6. Determinants of Crop Choices under Uncertainty

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In this chapter, the determinants of crop choices by sample households in the Pakistan Punjab are analyzed.[1] The analysis is based on a structural household model of production that incorporates the effects of incomplete insurance markets and the consideration for domestic food consumption.

A theoretical model is proposed in which households' crop choices are affected not only by their willingness to bear risk but also by their ordinal consumption preferences for individual goods, when both income and consumption prices are stochastic. Households' willingness to bear risk reflects their risk attitudes and the extent to which consumption smoothing arrangements are available. The household model is an attempt to link the intertemporal consumption model of risk-coping mechanism with the risk-management production model in which the distribution of household income is endogenously determined (Chapter 2), such as Morduch (1995, 1990), Rosenzweig and Wolpin (1993), and Rosenzweig and Binswanger (1993).

In this chapter emphasis is placed on testing econometrically whether or not a model with these characteristics is able to explain the behavior of sample households. In the first section, an intertemporal household model of crop choices under uncertainty is proposed. In the second section, econometric specifications are developed to test the hypotheses. Estimation and specification test results are presented in the third section. A non-nested likelihood test is applied to show that the model with ordinal consumption preference effects under incomplete insurance markets is superior to a model without these effects or a model of expected-profit maximization.

I. A Household Model

1. Income Risk, Insurance, and Crop Choices

The intertemporal household model in this study was inspired from Morduch (1990). Given the amount of "cash on hand" x_t, households maximize their lifetime utility by choosing the amount of assets held over into the next period S_t, the coverage of income insurance q_t, and the production portfolio l_t. The maximization problem is equivalent to finding the value function $V(x_t)$, defined by the functional equation

$$V(x_t) = \max_{\{-S_L \le S_t \le x_t, q_t, l_t\}} \left\{ u(c_t) + \frac{1}{1+\delta} E_t\left[V(x_{t+1})\right] \right\}, \tag{6.1}$$

subject to

$$c_t = x_t - S_t - I(q_t),$$
$$x_{t+1} = (1+r)S_t + Z(l_t, \varepsilon_{t+1}) + Q(q_t, \varepsilon_{t+1}),$$

where $u(c_t)$ is an instantaneous utility function that satisfies $u'(c_t) > 0$, $u''(c_t) < 0$, and $u'''(c_t) \ge 0$, δ is the rate of time preference, and r is the risk-free interest rate on S_t. The amount of net saving S_t is constrained in the interval of a floor of $-S_L$ (negative of the borrowing limit) and a ceiling of x_t. The purchase of insurance q_t incurs the premium payment of $I(q_t)$ and results in the insurance payment of $Q(q_t, \varepsilon_{t+1})$ in the next period, contingent on a realization of the exogenous shock ε_{t+1}. The choice of production portfolio l_t determines the distribution of production income $Z(..)$ in the next period, which is also contingent on a realization of ε_{t+1}. It is assumed that the value function exists and that it is unique and differentiable.

The first-order condition for the optimal choice of S_t is an Euler equation with a Lagrangean multiplier for the borrowing constraint (Morduch 1990; Deaton 1991). The first-order condition for the optimal production decision, on which emphasis is placed in this paper, is given as

$$E_t\left[V'(x_{t+1}) \frac{\partial Z}{\partial l_t}\right] = 0. \tag{6.2}$$

Equation (6.2) shows that the optimal portfolio choice is affected by the slope of the value function. At one extreme, when borrowing and saving are not allowed and income insurance is not available at all, $V'(x_{t+1})$ in (6.2) is replaced by $u'(c_{t+1})$, the slope of the instantaneous utility function. In this case, the optimal crop choice should reflect households' risk attitude, which is represented by the curvature of $u(c)$. This situation corresponds to the absence of ex post insurance arrangements. At the other extreme, when full insurance is available without constraint on q_t, households' crop choices do not depend on their risk preferences. They choose the crop portfolio that maximizes expected profit. This situation reflects the existence of complete insurance markets. In a more general situation between the two extreme cases, the curvature of the value function becomes less concave as ex post insurance arrangements become more available.[2] To summarize, the optimal crop choice depends on three factors: the extent to which ex post consumption smoothing mechanisms are available, the level of cash on hand, and the curvature of the instantaneous utility function.

2. Consumption Price Risk, Ordinal Preferences, and Crop Choices

The price level of consumption goods prevailing in the harvest period is usually unknown at the time of agricultural production decisions. To incorporate this type of price uncertainty, c_t is redefined in the instantaneous utility function as a vector of consumption goods. Since its price vector p_t is known when c_t is consumed, the instantaneous direct utility function $u(c_t)$ in (6.1) can be replaced by an instantaneous indirect utility function $v(y_t, p_t)$ where consumption expenditure y_t is the inner product of p_t and c_t.

This replacement does not alter equation (6.2) but adds another dimension that affects the optimal production choice. The curvature of the value function now depends on a realization of p_t as well as y_t, because the partial derivative of the instantaneous utility function, $\partial v/\partial y$, is a function of y_t and p_t. When y_t and p_t are positively correlated, the curvature of the value function becomes less concave since the positive correlation stabilizes the value of $\partial v/\partial y$. The effect of the variability of p_t on $\partial v/\partial y$ depends on ordinal preferences for individual goods, such as demand elasticities and budget shares (Newbery and Stiglitz 1981, p. 117).

