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Abstract

Cultivator households in some developing areas use off-farm labor supply as an insurance against crop income shocks, whilst employment is uncertain in this off-farm labor market. This paper hypothesizes that, given limited opportunities for ex post consumption smoothing, employment uncertainty influences risk-averse households' crop choice decisions-- they would opt for more conservative crop choices in case they expect unfavorable supply opportunities in the labor market. A two-period stochastic dynamic programming model is developed. A panel data set from the ICRISAT survey of the semi-arid tropics of India is examined. Estimation is based on random effects and fixed effects Tobit specifications. Estimation results indicate statistically significant impact of household expectation of harvesting period male unemployment rates on ex ante crop choices. Results also indicate strong influence of household irrigated land share on crop choices.

JEL Classification. O1
Keywords. Crop Choice; Off-farm Labor Market; Risk; Panel Data

1. Introduction

Risk factors, such as weather risk, influence cultivators' choices of crops. This is due to absence of a complete set of markets in developing country agricultural sector (Kurosaki (1998)). A competitive equilibrium is considered Pareto-optimal if the set of markets, including insurance markets against risk, is complete (Debreu (1959); Arrow (1964)). There is "separability" between production decisions taken by households and their risk and consumption preferences in that case (Singh, Squire and Strauss (1986); Bardhan and Udry (1999)). Since a complete set of markets does not exist in developing country agricultural sector-- this "separability" is absent and thereby risk considerations influence households' production decisions (Antle (1983); Roe and Graham-Tomasi (1986)).

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Apart from crop production, one important source of income for cultivator households, particularly small and medium farmers, in many areas of developing countries is participation in the off-farm labor market (Kochar (1999); Lamb (2003)). In the semi-arid areas of India, as it is documented in the ICRISAT survey, the off-farm labor market had a two-tier structure (Walker and Ryan (1990)). On one tier were the daily "casual" laborers while on another tier were the "permanent" laborers who were hired in advance for multiple periods of time at a fixed wage rate. The major portion of off-farm labor income was earned in the form of "casual" labor, especially in the daily off-farm wage labor market. Employees had freedom to choose among different employers. Contracts were typically negotiated for a short period, usually a single day or two, and payment was made each day for an agreed number of hours.

As long as labor market and own-farm productivity are not perfectly correlated, it is possible for households to use market labor supply as one means to cope with risk in own-farm crop production (Rose (2001)). Yet the off-farm labor market is not without its own aspects of uncertainty -- employment is uncertain in this market at any point in time. To the extent that a major portion of labor demanded in this off-farm labor market is agricultural, realizations of weather conditions play a role in contributing to uncertainty in this market, by partly influencing wage rates and unemployment rates. If weather shocks turn out to be positive, cultivators will have a higher output in the harvest season, which implies that their demand for own-farm labor will be higher. Since they will need to hire any excess demand of own-farm labor in their farms over and above their own family labor supply, this translates into a higher demand for off-farm labor. To the extent that changes in the supply of labor lags behind increases in the demand for labor in the village off-farm labor market, wage rates for labor in that market will tend to increase and likewise labor unemployment rates will tend to decrease. The reverse will tend to happen in case of negative realizations of rainfall shocks.

The testable hypothesis of this paper is that uncertainty of off-farm labor income influences crop choice decisions. Assuming ex post risk-coping mechanisms (i.e., credit, borrowing or transfers) are unavailable to households and they are to choose crops from among different output risk distributions-- we hypothesize that they would rather choose crops with lower output risks in the face of their expectation of a higher employment uncertainty in the off-farm labor market. One can consider this as a form of conservative ex ante risk-management strategy given unfavorable expectations of future off-farm labor income earnings.

The literature recognizes the role of off-farm labor supply as an insurance against crop income shocks (see Rose (1993), (2001); Kanwar (1999); Kochar (1999); Lamb (2003)). Our paper is a continuation of the literature with a focus on the plausible relationship between employment uncertainty in the off-farm labor market and the ex ante crop choice decisions. Among the literature, Rose (1993) is a study of the ex ante effect of the riskiness of distribution of rainfall as well as the ex post effects of weather shocks on the labor supply decisions of cultivator households. Households facing greater dispersion in rainfall allocate less labor towards risky own-farm production and more labor to the less risky alternative activity--the off-farm labor market. Also in periods of bad weather and low rainfall households partially compensate for shortfalls in own-firm production income through work in the labor market. Kochar (1999) focuses on the responsiveness of the market hours of work of cultivator households to idiosyncratic or household-specific shocks to crop income. Household males increase their market hours of work in response to unanticipated variations in crop profits. Conditional on hours of work, crop income shocks have negative effects on consumption, confirming that household ability to protect its' consumption from crop income shocks depends, in most parts, on its' adjustments in hours of work. Kanwar (1999) is one paper that mentions employment risk in the off-farm labor market. This focuses on whether a decrease in revenue uncertainty (in crop income) will affect off-farm labor supply and finds that since production risks are carried forward into the local labor market, households might not be able to use the labor market as a hedge against production risk. Lamb (2003) develops a two period model in which a risk-averse cultivator household uses off-farm labor supply to mitigate the effects of production shocks ex post, which leads to more efficient ex ante production choices in the presence of production risk, i.e., greater use of chemical fertilizers. Controlling for exogenous weather risk, this paper positively relates fertilizer use with the "depth" of the off-farm labor market.

We develop a two period dynamic stochastic model to show that under particular conditions, risk-averse households' expectations of a lower (higher) "depth"[1] or a lower (higher) wage rate in the off-farm labor market in the next period would lead them to allocate a higher (lower) proportion of their cultivable land to crops with safer returns-- a lower (higher) share of irrigated land also leads to a higher (lower) land share being allocated to crops with safer returns. A panel data set of cultivator households from the ICRISAT survey of the semi-arid areas of India is examined. Fixed effects and random effects Tobit regressions for estimating household land share as well as fixed effects and random effects regressions of differences of household land shares and that of crop returns have been used. The results indicate statistically significant impacts of household expectation of harvest period male unemployment rates in the off-farm labor market on crop choices, taking the planting period male unemployment rates as proxy. They also indicate statistically significant impacts of household irrigated land share on crop choices and land shares.

The paper is organized as follows. The next section develops a conceptual framework. After discussing data and estimation techniques in the following two sections, Sections 3 and 4 respectively, empirical results are presented in Section 5. Some concluding remarks are presented in the final section.

