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# The Demand for Inputs and the Supply of Output in Pakistan:

# Estimating a Fixed-Effects, Distributed-Lag Model for Wheat Farmers

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**Abstract**

The objective of this paper is to analyze the factors influencing the demand for farm inputs and the supply of farm outputs, using panel farm-level data on wheat farmers from Pakistan. A fixed-effects, distributed-lag model, in which farmers are presumed to adjust their inputs and outputs gradually over time in response to price and other changes, was estimated and found to offer plausible estimates of own- and cross-price elasticities, as well as speed-of-adjustment parameters. The estimates indicate the demand for labor and fertilizer is highly sensitive to changes in the wage rate for labor. Higher wage rates consistently lower labor use (regardless of type of labor -- hired versus family, or family male versus family female), fertilizer use, and farm output. Another important determinant of fertilizer demand is the price of wheat. The estimated elasticity of fertilizer use with respect to the wheat price is statistically significant and very large. Increased wheat prices are observed to lower demand for family labor, reflecting a potentially large and important income effect, especially as regards female labor. Speed-of-adjustment parameter estimates suggest that farming practices (weeding, ploughing, irrigation, and fertilizer application) adjust very quickly to changing economic conditions. Labor use, on the other hand, adjusts more slowly, particularly as regards family male labor. Policy implications and future research are discussed.

## Introduction

Agricultural growth in Pakistan over the past 3 decades has been very impressive, averaging 3.3 percent annually over the period 1965-80, and accelerating to 4.3 percent per year over the period 1980-90. But as impressive as these numbers are, questions arise regarding the success of the agricultural sector in terms of meeting food and employment needs, the potential for continuing or increasing growth rates in the future, the likely sources of future agricultural growth, and the technologies, policies, and institutional arrangements necessary to achieve that growth.

The truth is that agriculture in general, and food production in particular, have been working hard to just to keep pace with other sectors and with the food needs of the domestic population. Agriculture was the slowest growing sector in Pakistan over the past 30 years, with general economic expansion moving along at an average of 5.2 percent annually over the 1965-80 period, and of 6.3 percent per year over the decade of the 1980s. In addition, in spite of very substantial production and productivity gains for most major crops, the average index of food production per capita remained constant over the 1980-90 period, while the total volume of cereal imports nearly doubled to over 2,048 metric tons (World Development Report 1992).

And the future could be worse. Growth rates in agricultural productivity may not continue at historical levels, and the population growth rate is likely to continue at (or around) 3.0 percent annually for some time, thereby almost guaranteeing a population of over 150 million by the end of the century, and perhaps 250 million by the year 2025. Frighteningly, some estimates of the hypothetical size of a stationary Pakistani population are as high as 400 million people by the middle of the next century (World Development Report 1992).

That is a lot of mouths to feed and able-bodied individuals to employ, and agriculture will clearly have to do its share in meeting both needs, though rural-to-urban migration and intersectoral shifts in employment and growth emphases towards non-agricultural sectors suggest that a disproportionately large share of the burden will be borne by these sectors. But agriculture must grow, and the challenges for the 1990s (and indeed the next 25 years) is to identify potential sources of growth, and select and implement policies that promote it.

Historically, promoters of agricultural growth have focused their attention on bringing more area under plow, principally via the extension of large-scale irrigation projects, and on generating and disseminating higher-yielding varieties of basic cereal crops. As we look to the future, it is not clear whether these will continue to be the principal sources of growth over the next quarter-century. Indeed, the absolute amount of net cropped area (currently about 27% of total surface area in Pakistan, after an increase of 0.4% per year over the 1965-89

period) may even fall in the future due to urban encroachment and environmental degradation (principally soil salinity and waterlogging). Irrigated area (which stands at an astonishing 63% of total agricultural area) will be difficult and very expensive to increase broadly. In addition, yields among Pakistan's most productive farmers may not increase very much at all (Ministry of Food, Agriculture, and Cooperatives 1992; World Development Report 1992). Therefore, we must look for different sources of productivity increases to fuel agricultural growth, and help meet poverty and environmental management goals as well. Potential sources of future growth are: increases in gross cropped area via reduction in fallow periods, with proper care taken not to degrade the natural resource base; increases in labor productivity; increases in the application of traditional and chemical fertilizers, in both rainfed and irrigated areas; improvements in the quality of existing large-scale irrigation systems; increases in area serviced by small-scale irrigation projects, with particular focus on tubewell irrigation; and, generally improving farm management practices (Nag-Chowdhury and Vosti 1992). The sources of future agricultural growth will certainly differ across regions, as will the policies needed to promote growth. It is noteworthy that much of Pakistan's future agricultural growth may have to come from its currently poorest and least productive farmers (Raza and Vosti 1992).