When households' consumption expenditure on a food crop is large and its income elasticity is low, they are better off if their income and the food price are positively covariate. Growing the food crop on their farms is an obvious way to make their income and the food price covariate (Fafchamps 1992a; Finkelshtain and Chalfant 1991). According to Fafchamps (1992a), the advantage in terms of risk management of growing a crop whose profit is positively correlated with prices of major consumption items is referred to as "consumption price effects"; the advantage of growing a crop whose profit is negatively correlated with household income is referred to as "portfolio effects."[3]

II. An Empirical Model

1. Empirical Setting

Figure 6-1 shows the decision timing of the empirical model. Production choice variables in the empirical model are the acreage shares of the four major crops in the study area (basmati paddy, wheat, and *kharif* and *rabi* fodder crops). They are denoted by l_{si}, where subscripts s (= k, r) represent two cropping seasons of *kharif* and *rabi*, and subscripts i (= 1, 2) represent food-grain and fodder crops. Crops in different seasons do not compete for land directly. In addition to these crop activities, households keep livestock that produce milk. Milk production in the two seasons is treated as two distinct farm activities. Before the two cropping seasons begin, households decide on a production plan, which is implemented at the beginning of each cropping season. At the end of each season, after price and yield risks are resolved, households harvest crops and feed green fodder to livestock animals. After the two cropping seasons, households enjoy consumption, based on the realization of farm income and consumption prices. Considering the tight schedule of the consecutive farm operations of *kharif* harvest and *rabi* sowing, it is assumed that households do not adjust *rabi* crop choices at the beginning of *rabi*.

The six farm activities (basmati, wheat, *kharif* and *rabi* fodder, and *kharif* and *rabi* milk), together with nonfarm income Y_N that is assumed to be nonstochastic, constitute households' income flow $Z(l_t, \varepsilon_{t+1})$ as

$$Z(l_t, \varepsilon_{t+1}) = \sum_{s=k,r} \sum_{i=1,2} \pi_{si}(\varepsilon_{t+1}) l_{si,t} L_{s,t} + \sum_{s=k,r} \pi_{sm}(\varepsilon_{t+1}) A_{s,t} + Y_{N,t}, \qquad (6.3)$$

where $\pi(\varepsilon)$ is per-unit profit from farm activities net of production cost, L_s is the acreage of land available in s, and A_s is the size of a livestock herd in s. $\pi(\varepsilon)$ is stochastic due to price and yield risk represented by ε. Households are assumed to have rational expectations with respect to the distribution of ε.

The empirical model has additional constraints on production. Due to technological constraints, such as resource constraints or lumpiness of some inputs (Eswaran and Kotwal 1986; Chavas and Holt 1996), households cannot grow just one crop on all their land. They also have to leave a fixed portion of their land fallow. The following equations incorporate these constraints:

$$g_s(l_{s1,t}, l_{s2,t}; \alpha_s) = 0, \qquad s = k, r, \qquad (6.4)$$

where α is a vector of parameters characterizing the technical substitutability of two crops in each season.

Fig. 6-1. Decision Timing of the Household Model

t — Consumption decisions / Determination of household assets (L_k, L_r, A_k, A_r, etc.)
Production decisions on l_{k1}, l_{k2}, l_{r1}, and l_{r2} (based on ex ante income and prices)

Kharif season
Crop planting (implementation of l_{k1} and l_{k2})
$\downarrow$ ε_k is resolved
Crop harvesting and milk production (farm income in *kharif* determined)

Rabi season
Crop planting (implementation of l_{r1} and l_{r2})
$\downarrow$ ε_r is resolved
Crop harvesting and milk production (farm income in *rabi* determined)

t+1 — Consumption decisions / Determination of household assets
(based on the realized income and prices)
Production decisions on l_{k1}, l_{k2}, l_{r1}, and l_{r2}

Time horizon

Source: Prepared by the author.

With the specification in (6.3) and the additional constraints in (6.4), the first-order condition for the optimal production decision in (6.2) becomes

$$\begin{aligned} &E_t\left[V'\cdot\pi_{s1,t+1}\right]-\frac{\partial g_s}{\partial l_{s1,t}}\cdot\left[\frac{\partial g_s}{\partial l_{s2,t}}\right]^{-1}\cdot E_t\left[V'\cdot\pi_{s2,t+1}\right]=0, \qquad s=k,r,\\ &g_s\left(l_{s1,t},l_{s2,t};\alpha_s\right)=0, \qquad s=k,r, \end{aligned} \tag{6.5}$$

where the quotient of partial derivatives of g_s shows a marginal rate of transformation in season s (denoted MRT_s below). This system of four equations implicitly defines the optimal crop choices.

2. Specification of the Empirical Model

To convert the system of equations in (6.5) into an estimable system, two approximations were adopted. First, based on the discussion in the first section that the curvature of the value function depends on risk attitudes, insurance availability, and ordinal consumption preferences, the value function $V(x)$ was approximated by an instantaneous indirect utility function $v(y, p)$ with structural parameters β, γ, and ψ. Vectors β and γ represent ordinal preferences for individual goods. Households' willingness to bear risk is characterized by ψ. If households can use some ex post consumption-smoothing measures, ψ reveals the mixture of households' risk attitudes and the availability of these measures (Rosenzweig and Binswanger 1993). Second, following

Fafchamps (1992a), the slope of the value function in (6.5) was replaced by the first-order Taylor approximation to convert the expectation operator into manageable forms of means and variances. With these approximations and dropping time subscripts for simplicity, the first two equations in (6.5) became

$$0 = E\left[V' \cdot (\pi_{s1} - MRT_s \cdot \pi_{s2})\right] \approx E\left[v_y(y, p; \beta, \gamma, \psi) \cdot (\pi_{s1} - MRT_s \cdot \pi_{s2})\right]$$

$$\approx \overline{v_y}\left[(\overline{\pi_{s1}} - MRT_s \cdot \overline{\pi_{s2}}) + \sum_{j=1}^{n} \frac{\overline{v_{y,p_j}}}{\overline{v_y}} \cdot E\left[(p_j - \overline{p_j})(\pi_{s1} - MRT_s \cdot \pi_{s2})\right]\right.$$

$$\left. + \frac{\overline{v_{y,y}}}{\overline{v_y}} \cdot E\left[(Z - \overline{Z})(\pi_{s1} - MRT_s \cdot \pi_{s2})\right]\right], \quad s = k, r, \qquad (6.6)$$

where $v_y(..)$ denotes derivative of $v(..)$ with respect to y.