2. Conceptual Framework

2.A. Model Specification

The cultivator household is assumed to be an expected utility maximizer and it maximizes expected utility of income EU(I), where I is income, with $U'(I)>0$ and $U''(I)<0$-- it is risk averse. Savings is absent and current consumption is equivalent to current income.

There is a single agricultural crop season in the year and there are two decision points in that season, t_1 and t_2, each one preceding one period, period 1 (planting) and period 2 (harvesting),

[1] The "depth" of the off-farm labor market can be measured in two different ways. The labor market can be considered "deeper" or in other words more "diversified", the higher the share of non-agricultural labor in total labor demanded in that market, since that will indicate the market has a higher number of alternative sources of labor demand instead of being fully dependent on agriculture as the only source of demand. Another interpretation of the depth of the labor market could be based on its unemployment rate-- the lower the unemployment rate in that market the "deeper" or, in other words, the more vibrant is the labor market (Lamb (2003: 263)).

respectively. The household has two sources of income-- own-farm income from crop production and off-farm labor income from the village daily casual wage labor market. This model does not allow for credit, borrowing, remittances or transfers. The household has a fixed amount of cultivable land (set to unity) and has to distribute this land between two crops-- crop 1 and crop 2. Crop 1 is characterized by low mean and low variance of returns as well as less susceptibility to realizations of rainfall shocks. Crop 2 has high mean and high variance of returns and is more susceptible to realizations of rainfall shocks. The household has a portfolio selection problem-- a larger allocation of land to crop 2 at the expense of crop 1 exposes it more towards realizations of rainfall shocks whereas a smaller allocation of land to crop 2 reduces its exposure. At time t_1, the start of the planting period, the household decides on land allocation between crops 1 and 2. This crop choice decision is measured by the term *k*-- defined as the proportion of one unit of cultivable land allocated to the safer crop 1 ($0 \leq k \leq 1$); and the rest $(1-k)$ to crop 2. In between two decision points, t_1 and t_2, the rainfall shock γ is resolved, measured as difference between the actual rainfall and the expected rainfall and it is independently and identically distributed of zero mean and unity variance. At time t_2, the start of the harvest period, the household decides on allocation of harvest period family labor to crops 1 and 2. Consumption is assumed to take place only in period 2.

Crop production functions have been specified as (following Just and Pope (1978))[2]:

Crop 1: $Q_1 = f^{(1)}(k, L_1) + h^{(1)}(k, L_1)\gamma$

Crop 2: $Q_2 = f^{(2)}(1-k, L_2) + h^{(2)}(1-k, L_2)\gamma$

$E(\gamma) = 0$; $Var(\gamma) = 1$

$h^{(1)}(k, L_1), h^{(2)}(1-k, L_2) > 0$.

Here, Q_1 is the output function of crop 1, which consists of the deterministic component, $f^{(1)}(k, L_1)$, which relates inputs to mean output of the crop and a stochastic component, $h^{(1)}(k, L_1)\gamma$, which relates inputs to the variance of output of that crop. Q_2 is the corresponding expression for crop 2. The inputs are

2 Specification here is a simple restatement of a standard multiplicative random effects specification of random crop outputs common in literature. A conventional multiplicative random effect enters into a random production function in the following form: $Q = \theta f(x)$ where Q is a random crop output and x is input while θ is a random term with mean $\bar{\theta}$. Defining $\gamma \equiv \theta - \bar{\theta}$, $h(x) \equiv f(x)$ and $y(x) \equiv \bar{\theta} f(x)$ one can obtain $Q = y(x) + \gamma h(x)$. This is the Just and Pope (1978) specification (Feder (1980: 266)).

the share of cultivable land and harvest period labor allocated to the crop in question; these inputs are assumed gross complements in production. The randomness in crop outputs is contributed by the rainfall shock γ with mean zero and variance unity. This shock affects two crops differently, captured by the term $h^{(1)}(k, L_1)$ in the case of crop 1 and $h^{(2)}(1 - k, L_2)$ in the case of crop 2.

The household knows the means and variances of the crops and their relative magnitudes-- $E(Q_1) = f^{(1)}(k, L_1)$, $E(Q_2) = f^{(2)}(-k, L_2)$, $Var(Q_1) = [h^{(1)}(k, L_1)]^2$ and $Var(Q_2) = [h^{(2)}(1 - k, L_2)]^2$. By assumption, $E[Q_1(\bar{k}, \overline{L_1})] < E[Q_2(\bar{k}, \overline{L_1})]$ and $Var\ Q_1(\bar{k}, \overline{L_1}) < Var\ Q_2(\bar{k}, \overline{L_1})$.

The deterministic components of the production functions, $f^{(1)}$ and $f^{(2)}$, follow properties of a strictly concave production function. For example, in the case of $f^{(1)}$,

$\partial f^{(1)}/\partial L_1 > 0$, $\partial f^{(1)}/\partial k > 0$

$\partial^2 f^{(1)}/\partial L_1^2 < 0$, $\partial^2 f^{(1)}/\partial k^2 < 0$

$\partial[\partial f^{(1)}/\partial L_1]/\partial k = \partial[\partial f^{(1)}/\partial k]/\partial L_1 > 0$

$[\partial^2 f^{(1)}/\partial L_1^2][\partial^2 f^{(1)}/\partial k^2] - [\partial^2 f^{(1)}/\partial k \partial L_1]^2 > 0.$

The properties of the stochastic components, on the other hand, depend on the nature of the specific input in consideration and with respect to the particular crop in question (Just and Pope (1978: 74-75); Pope and Kramer (1979: 491)). The marginal production risk from an additional unit of input L_1 for crop Q_1, defined as $\partial Var(Q_1)/\partial L_1 = 2[h^{(1)}(k,L_1)]\ [\partial h^{(1)}(k,L_1)/\partial L_1]$,can be positive, negative or zero depending on the sign of the term $[\partial h^{(1)}(k,L_1)/\partial L_1]$. One can consider the term $[\partial h^{(1)}(k,L_1)/\partial L_1]$ as contribution to the riskiness of producing crop 1 from employing an additional unit of own-farm labor L_1. The input L_1 is risk increasing (risk decreasing) if $[\partial h^{(1)}(k,L_1)/\partial L_1]$ is positive (negative); it is neither risk increasing nor risk decreasing if $[\partial h^{(1)}(k,L_1)/\partial L_1]$ is zero. Similarly input L_2 is risk increasing (risk decreasing) if $[\partial h^{(2)}(k,L_2)/\partial L_2]$ is positive (negative), and it is neither risk increasing nor risk decreasing if $[\partial h^{(2)}(k,L_2)/\partial L_2]$ is zero. Here we assume that both own-farm labor and the share of cultivable land allocated to the crop are risk-increasing inputs.[3] Therefore, in the case of $h^{(1)}$,