Perhaps our best indicator of likely sources of future agricultural growth is the set of factors that influenced very recent agricultural change. The more we know about how farmers make resource (including human resource) allocation

decisions, the more likely we are to identify the technological and policy "hooks" on which to hang our hopes for the future of Pakistani agriculture (Reardon and Vosti 1992).

This paper uses a 1986-89 panel of farm-level data from several regions in Pakistan to examine the factors influencing the supply of wheat, and the demand for the various purchased and farm-produced inputs that go into wheat production. An analytical framework capable of capturing farm-level fixed effects and allowing for inter-farm differences in responses to changes in the agroeconomic environment is introduced. A fixed-effects, distributed-lag model derived from this framework is estimated, and the results interpreted. Conclusions and policy implications derived from the empirical results are presented, and avenues for future research are suggested.

## Analytical Framework

### A Static Model of Input Demand and Output Supply

The starting point for analyzing farm input and output decisions is the set of crop production functions

$$(1) \qquad Y_{ij} = \alpha_i + f_j (X_{ij}, A_{ij}),$$

where i indexes a farm, j indexes a crop, Y is the output harvested, **X** is the vector of variable inputs (such as tractor and bullock services, fertilizer, labor, etc.), and A is cropped area. The individual crop production functions represent the agricultural technology in use, and indicate the maximum physical output that can be obtained from the applied inputs. Of special interest here is the unobserved, farm-specific intercept, $\alpha_i$, that may represent the managerial ability of the farmer or the unobserved attributes of the farm, such as soil quality.

The restricted farm profit function can then be derived under the assumption that farmers maximize total farm profits, for a given season,

$$(2) \qquad \Pi = \Sigma_j p_j Y_j - \Sigma_j \mathbf{q} \mathbf{X}_j,$$

where $p_j$ is the price of crop j and **q** is the vector of input prices, subject to their total land constraint, viz.,

$$(3) \qquad \Sigma_j A_j = A,$$

where A is the total amount of land (size of operational holding) available.

While the crop production functions assume technical efficiency on the part of farmers, the restricted farm profit function assumes price (or allocative)

efficiency.[1] It is possible to derive the profit function from the individual crop production functions, and *vice versa*.[2] The profit function is:

$$(4) \qquad \Pi_i = \Pi(p_1, p_2, ..., p_n, q, A_i, \alpha_i).$$

The demand functions for variable inputs **X** are given by the relation:

$$(5) \qquad X(p_1, p_2, ..., p_n, q, A_i, \alpha_i) = - \partial\Pi(\cdot)/\partial q,$$

while the output supply function (not to be confused with the production function) for crop j is given by:

$$(6) \qquad Y_j(p_1, p_2, ..., p_n, q, A_i, \alpha_i) = \partial\Pi(\cdot)/\partial p_j.$$[3]

Equations (5) and (6) represent the reduced-form system of input demand and output supply equations. There are several points worth noting about this demand system. *First*, since the farmer is assumed to maximize total profits and since there may opportunities for substituting across various inputs and across

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[1]Although this assumption can be tested, given availability of appropriate data.

[2]While this is possible in principle, the derivation may not always be tractable, depending upon the functional form assumed for the production or profit functions.

[3]These relations are proven in McFadden (1970) and Lau (1969).

crops, all input and output prices enter the demand relation for each input and the supply relation for each crop. Thus, not only will the rental price of bullocks influence the demand for bullock services and that for tractor services (which may be close substitutes), but they may also affect the demand for fertilizer. Likewise, the prices of all possible crops that can be cultivated will influence the demand for each factor and the supply of every crop. This realistic approach to demand interrelationships is consistent with theory and common sense, but differs greatly from standard single-equation, single product estimation production (see, for example, Fertilizer Forecast 1991, p. 3.).

*Second*, within the above model, total cropped area as well as the area under individual crops are choice variables for the farmer; therefore, these do not enter the system of input demand and output supply equations. Instead, what enters the system is the variable A -- the size of operational holding -- which is treated as a fixed factor of production in the short term. Of course, to the extent that farmers can lease in and lease out land for cultivation, even the size of operational holding is not a fixed factor in the medium or long term. However, since tenancy contracts are typically long-term arrangements that are difficult to adjust in the short run, the assumption that the size of the operational holding is not a variable factor in the short run is not unrealistic.

*Third*, the unobserved, farm- (or farmer-) specific effect, $\alpha_i$, enters the system of input demand and output supply equations. Indeed, this is an important

reason why ordinary least squares estimates of the crop production functions in (1) are likely to be biased. In OLS estimates of a production function, any fixed effects, such as $\alpha$, are included in the disturbance term. Since the demand for all inputs will necessarily depend on these unobserved endowments (e.g., managerial ability, soil quality, locational advantage, etc.), the disturbance term in the production function is correlated with the included independent variables. As a result, OLS estimates of the production function will be biased.