In the estimation, a consumption demand system was added to the production equations to estimate β and γ reliably. The linear expenditure system (LES) with the following specification was adopted, since it has an explicit indirect utility function and allows income elasticity of demand to differ by commodity. To focus on the interaction between consumption prices and farm profits, consumption goods were divided into four categories: wheat (w), milk and milk products (m), rice (r), and other consumption goods (o). Thus, the demand system was specified as

$$p_{EP,k} x_k = p_{EP,k} \gamma_k + \beta_k \left(Y_{EP} - \sum_{j=w,m,r,o} p_{EP,j} \gamma_j \right), \quad k = w, m, r, o, \qquad (6.7)$$

with

$$\sum_{j=w,m,r,o} \beta_j = 1,$$

where $p_{EP,k}$ is the ex post price of consumption item k, x_k is its consumption quantity, Y_{EP} is the ex post consumption expenditure, γ is a vector of subsistence requirements, and β represents the marginal propensity to spend on each good after meeting the subsistence requirements.[4]

The indirect utility function associated with this demand system, which can incorporate risk aversion, is expressed as

$$v(y, p) = \frac{1}{1-\psi}\left[\frac{y - \sum_j p_j \cdot \gamma_j}{\prod_j p_j^{\beta_j}}\right]^{1-\psi}, \qquad (6.8)$$

where ψ is interpreted as the coefficient of relative risk aversion given the insurance availability, with respect to the argument inside the bracket. Using

(6.8), v_y, $v_{y,pj}$, and $v_{y,y}$ are calculated accordingly and their expected values are inserted into (6.6) such as

$$\frac{\overline{v_{y,y}}}{\overline{v_y}} = -\psi \cdot \frac{1}{\overline{y} - \sum_k \overline{p_k}\gamma_k}, \qquad \frac{\overline{v_{y,pj}}}{\overline{v_y}} = \frac{1}{\overline{p_j}}\left(\frac{\psi\,\overline{p_j}\gamma_j}{\overline{y} - \sum_k \overline{p_k}\gamma_k} - \beta_j(1-\psi)\right).$$

After rearrangement, the empirical equations for the optimal crop choices become

$$\left(f_s^1 - f_s^2 \cdot MRT_s\right) + \sum_{t=k,r}\sum_{i=1,2}\left[\left(f_s^{1ti} - f_s^{2ti} \cdot MRT_s\right) l_{ti}\right] = 0, \quad s = k, r, \tag{6.9}$$

where coefficient f_s^z is a nonlinear function of parameters β, γ, and ψ, and variables characterizing market and production environments, such as the ratios of expected returns, the coefficients of variation of prices and per-acre profits, correlation coefficients between prices and profits, the sizes of livestock, land, and nonfarm income (see Appendix to this chapter for exact definitions).

In the estimation, it is assumed that parameters ψ and β vary with household characteristics in the following way:

$$\begin{aligned} \psi_h &= \psi\left(Z_{\psi,h}\right) = \psi_0 + \sum_k \psi_k \cdot Z_{\psi,hk}, \\ \beta_{ih} &= \beta_i\left(Z_{\beta,h}\right) = \beta_{i0} + \sum_k \beta_{ik} \cdot Z_{\beta,hk}, \end{aligned} \tag{6.10}$$

where $Z_{\psi,h}$ is a vector of variables that affect households' ability to bear risk, such as physical and human capital assets, and $Z_{\beta,h}$ is a vector of variables that shift the taste for each consumption good, such as demographic composition. $Z_{\psi,h}$ includes the number of livestock animals and the size of landownership as a proxy to physical assets and the educational status of a household head as a proxy to a human capital asset. The dependency ratio, defined as the number of children under ten years old divided by the total number of household members, is used as a variable characterizing the demographic composition of a household.

The technological constraints on crop choices are specified by the following quadratic functions:

$$g_s\left(l_{s1}, l_{s2}; \alpha_s\right) = l_{s2} + \alpha_{s0} + \alpha_{sw} \cdot D_{tw} + \alpha_{s1} l_{s1} + \alpha_{s2} l_{s1}^2 = 0, \quad s = k, r, \tag{6.11}$$

where D_{tw} is a dummy variable for the ownership of a tubewell. The availability of tubewells is the most important technical factor in the Punjab agriculture. If the coefficient on the dummy variable is negative, land-use intensity in farms with a tubewell is higher than in farms without it.

3. Estimation Procedure

The system of seven equations [two first-order conditions for the optimal crop choices given in (6.9), two equations for the crop choice constraints in (6.11), and three equations for the consumption demand system in (6.7)] was estimated by a full-information maximum likelihood (FIML) method. Since the subsystem of four production equations in (6.9) and (6.11) cannot be solved explicitly, it had to be estimated in an implicit form.

To use the sample in econometric estimation, a normal error vector was added to the system. An exact form of the FIML log-likelihood function is given in the appendix to this chapter. The maximum likelihood estimator is defined as a root of the equations of the derivatives of the log-likelihood function with respect to each parameter. It is consistent and asymptotically efficient under fairly general conditions (Judge et al. 1985, pp. 178–80).

Table 6-1 summarizes the definitions and statistics of the empirical variables used in the estimation. The system to be estimated consists of seven endogenous variables: the acreage share of each crop l_{si} ($s = k, r$; $i = 1, 2$), defined as the area devoted to crop *si* divided by the area available for crop choices in season *s* including fallow land; and $p_{EP,k} \cdot x_{PC,k}$ ($k = w, m, r$), per capita expenditure for item *k*. These seven variables are constructed based on the household data of all sample observations.

Exogenous variables in the empirical model include market and production environment variables and household-characteristic variables. Among the market and production environment variables, the coefficients of variation (*CV*s) of prices and net profits at the individual farm level have been estimated already in Chapters 4 and 5, based on a model that incorporates idiosyncratic yield risks, structural differences in production technology among households, and input cost adjustments.