[3] The land input is risk increasing because raising the share of cultivable land allocated to a particular crop increases the scale of production of that crop, thereby raising variability of output from that crop. The case of labor as a risk increasing or risk

$\partial h^{(1)}/\partial L_1 > 0$, $\partial h^{(1)}/\partial k > 0$

$\partial^2 h^{(1)}/\partial L_1^2 < 0$, $\partial^2 h^{(1)}/\partial k^2 < 0$

$\partial[\partial h^{(1)}/\partial L_1]/\partial k = \partial[\partial h^{(1)}/\partial k]/\partial L_1 > 0$.

The second consideration is period 2 output price terms. These are specified as:

price of crop 1: p_1

price of crop 2: p_2.

-- p_1 is the expected period 2 price of crop 1 and p_2 is the expected period 2 price of crop 2. Prices are assumed exogenously determined, implying zero impact of local weather variations on prices, assuming crop output markets are regionally integrated. Prices are assumed "correctly" forecast.

The third consideration is the wage rate in the village off-farm labor market. Wage rate is hypothesized to be positively affected by shocks in rainfall-- high wage rates are caused by, among other factors, positive realizations of rainfall shocks whilst low wage rates are caused by, among other factors, negative realizations of the same[4]. It is possible to specify harvest period labor market wage rates as functions of realizations of rainfall shocks, such as this linear function,

$$W_K = \overline{w_k} + (1 - d_k)\gamma \qquad (0 \le d_k \le 1)$$

-- W_K and $\overline{w_k}$ are village-specific realized and expected period 2 wage rates, respectively. Here d_k is the "depth" of the village off-farm labor market that counteracts against the impact of shocks in

decreasing input, on the other hand, is not straightforward. It is possible to argue that labor is risk decreasing in the sense that a more intensive use of harvest period on-farm labor can help reduce the damage done to crop yield as a result of a negative rainfall shock. But, in the context of this particular model, harvest period on-farm labor is tied to the share of land allocation in a complementary way, i.e., a higher share of land allocation for a crop would lead to a higher amount of harvest period own-farm labor needed for that crop. Since land allocation is a risk-increasing input, labor is also considered risk increasing.

[4] There could be particular *institutional factors* involved which might prevent the wage rate from reaching exactly a market-clearing level-- once unemployment exists at the initial wage rate this may still persist at the new wage rate after the shock. Since the wage rate at the labor market may move from one disequilibrium level to another-- it is difficult to understand the impact of rainfall shocks on the unemployment rate. One possible outcome is that the unemployment rate decreases as a result of positive rainfall shocks-- this can be caused by a sharp increase in labor demand unmatched by increases in labor supply in the market. One can consider the situation where wage rates in the off-farm labor market are not at the market-clearing rates and unemployment persists in the market at the going wage rates. This is the case for the off-farm labor markets in the semi-arid tropics region of India, where unemployment rates have been found to be positive in each of the survey years and at each of the villages. The unemployment rates are affected by seasonal variations, local crop-labor use as well as gender-based segmentation in that market (Walker and Ryan (1990: 122-124)).

rainfall (Lamb (2003:363)) -- therefore $(1- d_k)$ is a measure of the impact of the rainfall shock on the realized wage rate. The mean value of the realized period 2 wage rate is $\overline{w_k}$ and variance is $(1- d_k)^2$.

The fourth consideration is of distribution of household family labor among competing demands for it. The household is assumed to have a given total labor time, T, in period 2 that it allocates among three alternative uses: on-farm family labor applied to crop 1 (L_1), on-farm family labor applied to crop 2 (L_2) and the residual time to daily wage labor in the off-farm labor market. We maintain the following assumptions regarding household labor allocation and related considerations: (a) households consider own- and off-farm labor as perfect substitutes, (b) households do not hire-in labor, (c) bullock labor used (family-owned or hired-in) to crops 1 and 2 in period 1 are proportional to family on-farm labor applied to crops, (d) the amount of fertilizer and insecticide applied to the crops is proportional to family own-farm labor applied to the crops in period 1 and (e) leisure in period 2 is a fixed proportion of the total family labor time available in period 2.

The testable hypothesis of this study is that cultivator households' expectations regarding the off-farm labor market at a later period influence its' crop choice decisions. Under the testable hypothesis, unfavorable household expectations regarding the off-farm labor market at a later period (i.e., a lower depth or a lower wage rate) would tend to cause its' *ex ante* crop choices to move towards less risky but less profitable crops. Building on the testable hypothesis, the model has two particular focus questions,

(1) $\partial k / \partial d_k < 0$?

(2) $\partial k / \partial \overline{w_k} < 0$?

In the presence of a risk-mitigating factor (i.e., share of irrigated land, denoted by a) the household can be more risk-taking in its approach to crop choices. We hypothesize that a higher share of irrigated land would tend to decrease the household land share allocated to the less risky crops. So there is one more focus question in the extended model-- (3) $\partial k / \partial a < 0$?

2.B. Maximization Problem

The households' crop income and off-farm labor income in period 2 are, Crop income ≡ $p_1Q_1 + p_2 Q_2$

$$= p_1[f^{(1)}(k, L_1) + h^{(1)}(k, L_1)\gamma] + p_2 [f^{(2)} (1 - k, L_2) + h^{(2)}(1 - k, L_2)\gamma]$$

Off-farm labor income ≡ $[\overline{w_k} + (1- d_k)\gamma] [T - L_1 - L_2]$

The household total income from crop production and off-farm labor supply is,

$$I = p_1[f^{(1)} (k, L_1) + h^{(1)}(k, L_1)\gamma] + p_2 [f^{(2)} (1 - k, L_2) + h^{(2)}(1 - k, L_2)\gamma]$$
$$+ [\overline{w_k} + (1- d_k)\gamma] [T - L_1 - L_2] \quad (1)$$

The household is assumed to use a two period dynamic programming algorithm to solve the maximization problem (Intriligator (1971)). It solves a conditional second period problem first, choosing the optimal allocation of labor between own-farm crop production and off-farm labor supply conditional on its choice of value of the land allocation term (k) in the first period and realization of rainfall uncertainty. Then it solves the first period problem, choosing the optimal value for the land allocation term conditional on the responses of labor allocation in the second period to the choice of value of the land allocation term (k) in the first period and realization of rainfall uncertainty.