*Fourth*, the effects of prices and fixed factors obtained in the input demand and output supply system are *mutatis mutandis* (as opposed to *ceteris paribus*) effects. This means that the estimated effect of wages on, say, the demand for tractor services reflects the (total) effect on tractor use of a change in wage rates after allowing all other inputs and outputs to also adjust to the wage rate change. Thus, even though labor and tractor services may be complementary inputs, an increase in wage rates could reduce output and thereby the demand for tractor services. If this (negative) output effect is larger than the (positive) substitution effect, the demand for tractor services could fall with an increase in wages.

The estimated parameters of the reduced-form demand model can be used to analyze the impact of policy changes on a number of behavioral variables. For instance, the estimated model can be used to simulate the effects of, say, a higher procurement price for wheat (holding other prices and policy variables constant) on the demands for labor (hired and family, male and female), bullock and tractor

services, fertilizer, and other inputs. The model also allows us to trace the simultaneous impact of several different policy changes -- say, a reduction in fertilizer and tractor subsidies -- on input use.

It is possible to control for the unobserved fixed effects, $\alpha_i$, in estimating the reduced-form input demand and output supply equations with panel data. Assuming a linear functional form for the demand/supply equations,[4] equations (5) and (6) can be written as:

$$X_{it} = \alpha_i + a\, p_{it} + c\, q_{it} + d\, A_{it}, \quad \text{and} \tag{7}$$

$$Y_{it} = \alpha'_i + a' p_{it} + c'\, q_{it} + d'\, A_{it}. \tag{8}$$

First-differencing the two equations yields:

$$\Delta X_i = a\, \Delta p_i + c\, \Delta q_i + d\, \Delta A_i, \quad \text{and} \tag{9}$$

$$\Delta Y_i = a' \Delta p_i + c' \Delta q_i + d' \Delta A_i, \tag{10}$$

where $\Delta Z$ is the first-difference operator (viz., $\Delta Z = Z_{it} - Z_{i,t-1}$). Estimation of the first-differenced equations (9) and (10) by ordinary least squares methods provides unbiased and consistent estimates of parameters in equations (7) and (8).

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[4]The assumption of the fixed effect, $\alpha_i$, entering linearly in the input demand and output supply equations is critical to the estimation.

A Dynamic Model of Demand Adjustment

So far we have assumed a static framework in which farmers can respond to price and other policy changes instantaneously. In fact, adjustment may be slow and spread out over several years. If this is the case, the current demand for inputs should be a function not merely of current prices but of past prices as well. Rewriting the input demand and output supply equations in (7) and (8), we would have:

$$(11) \qquad X_{it} = \alpha_i + \beta_0 Z_{it} + \beta_1 Z_{i,t-1} + \ldots + \beta_k Z_{i,t-k},$$

$$(12) \qquad Y_{it} = \alpha'_i + \beta'_0 Z_{it} + \beta'_1 Z_{i,t-1} + \ldots + \beta'_k Z_{i,t-k},$$

where the vector **Z** includes all the independent variables, $p_1, p_2, \ldots, p_n$, **q**, and A. Estimation of (11) and (12) would require an infinite time series of data; however, if one makes the assumption that the $\beta_j$'s decline geometrically, i.e., $\beta_1 = \lambda \beta_0$, $\beta_2 = \lambda^2 \beta_0$, $\beta_3 = \lambda^3 \beta_0, \ldots, \beta_k = \lambda^k \beta_0$, and $0 < \lambda < 1$, equations (11) and (12) reduce to:

$$(11a) \qquad X_{it} = \alpha_i + \beta_0 Z_{it} + \beta_0 \lambda Z_{i,t-1} + \ldots + \beta_0 \lambda Z_{i,t-k},$$

$$(12a) \qquad Y_{it} = \alpha'_i + \beta'_0 Z_{it} + \beta'_0 \lambda' Z_{i,t-1} + \ldots + \beta'_0 \lambda' Z_{i,t-k}.$$

For the time period t-1, we have:

(11b) $$\lambda X_{it-1} = \alpha_i + \beta_0 \lambda Z_{i,t-1} + \ldots + \beta_0 \lambda Z_{i,t-k-1},$$

(12b) $$\lambda Y_{it-1} = \alpha'_i + \beta'_0 \lambda' Z_{i,t-1} + \ldots + \beta'_0 \lambda' Z_{i,t-k-1}.$$

Subtracting (11b) from (11a) and (12b) from (12a), we get

(13) $$X_{it} - \lambda X_{it-1} = \beta_0 Z_{it}$$

(14) $$Y_{it} - \lambda Y_{it-1} = \beta'_0 Z_{it},$$

or

(15) $$X_{it} = \lambda X_{it-1} + \beta_0 Z_{it}$$

(16) $$Y_{it} = \lambda Y_{it-1} + \beta'_0 Z_{it}.$$

This is a standard distributed-lag model, with the lagged value of the dependent variable occurring on the right-hand side of the equation. Note that the distributed-lag model not only permits the assumption of farmers gradually (as opposed to instantaneously) adjusting to price and other exogenous changes, but it also controls for unobserved fixed effects, $\alpha_i$. In this sense, it is superior to the static fixed-effects model (contained in equations (9) and (10)) (Behrman, et al. 1992; Koyck 1954).