III. Estimation Results

1. Parameter Estimates

Table 6-2 reports the estimation results. Asymptotic standard errors are computed by inverting the sums-of-squares matrix of the outer products of the gradient of the likelihood function with respect to relevant parameters, according to Berndt et al. (1974). Estimated standard errors are relatively small compared with coefficient estimates—they are smaller than one-half of the coefficient estimates in twenty-one of the twenty-two estimated parameters.

All four parameters characterizing ψ, households' willingness to bear risk, are statistically significant (Table 6-2). Among the effects of three shifters, the

TABLE 6-1

DEFINITIONS AND STATISTICS OF THE EMPIRICAL VARIABLES

Variables	Definition	Unit	Mean	Standard Deviation
1. Optimal crop choice equations				
Endogenous variables				
l_{k1}	Basmati cropped land / L_k	unitless	0.653	0.162
l_{k2}	*Kharif* fodder cropped land / L_k	unitless	0.289	0.140
l_{r1}	Wheat cropped land / L_r	unitless	0.734	0.106
l_{r2}	*Rabi* fodder cropped land / L_r	unitless	0.209	0.097
Exogenous variables				
L_k	*Kharif* land available for two crops and fallow	acre	9.071	7.266
L_r	*Rabi* land available for two crops and fallow	acre	8.846	6.773
A_k	No. of *kharif* milk animals	adult units	4.742	2.987
A_r	No. of *rabi* milk animals	adult units	4.742	2.987
Y_N	Nonfarm income per household	Rs.	6,688	3,609
W	Deflated expected non-crop income[a]	unitless	14.64	7.084
W_{k1}	Normalized covariance of crop profit and milk income[a]	unitless	0.303	0.196
W_{k2}	(same)[a]	unitless	–1.519	0.988
W_{r1}	(same)[a]	unitless	1.242	0.791
W_{r2}	(same)[a]	unitless	–5.909	3.839
m_k	Ratio of expected crop profits in *kharif* (cereal over fodder)[a]	unitless	1.066	0.142
m_r	The same in *rabi*[a]	unitless	1.279	0.075
Q_{k1w}	Normalized covariance of crop profit and consumption price[a]	unitless	0.008	0.001
Q_{k2w}	(same)[a]	unitless	0.008	0.000
Q_{k1m}	(same)[a]	unitless	–0.001	0.000
Q_{k2m}	(same)[a]	unitless	0.037	0.002
Q_{k1r}	(same)[a]	unitless	0.036	0.005
Q_{k2r}	(same)[a]	unitless	–0.024	0.001
Q_{r1w}	(same)[a]	unitless	0.024	0.002
Q_{r2w}	(same)[a]	unitless	0.007	0.001
Q_{r1m}	(same)[a]	unitless	0.016	0.001
Q_{r2m}	(same)[a]	unitless	0.031	0.002
Q_{r1r}	(same)[a]	unitless	0.022	0.001
Q_{r2r}	(same)[a]	unitless	0.045	0.003
Exogenous variables (Preference shifters)				
EDU	Years of education completed by the household head	years	1.794	3.495
LAND	Size of owned agricultural land	acre	11.17	9.175
ANIMAL	No. of owned livestock animals	adult units	6.361	3.534

TABLE 6-1 (Continued)

Variables	Definition	Unit	Mean	Standard Deviation
2. Technological constraints on crop choices				
Endogenous variables				
$l_{k1}, l_{k2}, l_{r1}, l_{r2}$				
Exogenous variable				
D_{tw}	Tubewell ownership dummy, 1 for owner, 0 for non-owner	0 or 1	0.694	0.462
3. LES				
Endogenous variables				
$p_{EP,w}x_{PC,w}$	Per capita expenditure on wheat	Rs.	406.3	80.8
$p_{EP,m}x_{PC,m}$	Per capita expenditure on milk and its products	Rs.	826.0	167.3
$p_{EP,r}x_{PC,r}$	Per capita expenditure on rice	Rs.	125.4	32.8
Exogenous variables				
$p_{EP,w}$	Price of wheat at the farm gate	Rs. / 40 kg	93.9	10.8
$p_{EP,m}$	Price of milk at the farm gate	Rs. / 40 kg	135.0	17.8
$p_{EP,r}$	Price of Basmati paddy at the f.g.	Rs. / 40 kg	133.5	3.4
$p_{EP,o}$	Price index of other commodities	Year 1 = 200	218.0	17.1
$Y_{EP,PC}$	Total per capita consumption expenditure	Rs.	3,055	606.5
Exogenous variables (Preference shifters)				
DEP	Dependency ratio as the number of children under 10 divided by the total number in household	unitless	0.268	0.184

Note: The number of observations is 291.
[a] See the expression in Appendix to this chapter for the exact definitions.

coefficient on animal holding (ψ_A) is significantly negative and those on education (ψ_E) and landholding (ψ_L) are significantly positive. The accumulation of livestock makes households more willing to bear risk. This finding supports the argument that the liquid nature of animal holding should improve households' ability to smooth consumption (Rosenzweig and Wolpin 1993). Contrary to expectations, the estimates for land and education are not negative. There are several possible explanations for these results. First, since the land sale market is inactive in the study villages, the land asset may be somewhat illiquid. For this argument to be convincing, it must be shown that land cannot be used as collateral for consumption credit, an issue which is left for further study. Second, poorer households may be "forced to gamble" (Shahabuddin, Mestelman, and Feeny 1986, p. 122) to increase the chance of

TABLE 6-2

ESTIMATION RESULTS OF THE HOUSEHOLD MODEL (MODEL A)