2.C. The Second Period Problem

Following backward induction logic, we concentrate on the second period problem first. At the start of period 2, t_2, the rainfall uncertainty γ is resolved and value for the land allocation term k has already been determined. Since there is no uncertainty at this point, the problem now is a simple maximization problem conditional on the known realization of uncertainty and optimal decision taken in the previous period. Let γ be the realized rainfall shock, resolved on or before time t_2, and k^* be the optimal value of land allocation term chosen at time t_1.

At time t_2 the problem stands at,

$$\max_{L_1, L_2} I = p_1[f^{(1)}(k^*,L_1) + h^{(1)}(k^*,L_1)\gamma]+p_2 [f^{(2)}(1- k^*,L_2) + h^{(2)}(1 - k^*,L_2)\gamma]+[\overline{w_k} + (1- d_k)\gamma] [T - L_1 - L_2]$$

The first order conditions for the second period problem are,

With respect to L_1, $\partial I /\partial L_1 = p_1[\partial f^{(1)}(.)/\partial L_1 + [\partial h^{(1)}(.)/\partial L_1]\gamma] - [\overline{w_k} + (1- d_k)\gamma] = 0$ (2)

With respect to L_2, $\partial I / \partial L_2 = p_2 [\partial f^{(2)}(.)/\partial L_2 + [\partial h^{(2)}(.)/\partial L_2]\gamma] - [\overline{w_k} + (1 - d_k)\gamma] = 0$ (3)

Then, [value of marginal product of labor to crop 1]= [value of marginal product of labor to crop 2]= [opportunity cost of labor in the off-farm labor market].

The second order conditions for the second period problem are,

With respect to L_1, $\partial^2 I / \partial L_1^2 = p_1 [\partial^2 f^{(1)}(.)/\partial L_1^2 + [\partial^2 h^{(1)}(.)/\partial L_1^2]\gamma] < 0$ (4)

With respect to L_2, $\partial^2 I / \partial L_2^2 = p_2 [\partial^2 f^{(2)}(.)/\partial L_2^2 + [\partial^2 h^{(2)}(.)/\partial L_2^2]\gamma] < 0$ (5)

The second order cross partial derivative terms are (derived from (2) or (3)),

$\partial^2 I / \partial L_1 \partial L_2 = \partial I^2 / \partial L_2 \partial L_1 = 0$ (6)

In expression (4) the term $\partial^2 I/\partial L_1^2$ is negative, since $\partial^2 f^{(1)}(.)/\partial L_1^2$ and $\partial^2 h^{(1)}(.)/\partial L_1^2$ are negative following the previous discussions.[5] Similarly the term $\partial^2 I/\partial L_2^2$ is negative.

The other second order condition of the second period problem is also shown to be satisfied,

$[\partial^2 I / \partial L_1^2] [\partial^2 I / \partial L_2^2] - [\partial^2 I / \partial L_1 \partial L_2]^2 > 0$,

since $[\partial^2 I / \partial L_1^2] < 0$ (from (4)), $[\partial^2 I / \partial L_2^2] < 0$ (from (5)) and $[\partial^2 I / \partial L_1 \partial L_2] = 0$ (from (6)) (see Appendix 3).

2.E. The First Period Problem

At time t_1, the household chooses k to maximize expected utility of income $E_\gamma\{U(I)\}$. The household's choice of k is conditioned on the responses of the second period labor allocation L_1 and L_2 to the choice of k in the first period and realization of rainfall uncertainty. At time t_1, the households' maximization problem is given by (only choice variable is k),

$$\text{Max } E_\gamma\{U(I)\} = E_\gamma U\{ p_1[f^{(1)}(k, L_1) + h^{(1)}(k, L_1)\gamma] + p_2 [f^{(2)}(1 - k, L_2) + h^{(2)}(1 - k, L_2)\gamma] + [\overline{w_k} + (1 - d_k)\gamma] [T - L_1 - L_2] \} \quad (7)$$

The first order condition for the first period problem, with respect to k,

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[5] Expression (2.4) needs to be negative in order for the second order condition to hold, but this expression can still be negative with a negative $\partial^2 f^{(1)}(.)/\partial L_1^2$ outweighing a positive term of $[\partial^2 h^{(1)}(.)/\partial L_1^2]\gamma$. Therefore it is possible that the stochastic component of the production function can be *convex* instead of being *strictly concave* and still the second order condition for the second period problem to hold. This implies that the stochastic component can show *convexity* as well as *concavity*, but in order for the second period condition to hold, it is necessary that the negative second partial derivative of the deterministic component with respect to the inputs outweigh the second partial derivative of the stochastic component with respect to the same inputs. In other words, in order for the second order condition to hold, the input's marginal contribution to the mean productivity must decrease faster than the input's marginal contribution to the variance component of output (Feder (1980:267-268)). The same argument holds for expression (2.5).

$$E_\gamma[U'\{I\}\{\{p_1[\partial f^{(1)}(.)/\partial k + \partial h^{(1)}(.)/\partial k\,\gamma] - p_2[\partial f^{(2)}(.)/\partial(1-k) + \partial h^{(2)}(.)/\partial(1-k)\gamma]\}$$

$$+ \{p_1[\partial f^{(1)}(.)/\partial L_1 + [\partial h^{(1)}(.)/\partial L_1]\gamma] - [\overline{w_k} + (1-d_k)\gamma]\}\partial L_1/\partial k$$

$$- \{p_2[\partial f^{(2)}(.)/\partial L_2 + [\partial h^{(2)}(.)/\partial L_2]\gamma] - [\overline{w_k} + (1-d_k)\gamma]\}\partial L_2/\partial(1-k)\}] = 0 \quad (8)$$

