. 1994. "Sustainability of the Indus Basin: Impact of Tertiary Salinity/Sodicity on Wheat Productivity, Damage Assessment and Future Public Policy." Ph.D. Dissertation, Dept. of Agricultural Economics, University of Illinois, Urbana-Champaign.

Smith, V.K., 1998. "Should Pollution Reductions Count as Productivity Gains for Agriculture", *Am. J. Agr. Econ.* 80:591-594.

Squires, D. E. 1992. "Productivity Measurement in Common Property Resource Industries: An Application to the Specific Coast Trawl Fisheries," , *RAND J. Econ.*, 23(2): 221-236.

Thompson, G.D. 1988. "Choice of Flexible Functional Forms: Review and Appraisal," *West. J. Ag. Econ.* 13(2):169-83.

Weaver, R. D., 1998. "Measuring Productivity of Environmentally Interactive Technologies: The Case of Agriculture and the Environment", *Am. J. Agr. Econ.* 80: 595-599.

Policy Research Working Paper Series

	Title	Author	Date	Contact for paper
WPS2455	The Effects on Growth of Commodity Price Uncertainty and Shocks	Jan Dehn	September 2000	P. Varangis 33852
WPS2456	Geography and Development	J. Vernon Henderson Zmarak Shalizi Anthony J. Venables	September 2000	R. Yazigi 37176
WPS2457	Urban and Regional Dynamics in Poland	Uwe Deichmann Vernon Henderson	September 2000	R. Yazigi 37176
WPS2458	Choosing Rural Road Investments to Help Reduce Poverty	Dominique van de Walle	October 2000	H. Sladovich 37698
WPS2459	Short-Lived Shocks with Long-Lived Impacts? Household Income Dynamics in a Transition Economy	Michael Lokshin Martin Ravallion	October 2000	P. Sader 33902
WPS2460	Labor Redundancy, Retraining, and Outplacement during Privatization: The Experience of Brazil's Federal Railway	Antonio Estache Jose Antonio Schmitt de Azevedo Evelyn Sydenstricker	October 2000	G. Chenet-Smith 36370
WPS2461	Vertical Price Control and Parallel Imports: Theory and Evidence	Keith E. Maskus Yongmin Chen	October 2000	L. Tabada 36896
WPS2462	Foreign Entry in Turkey's Banking Sector, 1980–97	Cevdet Denizer	October 2000	I. Partola 35759
WPS2463	Personal Pension Plans and Stock Market Volatility	Max Alier Dimitri Vittas	October 2000	A. Yaptenco 31823
WPS2464	The Decumulation (Payout) Phase of Defined Contribution Pillars: Policy Issues in the Provision of Annuities and Other Benefits	Estelle James Dimitri Vittas	October 2000	A. Yaptenco 31823
WPS2465	Reforming Tax Expenditure Programs in Poland	Carlos B. Cavalcanti Zhicheng Li	October 2000	A. Correa 38949
WPS2466	El Niño or El Peso? Crisis, Poverty, And Income Distribution in the Philippines	Gaurav Datt Hans Hoogeveen	October 2000	T. Mailei 87347
WPS2467	Does Financial Liberalization Relax Financing Constraints on Firms?	Luc Laeven	October 2000	R. Vo 33722

Policy Research Working Paper Series

	Title	Author	Date	Contact for paper
WPS2468	Pricing, Subsidies, and the Poor: Demand for Improved Water Services in Central America	Ian Walker Fidel Ordoñez Pedro Serrano Jonathan Halpern	November 2000	S. Delgado 37840
WPS2469	Risk Shifting and Long-Term Contracts: Evidence from the Ras Gas Project	Mansoor Dailami Robert Hauswald	November 2000	W. Nedrow 31585
WPS2470	Are Larger Countries Really More Corrupt?	Stephen Knack Omar Azfar	November 2000	P. Sintim-Aboagye 38526
WPS2471	Validating Operational Food Insecurity Indicators against a Dynamic Benchmark: Evidence from Mali	Luc J. Christiaensen Richard N. Boisvert John Hoddinott	November 2000	L. Christiaensen 81463
WPS2472	Uzbekistan and Kazakkhstan: A Tale of Two Transition Paths	Asad Alam Arup Banerji	November 2000	L. Henson 84026
WPS2473	Banking Risks around the World: The Implicit Safety Net Subsidy Approach	Luc Laeven	November 2000	R. Vo 33722
WPS2474	Exports and Information Spillovers	Alessandro Nicita Marcelo Olarreaga	November 2000	L. Tabada 36896
WPS2475	Industrial Growth and the Quality of Institutions: What Do (Transition) Economies Have to Gain from the Rule of Law?	David A. Grigorian Albert Martinez	November 2000	A. Nelson 37117
WPS2476	Measuring Banking Efficiency in the Pre- and Post-Liberalization Environment: Evidence from the Turkish Banking System	Cevdet Denizer Mustafa Dinç Murat Tarimcilar	November 2000	M. Dinç 36233
WPS2477	Picking the Poor: Indicators for Geographic Targeting in Peru	Norbert R. Schady	November 2000	T. Gomez 32127
WPS2478	Institutions, Politics, and Contracts: The Attempt to Privatize the Water and Sanitation Utility of Lima, Peru	Lorena Alcázar Lixin Colin Xu Ana Maria Zuluaga	November 2000	P. Sintim-Aboagye 37644
WPS2479	Estimating the Effects of Corruption: Implications for Bangladesh	Aminur Rahman Gregory Kisunko Kapil Kapoor	November 2000	S. Powell 33526