1. Parameters characterizing households' willingness to bear risk			
ψ_0	intercept of ψ, the relative risk-aversion coefficient	1.585	(0.140)
ψ_E	effect of the years of education of household head on ψ	0.063	(0.016)
ψ_L	effect of the size of owned land on ψ	0.028	(0.008)
ψ_A	effect of the size of owned livestock animals on ψ	–0.042	(0.014)
2. Ordinal consumption preference parameters			
β_{w0}	intercept of β_w, marginal propensity to consume wheat	0.035	(0.016)
β_{wd}	effects of dependency ratio on β_w	0.279	(0.047)
β_{m0}	intercept of β_m, marginal propensity to consume milk	0.192	(0.009)
β_{md}	effects of dependency ratio on β_m	0.213	(0.046)
β_{r0}	intercept of β_r, marginal propensity to consume rice	0.014	(0.008)
β_{rd}	effects of dependency ratio on β_r	0.061	(0.020)
γ_w	per capita subsistence consumption quantity of wheat	4.134	(0.119)
γ_m	per capita subsistence consumption quantity of milk	5.783	(0.149)
γ_r	per capita subsistence consumption quantity of rice	0.906	(0.028)
γ_o	per capita subsistence consumption quantity of other items	7.221	(0.203)
3. Parameters characterizing technological constraints on crop choices			
α_{k0}	intercept in *kharif*	–0.636	(0.010)
α_{kw}	effect of tubewell ownership in *kharif*	–0.029	(0.005)
α_{k1}	coefficient on linear term in *kharif*	0.130	(0.035)
α_{k2}	coefficient on quadratic term in *kharif*	0.629	(0.031)
α_{r0}	intercept in *rabi*	–0.642	(0.013)
α_{rw}	effect of tubewell ownership in *rabi*	–0.017	(0.007)
α_{r1}	coefficient on linear term in *rabi*	0.289	(0.033)
α_{r2}	coefficient on quadratic term in *rabi*	0.424	(0.027)
Log-likelihood		–3,263.6	

Note: 1. Asymptotic standard errors are indicated in parenthesis.
2. The number of observations is 291.

survival under risk. Third, because households with more education and a larger land area enjoy a higher status in the village, their desire to protect their community status may induce them to behave in a more risk-averse way (Tversky and Kahneman 1991). Fourth, the land variable may capture returns to scale effects. These issues deserve more investigation.

Predicted values of ψ are positive for all observations and distributed between 1.12 and 3.34 (Table 6-3),[5] implying that sample households behave in a risk-averse way when they allocate land to crops, which is consistent with risk-averse attitudes and incomplete insurance markets. The estimates for ψ in this paper are comparable to previous estimates of the relative risk aversion coefficient in agriculture. Estimates from previous studies range from zero to over eight with most estimates between one and four (Binswanger 1981; Newbery and Stiglitz 1981; Saha, Shumway, and Talpaz 1994).

TABLE 6-3
STATISTICS OF SIMULATED PARAMETERS

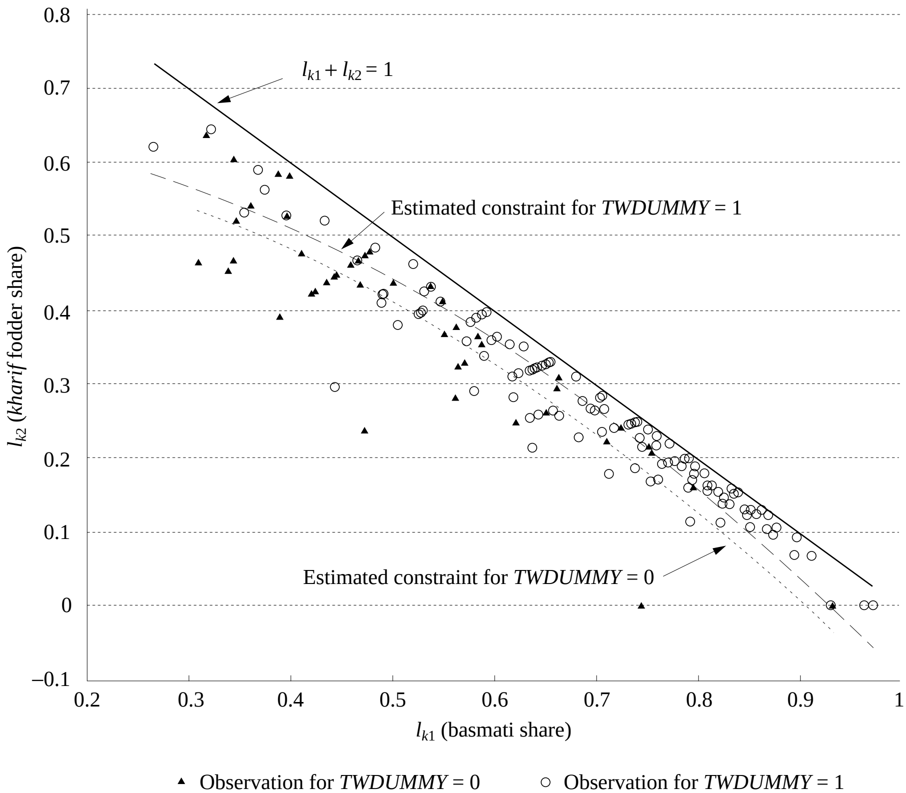
	Mean	Standard Deviation	Minimum	Maximum
1. Parameter characterizing households' willingness to bear risk				
ψ	1.741	0.322	1.115	3.338
2. Income elasticity of demand				
η_w	0.947	0.219	0.411	1.571
η_m	0.847	0.073	0.638	0.977
η_r	0.616	0.149	0.275	0.910
η_o	1.115	0.085	0.922	1.484

Results show that households with a higher ratio of children are more vulnerable to consumption price risk of food commodities. Most of the ordinal preference parameters in β and γ are individually significant with correct signs and reasonable magnitudes (Table 6-2). All three coefficients of the β shifter (β_{wd}, β_{md}, and β_{rd}) are positive and statistically significant, which implies that both the consumption shares of major food items and the marginal propensity to spend on them are higher for these households. Income elasticities are evaluated at expected income and expected consumption prices for all observations (Table 6-3). The income elasticity of "other consumption goods" has the highest sample mean. For most households, this item is a luxury good with income elasticity greater than unity.

All the coefficient estimates in the technological constraint equations are individually significant (Table 6-2). Linearity of the constraint is rejected in favor of a strictly concave curve since both α_{k2} and α_{r2} are significantly positive. Figures 6-2 and 6-3 plot the estimated curves of the technological constraints and observed choices by sample households.