It is to be noted that the effects from the second period responses to the first period choice, i.e., the second and third parts of equation (8), are zero from equations (2) and (3) (the envelope theorem). Thus the first order condition for the first period problem in equation (8) can be rewritten as,

$$E_\gamma[U'\{I\}\{p_1[\partial f^{(1)}(.)/\partial k + \partial h^{(1)}(.)/\partial k\,\gamma] - p_2[\partial f^{(2)}(.)/\partial(1-k) + \partial h^{(2)}(.)/\partial(1-k)\gamma]\}] = 0 \quad (9)$$

The second order condition requires that the total differential of equation (9) be negative,

$$E_\gamma[U''\{I\}\{p_1[\partial f^{(1)}(.)/\partial k + \partial h^{(1)}(.)/\partial k\,\gamma] - p_2[\partial f^{(2)}(.)/\partial(1-k) + \partial h^{(2)}(.)/\partial(1-k)\gamma]\}^2]$$

$$+ E_\gamma[U'\{I\}\{p_1[\partial^2 f^{(1)}(.)/\partial k^2 + \partial^2 f^{(1)}(.)/\partial k\partial L_1 * \partial L_1/\partial k]$$

$$+ p_1[\partial^2 h^{(1)}(.)/\partial k^2 + \partial^2 h^{(1)}(.)/\partial k\partial L_1 * \partial L_1/\partial k]\gamma$$

$$+ p_2[\partial^2 f^{(2)}(.)/\partial(1-k)^2 + \partial^2 f^{(2)}(.)/\partial(1-k)\partial L_2 * \partial L_2/\partial(1-k)]$$

$$+ p_2[\partial^2 h^{(2)}(.)/\partial(1-k)^2 + \partial^2 h^{(2)}(.)/\partial(1-k)\partial L_2 * \partial L_2/\partial(1-k)]\gamma\}] < 0 \quad (10)$$

The first term in the inequality (10) is negative since $U''\{I\}<0$ everywhere and the rest is a squared term. Therefore in order to show that the inequality holds one would need to show that the second term in that expression is negative as well.

The first term of the second expression is $[\partial^2 f^{(1)}(.)/\partial k^2 + \partial^2 f^{(1)}(.)/\partial k\partial L_1 * \partial L_1/\partial k]$. Substituting the expression for $\partial L_1/\partial k$ in equation A1 (in Appendix 3), one gets,

$$[\partial^2 f^{(1)}(.)/\partial k^2$$

$$+ \partial^2 f^{(1)}(.)/\partial k\partial L_1 * \{\partial^2 f^{(1)}(.)/\partial L_1\partial k + [\partial^2 h^{(1)}(.)/\partial L_1\partial k]\gamma\}/ - \{\partial^2 f^{(1)}(.)/\partial L_1^2 + [\partial^2 h^{(1)}(.)/\partial L_1^2]\gamma\}]$$

This expression is difficult to sign, but at the expected value of the rainfall shock $\gamma=0$ one can observe a definite sign, such as,

$$\partial^2 f^{(1)}(.)/\partial k^2 + \partial^2 f^{(1)}(.)/\partial k\partial L_1 * [\{\partial^2 f^{(1)}(.)/\partial L_1\partial k\}/ - \{\partial^2 f^{(1)}(.)/\partial L_1^2\}]$$

which is the same as $\partial^2 f^{(1)}(.)/\partial k^2 - [\partial^2 f^{(1)}(.)/\partial k\partial L_1]^2 / [\partial^2 f^{(1)}(.)/\partial L_1^2]$.

This last expression is negative from the strict concavity of the deterministic component of the production function. One can similarly show that the third term is also negative evaluated at the expected value of rainfall shock γ=0 (the second and the fourth term drop out at γ=0). Assuming the sign holds in the more general structure of the expressions, these terms are negative and since $U'\{I\}$ is positive everywhere, the second term in expression (10) is negative. Thus the second order condition in the first period problem holds.

2.F. The First Period Problem: Comparative Statics

We now analyze the impact of changes in d_k on the optimal value of k. By totally differentiating equation (9) with respect to d_k and k one gets,

$$\partial k/\partial d_k = [\partial^2 E_\gamma U'\{I\}/\partial k \partial d_k] / -[\partial^2 E_\gamma U'\{I\}/\partial k^2] \tag{11}$$

The denominator is expression (10). The numerator term is

$$[\partial^2 E_\gamma U'\{I\}/\partial k\partial d_k] = E_\gamma [U''\{I\}\{p_1[\partial f^{(1)}(.)/\partial k + \partial h^{(1)}(.)/\partial k\, \gamma] - p_2 [\partial f^{(2)}(.)/\partial(1-k) + \partial h^{(2)}(.)/\partial(1-k)\gamma]\} * \{[-\gamma][T - L_1 - L_2]\}\}].$$

The term $U''\{I\}$ is negative for a risk-averse cultivator household, also the off-farm labor supply term $[T - L_1 - L_2]$ is nonnegative and γ is negative for negative rainfall shocks. In order to determine the sign of the numerator, one needs to determine the sign of the term $\{p_1[\partial f^{(1)}(.)/\partial k + \partial h^{(1)}(.)/\partial k\, \gamma] - p_2 [\partial f^{(2)}(.)/\partial(1-k) + \partial h^{(2)}(.)/\partial(1-k)\gamma]\}$. This term is the *marginal return* for household from increasing the share of available land allocated to the low-mean and low-variance crop 1 (raising the value of k) at the expense of the share of available land allocated to high-mean and high-variance crop 2 (a lowered value of $1-k$). Under expectation of a negative realization of rainfall shock $\gamma<0$, the risk averse cultivator household will raise the value of k if it finds this term to be positive, i.e., if the *marginal benefit* of raising the value of k outweighs the *marginal cost* of raising the value of k. The *marginal cost* of raising the value of k is to reallocate to a lower mean productivity of land, expressed by the term $[p_1\partial f^{(1)}(.)/\partial k - p_2\partial f^{(2)}(.)/\partial(1-k)]$, this is negative for the cultivator household since mean productivity of land is higher for crop 2 compared to the case of crop 1, assuming the exogenous price terms do not significantly alter the comparisons of returns for the two crops. On the other hand under expectation of negative realization of rainfall shock $\gamma<0$, the *marginal benefit* of raising the value of k is to reallocate to a lower marginal risk contribution of land use, expressed by the term