Functional Form

The only major question that remains is of functional form. If the underlying profit function is of the generalized quadratic form, viz.,

$$(17) \qquad \Pi = \alpha + b_0 p + \tfrac{1}{2} b_1 p^2 + b_2 q + \tfrac{1}{2} b_3 q^2 + \tfrac{1}{2} b_4 p q + b_5 A + \tfrac{1}{2} b_6 A^2 + \tfrac{1}{2} b_7 p A + \tfrac{1}{2} b_8 q A + \tfrac{1}{2} b_9 p \alpha + \tfrac{1}{2} b_{10} q \alpha + \tfrac{1}{2} b_{11} A \alpha,$$

where the subscripts i and t have been dropped, the input demand and output supply equations can be obtained as the first derivatives of the profit function with respect to **q** and **p**, respectively (see equations (5) and (6)). This yields:

$$(18) \qquad -X = b_2 + b_3 q + \tfrac{1}{2} b_4 p + \tfrac{1}{2} b_8 A + \tfrac{1}{2} b_{10} \alpha$$

$$(19) \qquad Y = b_0 + \tfrac{1}{2} b_4 q + b_1 p + \tfrac{1}{2} b_7 A + \tfrac{1}{2} b_9 \alpha.$$

Thus, the appealing feature of the generalized quadratic profit function is that the resulting input demand and output supply equations are linear in parameters.

To control for fixed effects, $\alpha$, the equations in (18) and (19) can be estimated in first-differenced form. As discussed earlier, a dynamic adjustment

model would lead essentially to the same estimating equations, but with the lagged value of the dependent variable as an additional right-hand side variable.

## Empirical Model

The model developed above treats cropping pattern as a choice variable, and enables us to analyze the demand for inputs used in all crops and the output supply of all crops. However, for the purposes of this exercise, we have confined the analysis to a single crop, viz., wheat, one of the principal agricultural outputs in Pakistan (Hapke and Vosti 1992). We have used the IFPRI Pakistan panel data for three rounds: Rabi 1986-87, Rabi 1987-88, and Rabi 1988-89. This provides us with 720 observations over three rounds.

In all, information on one output (viz., harvested quantity of wheat in maunds) and thirteen inputs is available for the three rounds. The inputs are hired labor use (in days per season), family male labor, family female labor, tractor use (hours), bullock use (days), farm manure use (number of carts), fertilizer use (total as well as DAP, urea, and nitrogen) (number of 50 kilogram bags), number of weedings, number of irrigations after planting, and number of ploughings. Descriptive statistics and variable labels appear in Table 1.

The resulting input demand and output supply system has one output price (viz., wheat) and three input prices (rental price of bullocks, rental price of tractor

services, and wage rate for labor) as explanatory variables (all expressed in terms of 1986 Rupees). In addition, fixed factors of production in the system are acres of rainfed land, canal-irrigated and well-irrigated land in the operational holding. Dichotomous variables for the different Rabi seasons are also included as shift variables.

Household-level input and output prices were not used because differences in "unit values" (amount paid or received per unit of an input or output quantity) reported by households may reflect quality variations rather than genuine price variation. Instead, prices reported by farm households were averaged over the four districts and three rounds. As a result, the price variation in the sample is somewhat limited. In addition, data on fertilizer prices were not available at the time this model was estimated and therefore were not included in this demand system. This obvious shortcoming will hopefully be remedied in subsequent versions of this paper.