Coefficients for the tubewell ownership dummy (α_{kw} and α_{rw}) are negative and statistically significant in both seasons, implying that farms with tubewell machinery can allocate land more freely. The absolute value of the tubewell coefficient is much larger in the *kharif* season than in the *rabi* season. The difference between the two seasons reflects the importance of tubewell ownership for the cultivation of *kharif* crops including basmati paddy. Results in Chapter 3 imply that active market transactions of groundwater resulted in equalization of crop yields regardless of tubewell ownership. Nevertheless, the findings here imply that the control of irrigation risk by owning a tubewell is an important factor in production decisions in a sense that the ownership status affects households' cropping decisions.

Fig. 6-2. Estimated Production Constraints and Observed Choices in *Kharif*

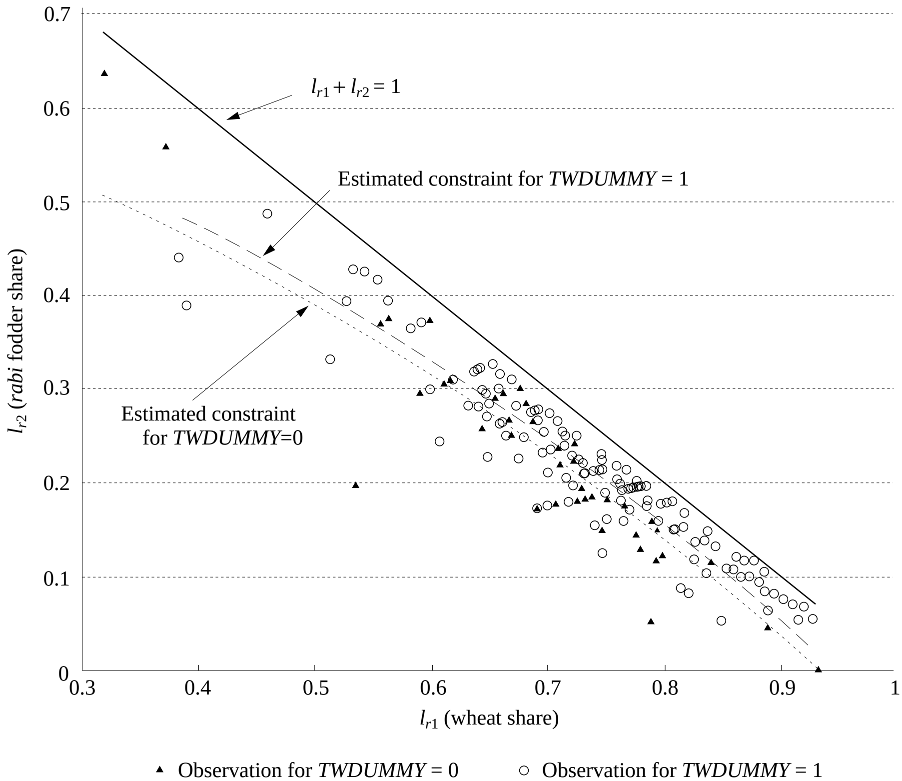


2. Testing for the Effect of Ordinal Preferences on Crop Choices

Do ordinal consumption preferences really affect crop choices under uncertainty when markets for all consumption goods exist? To answer this question, a non-nested test of the model specification is implemented. Two recent studies that emphasized the importance of ordinal preference effects on production decisions were mostly theoretical and did not test their models econometrically (Fafchamps 1992a; Finkelshtain and Chalfant 1991).[6] Therefore, the specification test is interesting both methodologically and empirically, because it sheds light on whether a bias is introduced when the effects of ordinal preferences are ignored.

The hypothesis that ordinal consumption preferences affect crop choices is supported by the following model specification test. Let Model A represent the model *with* ordinal preference effects, and Model B represent the model

Fig. 6-3. Estimated Production Constraints and Observed Choices in *Rabi*



without these effects. Model B is based on the assumption that households maximize expected utility defined on household income alone when they choose crop portfolio. Since the two models are strictly non-nested,[7] a non-nested specification test by Vuong (1989) was applied. Denoting the difference of log-likelihood by LR and the contribution of observation n to the log-likelihood by l_n^A and l_n^B, the test statistic V is defined as

$$V = \frac{1}{\sqrt{N}} \cdot LR \cdot \frac{1}{\hat{w}}, \qquad (6.12)$$

where

$$\hat{w}^2 = \frac{1}{N}\sum_{n=1}^{N}\left[\left(l_n^A - l_n^B\right)^2\right] - \left[\frac{1}{N}\sum_{n=1}^{N}\left(l_n^A - l_n^B\right)\right]^2.$$

Under the null hypothesis that the two models equally fit the data, V is distributed as a standard normal variable. If Model A is better than Model B, $V \to \infty$; and if Model B is better, $V \to -\infty$.

Table 6-4 gives the FIML estimation results of Model B and the results of Vuong's test. The test statistic V in the last row is 4.62, a value sufficiently large to reject Model B in favor of Model A.

Comparison of the two sets of parameter estimates (Tables 6-2 and 6-4) indicates that the risk preference parameters are larger for Model B than for Model A—the estimate for ψ is 1.74 in Model A and 1.83 in Model B at the sample mean, which implies that households' willingness to bear risk may be underestimated if ordinal preference effects are ignored. Though the difference is not large relative to the estimated standard errors, it was found robustly that the estimate for ψ was larger for Model B than for Model A.[8] Therefore, the clear rejection of Model B in the specification test suggests that the role of the risk-aversion factor may be exaggerated if ordinal preference effects on production decisions are ignored. As shown in Chapter 4, the prices of major food items are not very volatile in the study area. If a similar test had been implemented in an empirical situation with more volatile market prices of foods, the difference in the estimates for risk preference parameters might have been larger.