$[p_1\partial h^{(1)}(.)/\partial k\gamma - p_2\partial h^{(2)}(.)/\partial(1-k)\gamma]$. Under $\gamma<0$, this term is positive for the cultivator household since marginal contribution to risk from land use is higher for crop 2 compared to the case of crop 1, assuming the exogenous price terms do not significantly alter the comparisons of risk contributions from the two crops. Therefore the term $\{p_1[\partial f^{(1)}(.)/\partial k + \partial h^{(1)}(.)/\partial k\gamma] - p_2[\partial f^{(2)}(.)/\partial(1-k) + \partial h^{(2)}(.)/\partial(1-k)\gamma]\}$ is positive under expectation of negative rainfall shock $\gamma<0$, provided the positive *marginal benefit* of raising the value of k from reduced marginal risk contribution from land use outweighs the negative *marginal cost* of raising the value of k from reduced mean productivity contribution from land use. This implies the abovementioned expression is positive under a negative rainfall shock. The denominator term is negative from the second order condition of the second period problem. Therefore,

$\partial k/\partial d_k \leq 0$, under a negative rainfall shock (focus question (1)).

We now analyze the impact of changes in $\overline{w_k}$ on the optimal value of k. By totally differentiating equation (9) with respect to $\overline{w_k}$ and k one gets,

$$\partial k/\partial \overline{w_k} = [\partial^2 E_\gamma U'\{I\}/\partial k\, \partial \overline{w_k}] / -[\partial^2 E_\gamma U'\{I\}/\partial k^2] \tag{12}$$

The denominator term is positive since $\partial^2 E_\gamma U'\{I\}/\partial k^2$ is negative from expression (10). The numerator term is

$$E_\gamma [U''\{I\}\{p_1[\partial f^{(1)}(.)/\partial k + \partial h^{(1)}(.)/\partial k\gamma] - p_2[\partial f^{(2)}(.)/\partial(1-k) + \partial h^{(2)}(.)/\partial(1-k)\gamma]\}*[T - L_1 - L_2]]$$

The first term in the numerator $U''\{I\}$ is negative everywhere. The term $\{p_1[\partial f^{(1)}(.)/\partial k + \partial h^{(1)}(.)/\partial k\gamma] - p_2[\partial f^{(2)}(.)/\partial(1-k) + \partial h^{(2)}(.)/\partial(1-k)\gamma]\}$ is positive provided the positive *marginal benefit* from raising the value of k for the cultivator household outweighs the negative *marginal cost* of raising the value of k (previous discussion in the case of $\partial k/\partial d_k$) under expectation of negative rainfall shocks, the off-farm labor supply term $[T-L_1-L_2]$ is nonnegative from specifications. The denominator term $[\partial^2 E_\gamma U'\{I\}/\partial k^2]$ is expression (10). Therefore,

$\partial k/\partial \overline{w_k} \leq 0$, under a negative rainfall shock (focus question (2)).

2.G. The Two Period Model: An Extension

The households have some instruments at their disposal to counter the adverse effects of weather uncertainty, i.e., irrigation. The household with the full amount of its cultivable land irrigated would be secured from realizations of rainfall uncertainty through its impact on own crop production-- but would still be subject to realizations of rainfall uncertainty through its impact on the village off-farm labor market. The instrument term, share of irrigated land, can be considered to be a choice variable for the household in the long run-- whereas in the short run, this can be treated as given.

The two period model can be extended to take into account this instrument. The household share of irrigated land, denoted by a (here $0 \le a \le 1$), has been introduced in a multiplicative fashion with the rainfall uncertainty term γ-- the reason is that this instrument is expected to directly reduce the immediate impact of rainfall shocks. The specifications for the "extended" model are as follows,

Crop 1: $Q_1 = f^{(1)}(k, L_1) + h^{(1)}(k, L_1)\,\gamma(1-a)$ and

Crop 2: $Q_2 = f^{(2)}(1-k, L_2) + h^{(2)}(1-k, L_2)\,\gamma(1-a)$

Wage in off-farm labor market at period 2: $W_K = \overline{w_k} + (1 - d_k)\gamma$

Following the previous discussion, in the extended model, it is possible to show that, in the case of negative rainfall shocks, $\partial k/\partial a \le 0$ (focus question (3)) (see Appendix 4).

3. Data

3.A. ICRISAT Data We use a panel data from the village longitudinal studies (VLS) survey in the semi-arid tropics areas of India from the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT). The data was collected for the complete ten-year period (1975/76-84/85) for one village in each region of the three regions selected-- these villages were Aurepalle in the Mahbubnagar region, Shirapur in the Sholapur region and Kanzara in the Akola region. These three villages were referred to as "continuous" villages and the 104 households who stayed in the panel all throughout the entire survey period from these three villages belonged to the subsection of the data called "continuous" sample. For our study, we concentrate on this “continuous” sample subsection of the data set for completeness of information (see Walker and Ryan (1990) for a discussion of the study villages).

3.B. Construction of Variables

Rainfall Shocks. From the rainfall information ten variables have been generated, in order to adequately capture “rainfall uncertainty” faced by the cultivator households, these are, monsoon onset date, monsoon end date, total monsoon rainfall, number of rainy days within monsoon, intraseasonal drought days within monsoon (period 1), intraseasonal drought days within monsoon (period 2), length of monsoon, fraction of days with rain within monsoon, average rain per day within monsoon and average rain per rainy day within monsoon. Three classes of information have been generated, namely village-specific mean and standard deviation of the variables and yearly deviation of the variables (deviation from the village mean).

Monsoon onset date was determined following its definition by Rosenzweig and Binswanger (1993:63). They propose the monsoon onset date to be specified at the point of “the date after which there has been at least 20 mm of rain within several consecutive days after 1 June.” The monsoon end date is defined at the starting point of a large discontinuity in rainfall (in terms of days with rain) after a fairly regular spell of rainfall. Total monsoon rainfall is defined as the sum of rainfall within the period of onset date to end date of monsoon. Intraseasonal drought days (period 1) is defined as the largest number of consecutive days without rain within a monsoon season, whereas intraseasonal drought days (period 2) is the second largest number of consecutive days without rain.

Consumer Price Index Information. The source of consumer price index information for the three study villages are the state-level nonfood price indices taken from the Consumer Price Index for Agricultural Labor (CPIAL) compiled by the Directorate of Economics and Statistics (1982) for each state in India (Walker and Ryan 1990: 67).