Table 1: Descriptive Statistics and Variable Labels

| Descriptive Statistics - Wheat Production | | | |
|---|---|---|---|
| Variable Description | Units of Measure | Mean | Standard Deviation |
| Bullock hire rate | 1986 Rupees per day | 147.9 | 268.1 |
| Bullock days | Days | 11.9 | 1.3 |
| Canal-Irrigated land | Acres | 8.3 | 0.2 |
| DAP | 50 kg sacks | 2.1 | 5 |
| Female family labor | Days | 3.2 | 87.2 |
| Hired labor | Days | 19.6 | 84.9 |
| Male family labor | Days | 63.4 | 11.3 |
| Manure | Carts | 3.7 | 8 |
| Nitrogen | 50 kg sacks | 1.0 | 3 |
| Number of irrigation | Number | 2.4 | 2.8 |
| Number of ploughings | Number | 4.0 | 2.6 |
| Number of weedings | Number | 0.2 | 0.7 |
| Rainfed land | Acres | 2.3 | 6.4 |
| Rural wage | 1986 Rupees per day | 38.7 | 12.0 |
| Total family labor | Days | 66.7 | 13.1 |
| Total fertilizer | Sacks | 7.0 | 7.2 |
| Tractor hire rate | 1986 Rupees per hour | 65.3 | 5.7 |
| Tractor hours | Hours | 6.8 | 20.1 |
| UREA | 50 kg sacks | 3.4 | 4.7 |
| Well-Irrigated land | Acres | 0.0 | 50.4 |
| Wheat harvested | maunds | 64.0 | 86.2 |
| Wheat price | 1986 Rupees per maund | 90.4 | 13.1 |

## Empirical Results

Parameters estimates from the fixed-effects, distributed-lag model of the input demand and output supply system are reported in Table 2. T-ratios appear beneath each of the parameter estimates, and summary statistics for each equation appear in the final two columns of Table 2. Since the system is linear in parameters, the coefficients represent the change in input use or output quantity due to a unit change in price or land holding. The corresponding elasticities, evaluated at the sample means of variables, are calculated and reported in Table 3.

Several points can be made about these estimates. *First*, a large number of estimated effects in the demand system are significant. For example, the majority of the 56 price effects estimated (tractor hire rate, bullock hire rate, wheat price, and wage rate) were statistically significantly different from zero at the 10 percent level. Canal-irrigated land is significant in 10 of the 14 equations estimated, while rainfed land is significant in 9 equations. The parameters are thus estimated with a high level of precision. The explanatory power of the regressions is also generally high; for example, the included prices, fixed factors, and lagged dependent variable account for 77 percent of the variation in wheat output. The $R^2$'s of the other equations are also relatively high.

*Second*, the estimated effects of the rental price of tractor services are very large in magnitude. The tractor price elasticity of input demand and output supply

Table 2: Input Demand Equations, Dynamic Model Estimates, Pakistan Panel, 1986/7 to 1988/9