Furthermore, the two models predict different responses to a change in exogenous parameters. For example, there should be no supply response when only ordinal preferences are changed in Model B, such as a change in household demographic composition. The effects of demographic variables on farm production have been analyzed in the agricultural household models in which production decisions are non-separable from consumption preferences due to incomplete labor markets (Pitt and Rosenzweig 1986; Benjamin 1992). This study shows that similar non-separable effects of demographic factors might exist due to incomplete insurance markets.

3. Testing for the Implication of Complete Insurance Markets

The estimates for ψ can be interpreted as a measure of ex post consumption smoothing possibilities. At the extreme, if risk-averse households are able to smooth consumption perfectly after the random income is realized, they are likely to decide on production plans as if they were expected-profit maximizers.

Vuong's test was applied to test this implication of complete insurance markets (Table 6-4). Model A is the same model with ordinal preference effects under incomplete insurance markets. The alternative model with complete insurance markets (Model B) is characterized by the crop portfolio equations for expected-profit maximization. The log-likelihood of the estimation

TABLE 6-4

ESTIMATION RESULTS OF ALTERNATIVE MODELS (MODEL B)

	Model without Ordinal Preference Effects on Crop Choices		Model of Expected Profit Maximization	
1. Parameters characterizing households' willingness to bear risk				
ψ_0	1.691	(0.382)		
ψ_E	0.068	(0.242)		
ψ_L	0.029	(0.040)		
ψ_A	–0.049	(0.017)		
2. Ordinal consumption preference parameters				
β_{w0}	0.035	(0.017)	0.032	(0.071)
β_{wd}	0.278	(0.090)	0.282	(0.149)
β_{m0}	0.192	(0.011)	0.184	(0.013)
β_{md}	0.211	(0.067)	0.227	(0.286)
β_{r0}	0.014	(0.012)	0.166	(0.015)
β_{rd}	0.061	(0.057)	0.052	(0.030)
γ_w	4.126	(0.500)	4.114	(0.295)
γ_m	5.770	(0.437)	5.750	(0.216)
γ_r	0.904	(0.028)	0.888	(0.087)
γ_o	7.202	(0.604)	7.174	(0.577)
3. Parameters characterizing technological constraints on crop choices				
α_{k0}	–0.636	(0.290)	–0.586	(0.080)
α_{kw}	–0.029	(0.039)	–0.023	(0.019)
α_{k1}	0.122	(1.193)	–0.181	(0.525)
α_{k2}	0.642	(1.004)	0.959	(0.544)
α_{r0}	–0.642	(0.171)	–0.183	(0.082)
α_{rw}	–0.016	(0.030)	–0.014	(0.022)
α_{r1}	0.280	(0.202)	–1.245	(0.210)
α_{r2}	0.436	(0.039)	1.636	(0.109)
Log-likelihood	–3,269.91		–3,483.61	
Vuong's test statistics:				
$\hat{w}$	0.0801		3.1167	
V	4.620		4.138	

Note: 1. Asymptotic standard errors are indicated in parenthesis.
2. Vuong's test is applied against Model A, the model with ordinal preference effects (Table 6-2).

results of Model B is significantly lower than that of Model A with Vuong's test statistic greater than four. Therefore, the implication of complete insurance markets is rejected. The econometric test confirms the claim that sample households behave in a risk-averse way since they are risk-averse and insurance markets are incomplete, which is consistent with the findings reported by Morduch (1990, 1991), Udry (1994), and Townsend (1994).

IV. Summary and Conclusions

In this chapter, a household model of production decisions under uncertainty and incomplete insurance markets has been proposed. The model has a unique characteristic in that ordinal consumption preferences affect crop portfolio choices even when markets for all consumption goods exist. Households' willingness to bear risk, which reflects their risk attitudes and the extent to which consumption smoothing mechanisms are available, is another factor that affects crop choices. These structural parameters have been estimated by a full-information maximum likelihood method using the household data.

The parameter estimates for ordinal preferences and households' willingness to bear risk have been found in a reasonable range. These parameters vary systematically depending on household characteristics. An interesting finding is that holding wealth in the form of livestock increases households' ability to smooth consumption so that they become more willing to bear risk in production.

A non-nested model specification test has demonstrated that production decisions by sample households were significantly affected by their ordinal consumption preferences for goods they produce. Parameter estimates have shown that sample households behaved in a risk-averse way when allocating land, a finding consistent with incomplete insurance markets. This finding has been further supported by a similar specification test, in which a model of expected profit maximization under complete insurance markets was rejected.

The major result of the findings in this chapter is that households' ability to smooth consumption ex post and households' ordinal consumption preferences for goods should be considered in analyzing the production behavior of subsistence farmers in Pakistan. When markets for some consumption goods are completely missing, farm households have to produce these goods by themselves, so that ordinal preferences inevitably affect crop choices. Similarly, when ex post insurance mechanisms are not available at all, households have to decide on their production plan according to their risk attitudes. As markets evolve, however, households no longer have to produce these goods or insure themselves through production choices—they now have an option to use markets. Nevertheless, when the markets for goods are thin and insurance markets are incomplete, they still find it advantageous to grow consumption goods on their farms as a hedge against price risk and to choose less risky crop portfolio. This chapter has shown empirically that the presence of risk forges this kind of link between production and consumption. Furthermore, the results suggest that ignoring ordinal preference effects might lead to an under-estimation of households' willingness to bear risk.