Household Characteristics. We collect information on a list of fourteen demographic variables, these are-- household size, age of household head, a dummy for households headed by women, the number and average age of household males within the age range of 15 to 45, the number and average age of household females within the age range of 15 to 45, the sum of numbers of household males and females within the age range of 15 to 45, a dummy for households with at least one member within age range of 15 to 45, the education level of household head and that of household female principal member, a dummy for households of whose heads are not illiterate, the number of remittance members for the household and also a dummy for households receiving remittance.

In calculating the household size in any year we excluded household members who were currently staying outside the village and full-time or part-time permanent servants who were currently staying in the households. The household size changed over time as members were moving in or out due to marriage, search for jobs, disintegration of joint family into smaller units or return home after a period of absence or due to birth or death of a member. The variables of number and age of male and female household members aged within the range of 15 to 45 is meant to measure households' ability to participate in the village off-farm labor market (Kochar (1999:57)). A dummy variable is therefore constructed for the households who have at least one able-bodied male or female member within that age range. Education levels of the head and female head of the household were also recorded along with a related dummy variable for the households whose heads were not illiterate. The number of members who were staying outside and sending remittances was also recorded along with a dummy variable for the households receiving remittances in that particular year. A number of caste rankings are also reported, one of them is the ranking prepared by Jere R. Behrman-- his was based on rank ordering of sample household castes, this took into account the relative frequency with which households of different castes appeared in the sample (Singh, Binswanger and Jodha (1985: 37))-- it is progressively between 0 and 99.

Household Assets. Total household assets have been calculated by summing valuation of total household non-financial assets, valuation of "farm buildings" owned by the household and valuation of household assets excluding farm buildings. These include durables and non-durables such as inventory of livestock, animal products, agricultural equipments, major farm machinery and equipments, fodder and fuel items, consumer durables and production capital.

Crop Grouping. Rainfall uncertainty is more prominent in case of the *kharif* (rainy) season crops we concentrated on dealing within information from the *kharif* season only, following Lamb (2003). We needed to classify the *kharif* season crops into two distinguishable groups, such as a "*high mean and high variance*" group and a "*low mean and low variance*" group. From this information, we divided the crops into two groups, "high" crop groups and "low" crop groups. Out of 31 crops listed, a total of 16 crops have been placed in the "high" group while the remaining 15 crops have been placed in the "low" group[6] (see Appendix 1 for a listing of crop groupings and Appendix 5 for the methods).

Demarcation Dates for Start of Planting, Start of Harvesting and End of Harvesting. The plot-level crop operations include planting period work such as field preparation, minor repairs/fencing, manuring, uses of fertilizers, sowing, transplanting or planting, weeding and thinning, interculturing, plant protection such as uses of pesticides or insecticides, irrigating crops, harvest period work such as harvesting (including transport from field to threshing floor) main product and/or byproduct, harvest processing and works that can be done in either of the periods such as nursery raising, vegetable gardening, orchard cultivation, watching, supervision/management etc. For each plot with a kharif season crop we recorded a date for starting of planting period operations, a date for starting of harvest period operations and a date for end of harvest period operations. We take average dates of the start of planting, start of harvesting and end of harvesting from plots operated by cultivator household in the sample by taking averages over the dates from all the plots. Then we take average dates of start of planting, start of harvesting and end of harvesting for a particular village in a given year by taking averages over the average dates obtained. The demarcation dates for Kharif season differed from villages to villages and years to years.

Wage Rates. We followed methods followed by Walker and Ryan (1990:127) to calculate male and female wage rates for the first periods in the study villages. For each *kharif* season we summed the total amount of crop operations within the time periods specified; we also record the hours and wages of

6 The method that has been followed here to classify the crops concentrates on rankings in terms of mean returns and standard deviation of returns. An alternative specification could have been rankings of crops in terms of their coefficient of variations of returns. The selection of rankings therefore centers on one particular question that is *which one of these two is a better measurement of "risk"-- standard deviation or coefficient of variation?* Given the crop returns data at hand we argue that the rankings in terms of coefficients of variations can provide a flawed comparison of crops in terms of "risk". For example, a particular crop with a low mean of net return and low standard deviation of net return can have the same *coefficient of variation* (ratio of standard deviation and mean) as another crop with a much higher average net return and a much higher standard deviation of net return (the ratios in both cases could be the same). A ranking of these two crops would then be the same in terms of *coefficients of variation* but the two crops actually would be much different in terms of their respective *riskiness*.

particular crop operations done by a particular sex. For each sex, we calculate the average village-level nominal wage taking a weighted average of wages for particular crop operations done by that sex. Weights corresponded to the proportions of crop operations in the total amount of work done by that sex during the specified period. For calculating real wages, we divide nominal wages by corresponding consumer price indices.

Labor Employment. Schedule K[7] records classification of labor employment by characteristics, such as farm work, off-farm non-government work, off-farm government work and own farm work etc. Farm work includes all work done for another farmer, regardless of its nature; off-farm non-government work includes all work done for private nonfarmer employers, this also regardless of the nature of work and off-farm government work includes all work for any government schemes (Singh, Binswanger and Jodha (1985:57)). The schedule also records "*involuntary unemployment*"[8] (see Appendix 6 for the definitions of labor employment categories).

Price Information. Schedule "Y" provides the harvest period prices of the crops. Relative prices were calculated from these harvest period prices, between two crops representing two different crop return groups (the "high" and the "low").

4. Estimation

4.A. Censoring in a Panel Data

The estimation of this study centers on the household shares of cultivable land allocated to the low-mean low-variance crop group (the term "*k*" in the model section). From the ICRISAT-India data set, a total of 467 observations have been collected from a total of 102 households from the three study villages-- Aurepalle, Shirapur and Kanzara -- ranging over the *kharif* seasons in a six-year period from

[7] The structure of the questionnaire in schedule K changed in 1979, while in the years 1975 to 1978 the respondents were asked how many hours they worked the previous day in different activities, from 1979 onwards they were asked how many hours they had worked since the previous interview (interviews were taken at three-to-four week intervals). Now the section of schedule K from 1979 to 1984 is usable; yet again data for village Kanzara for 1983 is missing.

[8] The respondent was asked the question: "*on how many days since the last visit (interview) did you try to find a job but failed to find one at the usual rates during this season*?" The respondent was considered involuntarily unemployed if he/she wanted to find a job but failed to find that at any wage, even in the case the respondent on failing to find an off-farm job returned to his/her own farm to work some extra hours (Singh, Binswanger and Jodha (1985: 59)).