| | | Independent Variables | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Operational Holding (acres) | | | | |
| Dependent Variable | Estimate | Intercept | Lagged Dependent Variable | Rabi 1987/8 | Rabi 1988/9 | Tractor Hire Rate | Bullock Hire Rate | Wheat Price | Wage Rate | Rainfed | Canal-Irrigated | Well-Irrigated | F-Ratio | R-Square |
| Wheat harvested | Parameter | -564.353 | 0.603 | -41.511 | -32.360 | 7.273 | -0.01 | 1.945 | -1.391 | 1.446 | 2.094 | 2.334 | 235.540 | 0.769 |
| | T-ratio | -5.3 | 24.5 | -3.2 | -1.9 | 6.9 | -1.0 | 3.4 | -4.4 | 4.8 | 11.8 | 0.3 | | |
| Hired labor | Parameter | -184.987 | 0.482 | -13.051 | -20.566 | 2.656 | 0.007 | 0.659 | -0.845 | 1.627 | 0.970 | -3.528 | 21.890 | 0.236 |
| | T-ratio | -1.7 | 9.0 | -1.0 | -1.1 | 2.6 | 0.7 | 1.1 | -2.7 | 5.4 | 5.7 | -0.4 | | |
| Family male labor | Parameter | 396.406 | 0.698 | -73.744 | -36.226 | 2.224 | 0.036 | -2.962 | -5.391 | 0.641 | 0.073 | 1.797 | 148.020 | 0.676 |
| | T-ratio | 3.3 | 13.1 | -4.8 | -1.8 | 2.0 | 3.1 | -4.3 | -15.1 | 1.9 | 0.4 | 0.2 | | |
| Family female labor | Parameter | 254.586 | 0.201 | 30.378 | 34.569 | -2.266 | -0.019 | -1.385 | -0.108 | -0.001 | 0.062 | 0.031 | 26.470 | 0.272 |
| | T-ratio | 10.6 | 6.8 | 10.2 | 8.7 | -10.0 | -8.2 | -10.4 | -1.6 | 0.0 | 1.7 | 0.0 | | |
| Tractor hours | Parameter | 3.116 | 0.747 | -7.475 | -5.857 | 0.180 | -0.004 | -0.044 | -0.090 | 0.252 | 0.112 | 0.436 | 54.570 | 0.435 |
| | T-ratio | 0.1 | 18.8 | -2.4 | -1.4 | 0.8 | -1.6 | -0.3 | -1.3 | 3.7 | 2.9 | 0.2 | | |
| Bullock days | Parameter | 68.852 | 0.631 | -18.979 | -7.466 | 0.816 | 0.009 | -0.625 | -1.327 | 0.034 | 0.068 | 0.257 | 63.650 | 0.473 |
| | T-ratio | 1.8 | 10.3 | -4.0 | -1.2 | 2.3 | 2.5 | -3.0 | -12.2 | 0.3 | 1.2 | 0.1 | | |
| Manure | Parameter | -56.487 | 0.048 | -4.633 | -3.844 | 0.911 | -0.001 | 0.143 | -0.227 | -0.031 | -0.033 | -0.608 | 12.430 | 0.149 |
| | T-ratio | -2.9 | 1.5 | -2.0 | -1.2 | 5.0 | -0.3 | 1.4 | -4.3 | -0.6 | -1.2 | -0.5 | | |
| Total fertilizer | Parameter | -65.324 | 0.435 | 11.378 | -8.797 | 1.010 | 0.001 | 0.260 | -0.355 | 0.192 | 0.198 | -0.597 | 31.120 | 0.305 |
| | T-ratio | -3.0 | 7.3 | -4.3 | -2.5 | 4.9 | 0.3 | 2.2 | -5.8 | 3.1 | 5.7 | -0.4 | | |
| DAP | Parameter | -12.092 | 0.090 | -3.347 | -0.945 | 0.280 | -0.002 | 0.023 | -0.150 | 0.119 | 0.088 | 0.186 | 12.020 | 0.145 |
| | T-ratio | -1.1 | 1.3 | -2.4 | -0.5 | 2.6 | -1.4 | 0.4 | -4.6 | 3.7 | 4.9 | 0.2 | | |
| Urea | Parameter | -38.948 | 0.208 | -5.503 | -4.708 | 0.540 | 0.000 | 0.164 | -0.138 | 0.094 | 0.096 | -0.299 | 19.600 | 0.217 |
| | T-ratio | -3.7 | 3.7 | -4.2 | -2.7 | 5.4 | 0.2 | 2.8 | -4.6 | 3.3 | 5.7 | -0.4 | | |
| Nitrogen | Parameter | -16.747 | 0.123 | -1.380 | -1.698 | 0.189 | 0.000 | 0.086 | -0.037 | 0.068 | 0.025 | -0.368 | 6.530 | 0.084 |
| | T-ratio | -2.4 | 2.3 | -1.6 | -1.4 | 2.8 | 0.3 | 2.2 | -1.8 | 3.4 | 2.4 | -0.7 | | |
| No. of weedings | Parameter | 2.845 | 0.002 | 0.042 | 0.678 | -0.027 | -0.001 | -0.010 | -0.008 | 0.002 | -0.001 | -0.097 | 7.000 | 0.090 |
| | T-ratio | 1.7 | 0.2 | 0.2 | 2.4 | -1.6 | -3.7 | -1.1 | -1.5 | 0.5 | -0.6 | -0.8 | | |
| No. of irrigations | Parameter | -18.342 | 0.117 | -3.143 | -2.404 | 0.367 | 0.001 | 0.012 | -0.069 | -0.011 | 0.014 | -0.135 | 59.800 | 0.458 |
| | T-ratio | -3.5 | 1.9 | -4.7 | -2.8 | 7.3 | 2.5 | 0.4 | -4.7 | -0.8 | 1.8 | -0.4 | | |
| No. of ploughings | Parameter | -21.705 | 0.083 | -2.758 | -2.363 | 0.478 | 0.000 | 0.016 | -0.14 | 0.022 | 0.011 | -0.198 | 82.510 | 0.538 |
| | T-ratio | -4.8 | 1.7 | -5.0 | -3.3 | 10.7 | 1.1 | 0.7 | -11.2 | 1.9 | 1.7 | -0.6 | | |

Table 3: Elasticities of Input Demand, Dynamic Model Estimates, Pakistan Panel, 1986/7 to 1988/9