Appendix to Chapter 6

Details of the FIML Estimation

The system comprises seven equations with an error term v_h ($h = 1,..,7$):

(i) First-Order Conditions for the Optimal Crop Choice [$(h, s) = (1, k), (2, r)$]

$$F_h(l;\alpha,\beta,\gamma,\psi) = \left(f_s^1 - f_s^2 \cdot MRT_s\right) + \sum_{t=k,r}\sum_{i=1,2}\left[\left(f_s^{1ti} - f_s^{2ti} \cdot MRT_s\right) l_{ti}\right] = v_h, \tag{6.A1}$$

where

$$f_s^d = \frac{(W-\Gamma)}{L_s}\left[\frac{\overline{\pi_{sd}}}{\overline{\pi_{s2}}} - \sum_j \beta_j (1-\psi) Q_{sdj}\right] + \frac{1}{L_s}\psi \sum_j \frac{\overline{p_j}\gamma_j}{\overline{\pi_{k2}}} Q_{sdj} - \psi \frac{W_{sd}}{L_s},$$

$$f_s^{dti} = \frac{L_t}{L_s} \cdot \frac{\overline{\pi_{ti}}}{\overline{\pi_{k2}}}\left[\frac{\overline{\pi_{sd}}}{\overline{\pi_{s2}}} - \sum_j \beta_j (1-\psi) Q_{sdj}\right] - \psi \frac{L_t}{L_s} \frac{\mathrm{Cov}(\pi_{ti}, \pi_{sd})}{\overline{\pi_{k2}} \cdot \overline{\pi_{s2}}},$$

for $s = k, r$ (season subscript for FOC equations), $d = 1, 2$ (crop subscript in function f), $t = k, r$ (season subscript inside the summation), $i = 1, 2$ (crop subscript inside the summation), $j = w, m, r, o$ (subscript for consumption items), where W and Q are constructed variables and Γ is a constructed parameter, defined as

$$W = \frac{1}{\overline{\pi_{k2}}}\left(\overline{\pi_{km}} \cdot A_k + \overline{\pi_{rm}} \cdot A_r + Y_N\right),$$

$$W_{sd} = \frac{\mathrm{Cov}(\pi_{sd}, \pi_{km})}{\overline{\pi_{k2}}\,\overline{\pi_{s2}}} \cdot A_k + \frac{\mathrm{Cov}(\pi_{sd}, \pi_{rm})}{\overline{\pi_{k2}}\,\overline{\pi_{s2}}} \cdot A_r,$$

$$Q_{sdj} = \frac{\mathrm{Cov}(p_j, \pi_{sd})}{\overline{p_j}\,\overline{\pi_{s2}}} = \frac{\overline{\pi_{sd}}}{\overline{\pi_{s2}}} \cdot CV_{p_j} \cdot \rho_{p_j,\pi_{sd}} \cdot CV_{\pi_{sd}},$$

$$\Gamma = \frac{\sum_j \overline{p_j}\gamma_j}{\overline{\pi_{k2}}}.$$

(ii) Technological Constraints on Crop Choices [(h, s) = (3, k), (4, r)]

$$F_h(l;\alpha) = l_{s2} + \alpha_{s0} + \alpha_{sw} \cdot D_{tw} + \alpha_{s1} l_{s1} + \alpha_{s1} l_{s1}^2 = v_h. \tag{6.A2}$$

(iii) Consumption Demand System [(h, s) = (5, w), (6, m), (7, r)]

$$F_h(x;\beta,\gamma) = -p_{EP,s}x_s + p_{EP,s}\gamma_s + \beta_s\left(Y_{EP} - \sum_{j=w,m,r,o} p_{EP,j}\gamma_j\right) = v_h. \tag{6.A3}$$

If the error vector v is independently and identically distributed across observations and has a jointly normal distribution, a log-likelihood function for the FIML is written as

$$\begin{aligned} &\ln L(\alpha,\beta,\gamma,\psi,\Sigma|l,x) \\ &= -\frac{MN}{2}\ln(2\pi) - \frac{N}{2}\ln|\Sigma| + \sum_n \ln|J_n| \\ &\quad -\frac{1}{2}F(x,l;\alpha,\beta,\gamma,\psi)'\left(\Sigma^{-1}\otimes I_N\right)F(x,l;\alpha,\beta,\gamma,\psi), \end{aligned} \tag{6.A4}$$

where N is the number of observations; M is the number of simultaneous equations, which equals seven; Σ is an M-dimensional covariance matrix of the disturbance vector v; J_n is a Jacobian matrix of the transformation for observation n; and $F(x, l; \alpha, \beta, \gamma, \psi)$ is a ($MN \times 1$) vector that stacks up the seven equations for N observations (Judge et al. 1985, p. 601).

A complicated term in (6.A4) is the Jacobian matrix. Since the subsystem of (6.A1) and (6.A2) does not have an explicit solution for the endogenous variables l, it has to be estimated in implicit form. The Jacobian matrix expresses this implicit transformation. It is block-diagonal between the subsystem of production decisions (the first four equations) and that of consumption demand (the last three equations).

Notes

1 This chapter is based on Kurosaki (1996b).
2 See Morduch (1990) for a case where no explicit insurance is available but saving is allowed in the interval of [0, x_t].
3 See Kurosaki (1995b, chap 3) for more exact definitions and characteristics of these effects.
4 The magnitude of γ is assumed to be proportional to the household size, so that the model in (6.7) is estimated based on variables defined in per capita terms in order to control the effect of household size. The fourth equation for "other con-

sumption goods" is omitted in the estimation, since the sum of expenditures on each commodity is the total expenditure by construction.

5 Since ψ is the coefficient of relative risk aversion with respect to the real income indicated in the bracket in (6.8), the Arrow-Pratt coefficient of relative risk aversion was also evaluated for each sample. Its estimates for 285 observations are distributed between 1.54 and 18.94 with a mean of 3.51 (six observations in which the expected value of $Y - \Sigma p_k \gamma_k$ was negative were omitted).

6 Park and Ren (1994) estimated a model that incorporates the effects of ordinal consumption preference on crop choices. Using a reduced-form approach and aggregate data on Chinese agriculture, they found that production response to consumption price risk is different from that to profit risk, which is consistent with the implications of a model with the effects of ordinal preferences on crop choices.

7 Both models are composed of the crop-portfolio equations, the technological constraint equations, and the consumption equations. The alternative assumption of Model B results in the crop-portfolio equations without β and γ. Since the sum of β_j's in the consumption equations is unity because of the adding-up property of a consumption demand system, the vector β cannot be a zero vector. Therefore, the two models are strictly non-nested.

8 These results were obtained under a different error structure and using subsets of sample observations (Kurosaki 1995b, chap. 5).