| | With respect to: | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | Operational Holding (acres) | | |
| Elasticity of: | Tractor Hire Rate | Bullock Hire Rate | Wheat Price | Wage Rate | Rainfed | Canal-Irrigated | Well-Irrigated |
| Wheat harvested | **8.094** | -0.026 | **2.960** | **-0.935** | **0.051** | **0.308** | 0.001 |
| Hired labor | **9.735** | 0.062 | 3.302 | **-1.869** | **0.189** | **0.469** | -0.003 |
| Family male labor | **2.392** | **0.090** | **-4.355** | **-3.501** | **0.022** | 0.010 | 0.000 |
| Family female labor | **-38.571** | **-0.755** | **-32.247** | **-1.107** | 0.000 | **0.139** | 0.000 |
| Tractor hours | 1.855 | **-0.088** | -0.627 | -0.559 | **0.083** | **0.153** | 0.001 |
| Bullock days | **4.867** | **0.128** | **-5.100** | **-4.783** | 0.007 | 0.054 | 0.000 |
| Manure | **18.353** | -0.026 | 3.946 | **-2.761** | -0.020 | -0.088 | -0.003 |
| Total fertilizer | **10.509** | 0.014 | **3.697** | **-2.230** | **0.063** | **0.273** | -0.002 |
| DAP | **9.828** | -0.129 | 1.092 | **-3.191** | **0.132** | **0.407** | 0.002 |
| Urea | **11.485** | 0.008 | **4.762** | **-1.767** | **0.064** | **0.269** | -0.002 |
| Nitrogen | **13.868** | 0.031 | **8.607** | **-1.665** | **0.158** | **0.247** | -0.007 |
| No. of weedings | **-9.135** | **-0.481** | -4.822 | -1.562 | 0.024 | -0.065 | -0.008 |
| No. of irrigations | **10.252** | **0.083** | 0.470 | **-1.173** | -0.010 | **0.053** | -0.001 |
| No. of ploughings | **8.194** | 0.019 | 0.384 | **-1.453** | **0.012** | **0.025** | -0.001 |

Notes: Figures in bold indicate statistical significance at the 10% level.

(see Table 3, column 1) ranges from -39 (for family female labor use) to 19 (for manure demand), suggesting very strong links between mechanization costs and the use of other farm inputs.

*Third*, estimated wheat price effects are consistent with the *a priori* predictions of the analytical framework. The profit maximization model predicts the impact of output price on output supply and most input demands to be positive. The estimated model indicates a very strong supply response (with an elasticity of harvested output with respect to the wheat price of 3.0), and strong positive effects of wheat price on the demand for manure and fertilizer (especially urea and nitrogen). However, wheat prices are estimated to significantly depress the demand for family labor, especially family female labor. These negative effects on labor demand probably reflect an income effect: increase in wheat prices (the dominant crop for many households) improves income and prompts the substitution of purchased inputs for family labor.

*Fourth*, the bullock price elasticities are generally small in magnitude. The own-price effect of bullock rental rates on the demand for bullock services is estimated to be positive (although, at 0.128, the elasticity is small). This slightly positive slope to the bullock "demand curve" is quite plausible if bullock ownership is common among sample households, and price variations over time are a consequence of demand, and not supply, shifts. Increased bullock rental rates led

to increased demand for family male labor (as a consequence of increased bullock use), but reduced demand for family female labor.

*Fifth*, the estimated wage rate effects on labor demand and output supply are generally well-behaved. They are consistently estimated to be significantly less than zero. The results suggest that a one percent increase in the wage rate reduces harvested wheat output by about 1 percent, hired labor use by 1.9 percent, and family male labor by 3.5 percent. These results suggest that as the market wage increases, male family members switch from own farming to other activities (including paid, wage labor). Female members participate less frequently in wage labor markets and do not seem to substitute for males (family or hired) as wages rise.

The estimated effect of the wage rate on bullock use is highly negative (elasticity of -4.8), again confirming the strong complementarity between bullock and human labor. The statistically insignificant wage elasticity of tractor services indicates that there is a greater degree of complementarity between bullocks and labor than between tractors and labor. Finally, the estimated effects of the wage rate on fertilizer demand (particularly, DAP) are very strongly negative. A one percent increase in wages is estimated to reduce the demand for DAP by as much as 3.2 percent, indicating strong complementarity between fertilizer and labor use.

*Sixth*, the effects of the quantity of land holding by access to irrigation on input demand and output supply are also generally in line with *a priori* expectations. Of the two types of irrigation, only canal irrigation appears to have a strong impact on input demand and output supply; well irrigation had virtually no significant effects on farmer behavior, perhaps due to the limited presence of tubewells in our sample of wheat farmers. All of the estimated land holding effects that are significantly different from zero are positive, implying that an increase in land holding (almost regardless of access to canal water) increases the harvested quantity of wheat and the demand for most inputs. However, the elasticities based on estimated parameters for canal-irrigated areas are generally much larger than the rainfed elasticities. For example, an increase in canal-irrigated land is observed to have much larger effects on wheat supply than an increase in rainfed land (elasticities of 0.31 and 0.05, respectively), suggesting that canal-irrigated land is roughly six times as productive as rainfed land. The elasticities of fertilizer and tractor use with respect to canal-irrigated land are two to three times as large as those with respect to rainfed land.

The coefficients on the lagged dependent variable (the $\lambda$'s) in the distributed-lag model indicate the speed of farmer response over time. The smaller the value of $\lambda$, or the larger the value of the "adjustment parameter" ($1-\lambda$), the smaller is the lag between the independent variables and the dependent variables. The estimates in Table 4 imply that the speed of responding to price and other agroeconomic changes is the longest for tractor use, family male labor,

Table 4: Estimates of $\lambda$ and the Speed of Adjustment

| Variable | Estimate of $\lambda$ | Adjustment Parameter $(1 - \lambda)$ |
|---|---|---|
| Wheat harvested | **0.603** | **0.397** |
| Hired labor | **0.482** | **0.518** |
| Family male labor | **0.698** | **0.302** |
| Family female labor | **0.201** | **0.799** |
| Tractor hours | **0.747** | **0.253** |
| Bullock days | **0.631** | **0.369** |
| Manure | 0.048 | 0.952 |
| Total Fertilizer | **0.435** | **0.565** |
| DAP | 0.090 | 0.910 |
| Urea | **0.208** | **0.792** |
| Nitrogen | **0.123** | **0.877** |
| No. of weedings | **0.002** | **0.998** |
| No. of irrigations | **0.117** | **0.883** |
| No. of ploughings | **0.083** | **0.917** |

Notes: Figures in bold indicate statistical significance at the 10% level

bullock labor, and output, but that farmers do adjust inputs, such as fertilizer, family female labor, weeding, ploughing and irrigation practices, rapidly as prices or other factors change. However, due to market rigidities and supply constraints, other inputs take much longer to fully adjust to the price and other shocks.

## Conclusions and Policy Implication

We have found that a distributed-lag model, in which farmers are presumed to adjust their inputs and outputs gradually over time in response to price and other changes, offers plausible estimates for the Pakistan panel of wheat farmers over the 1986-89 period, and highlights the nature of farm-level resource allocation and production decisions.

The model confirms the highly interrelated nature of input use, and the policies known to influence it. In almost every case, own-price elasticities were statistically significant, and in line with theoretical predictions. More importantly, many of the cross-price elasticities were statistically significant and quite strong, emphasizing the need for comprehensive analyses of the responses by farmers to policy shifts. For example, the model suggests that an increase in the price of wheat will not only increase output of wheat, but also increase the demand for key purchased and farm-produced inputs. Therefore, an increase in the price of wheat might more than offset any (supposed, but not estimated here) decrease in total fertilizer use brought about by the removal of a price control on that important

input. In addition, the elasticities associated with input changes in response to a change in wheat prices are not equal, suggesting a change in production technology, which policymakers need to be aware of.

The substitutability of agricultural mechanization for some types of rural labor was borne out by the data, and this model. Increases in tractor use in response to a decrease in tractor hire rates (a likely, but not statistically demonstrable effect in these data), would lead to a decrease in the quantity of hired and family male labor used, and an increase in family female labor used. Therefore, areas experiencing rapid rates of agricultural mechanization should pay close attention to rural unemployment, and potentially initiate programs to increase off ' .ı, and perhaps non-agricultural employment opportunities.

Input demand and output supply responses to increases in land availability were uniformly positive, and particularly strong for canal-irrigated areas. The output relation is well known, but the implications of increased canal irrigation for hired labor and fertilizer use (strong increases in demand, for all cases) is a clearly beneficial side-effect, perhaps achievable without any additional price policy intervention.

Changes in rural wages clearly affect farm production, as well as input choice. Labor is a key ingredient to agricultural production, and its sparing use in the face of increases in wage rates is likely (according to this model) not to be fully

compensated for by the use of other inputs. Indeed, use of virtually all other inputs declines along with labor input when wages rise. The most logical substitute for labor, mechanical traction, does not seem to react to wage increases, suggesting some imperfections in rental and purchase markets for tractors.

Finally, the speed with which different output and factors of production reacted to price and other agroecological changes differed greatly. Farming practices, such as the number of weedings, irrigations, and ploughings, were quickest to adjust -- usually making complete transitions in a single period or season. Adjustments to fertilizer application rates were slightly slower, but still managed to complete the transition in a single season, more or less. Labor use displayed a more diverse pattern of adjustment. Family female labor adjusted quickly, followed by hired labor, ending with family male labor, which took several periods to make complete adjustments. Limited off-farm labor opportunities for females, functioning daily hired and other labor markets for males, and fairly rigid on-farm responsibilities for family males are likely explanations for differences in speed of adjustment across labor groups. Improvements in rural labor markets could speed transitions for some of these groups.

There are several ways in which the research reported in this paper will be extended. First, an attempt will be made to include fertilizer prices paid by farmers in the sampled provinces. This will enable estimation of fertilizer price elasticities. Second, multi-crop input demand and output supply systems could be

estimated with data on several alternative crops during the Rabi season. Third, analysis will be extended to include a separate input/output demand system for the Kharif seasons. Fourth, we will attempt to control for differences across villages as regards key agroecological characteristics known to affect crop choice and production technology decisions. Finally, we will attempt to decompose the "fixed effects" into farmer and farm-specific components relevant for policy and future research.

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