1979 to 1984 (see Appendix 3 for summary statistics of the variables). For each particular household in a given year, the share of cultivable land is recorded if it engages in crop cultivation during the *kharif* season of that year. On average, a total of 4.58 *kharif*-years of observations have been recorded for each household, whereas the minimum is one and the maximum is six.

The observations of household share of cultivable land are *censored* by the very nature of the construction of the term. The term has been constructed in the following manner. For each household, for a particular *kharif* season in a particular year, the total amount of cultivated land has been recorded, as well as total amount of land allocated to the crops falling into the category of "high" crop group and "low" crop group (in some cases, the land is allocated to some crops which do not fall into either of these groups, this is termed the "undecided" group). For a household, the sum of shares of land allocated to the "high", "low" and "undecided" groups is unity. Each of these groups --"high", "low" and "undecided"-- is therefore doubly *censored* at the points of zero and one. Censoring in this case occurs because the variables to be explained are partly continuous but they have positive probability masses at the two extreme points-- zero and one. One can imagine censoring in this situation is due to some *corner solution outcomes*-- the household solves an optimization problem of distribution of land among groups of crops with different return characteristics-- and for some households the optimal solution is at 0 or 1.

Besides the issue of data censoring, the panel nature of the data brings in some additional complications. The problem arises from the influence of an unobserved, time-constant variable in the observations-- the *unobserved effect*. As we follow the same households for some periods, their observed decision making or performance in each period will be influenced by their *unobserved* characteristics.

One relevant discussion regards the way one can treat the *unobserved effect*-- it is possible to treat it as a *fixed effect* or a *random effect*. Wooldridge (2002:251-2) argues that, for microeconometric panel data applications, with a large number of random draws from the cross section, it is reasonable to treat the *unobserved effects* as random draws from the population. The key issue, he argues, involves whether the *unobserved effects* is whether or not it is uncorrelated with the observed explanatory variables. The question whether the random effects or the fixed effects are appropriate depiction of the *unobserved effect* in a particular panel data setting is to be solved empirically (aforementioned, pp. 252).

4.B. The Unobserved Effects Tobit Model Under Strict Exogeneity

Given the panel nature of the data set and censoring in it, an unobserved effects Tobit model under strict exogeneity is suited to describing the estimation of household land allocation shares. The estimation will concentrate on the linear approximations to the underlying household land allocation share equations as in expression (9). The econometric specification can be written as a notional demand for land allocation share of the form:

$K_{it}^* = x_{it}\beta + c_i + u_{it}, \quad t = 1,2,\ldots,T$ (13)

$K_{it} = 0 \qquad \text{if } K_{it}^* \leq 0$

$K_{it} = K_{it}^* \qquad \text{if } 0 \leq K_{it}^* \leq 1$

$K_{it} = 1 \qquad \text{if } K_{it}^* \geq 1$

$u_{it} \mid x_i, c_i \sim \text{Normal}(0, \sigma_u^2)$.

In equation (13) the term i refers to household while t refers to *kharif* crop-year. Here x_{it} is a vector of regressors and β is the coefficient to be estimated. While the *latent* land allocation share K_{it}^* may take values below 0 and above 1, one only observes a land allocation share K_{it} that takes values within the range of 0 and 1; K_{it} is 0 for values of K_{it}^* at zero and below and it is 1 for values of K_{it}^* at 1 and above. Therefore this is a case of doubly censored Tobit estimation. The term c_i is the *unobserved effect* and x_i contains x_{it} for all t. It is assumed that the idiosyncratic errors u_{it}, given the vector of regressors x_i and *unobserved effect* c_i are normally distributed. This assumption also implies that the x_{it} are *strictly exogenous* conditional on c_i. With an *unobserved effect*, this strict exogeneity assumption takes the form of, $E(y_{it} \mid x_{i1}, x_{i2}, \ldots\ldots\ldots, x_{iT}, c_i) = E(y_{it} \mid x_{it}, c_i) = x_{it}\beta + c_i$ for $t = 1,2,\ldots,T$.

-- this assumption implies that, once x_{it} and c_i are controlled for, x_{is} has no partial effect on y_{it} for $s \neq t$. In household crop cultivation context this assumption implies that once the current inputs have been controlled for along with the *unobserved effects* c_i, inputs used in other years would have no effect on output during the current year (Wooldridge (2002: 252-3)).

5. Results

5. A. Random Effects Tobit Estimation

Table 1 reports the random effects Tobit estimation results (dependent variable is household kharif-season land allocation share to low-mean and low-variance crop group) with a number of regressors including the planting period labor market wage and unemployment rates for both sexes, household share of irrigated land, a number of rainfall uncertainty terms, log of valuation of household non-financial assets, some household characteristics indicators and one previous-year harvest period crop price ratio (price ratios are in the pattern of price of one crop from the "high" crop group in the numerator and price of one crop from the "low" crop group in the denominator). Table 2 reports the coefficients (computed as marginal effects at mean value) and the partial elasticities of the regressors at their respective mean values as well as some chi-square results for joint significance tests.

The planting period unemployment rates in the off-farm labor market are used a proxy for the harvest period unemployment rates in those markets (for both sexes). We argue that, since the latter information is unavailable to the households at the start of the planting period, they would be forming their expectations regarding the harvest period unemployment rates based on the available information at hand-- the planting period unemployment rates. Therefore if it is found that the planting period unemployment rate is a good predictor of the harvest period unemployment rate, households may successfully use this information.[9] The coefficients for both male and female planting period labor market unemployment rates are statistically significant but of opposite signs-- this remains difficult to explain. One plausible explanation could be that male and female planting period unemployment rates carry different information for the household forming an expectation of the harvest period unemployment rates and also contribute differently to household crop choice decisions. One can argue that (a) since male wage rates are much higher compared to those of females for both planting and harvesting periods, (b)

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[9] Male harvesting period unemployment rate is found to be statistically significantly and positively correlated with male planting period unemployment rate (for N=17 Pearson correlation of coefficient is 0.66525 and the p-value for the null of no linear correlation is 0.0036). Female harvesting period unemployment rate is found to be statistically significantly and positively correlated with female planting period unemployment rate in the market (N= 17 coefficient is 0.76576 and p-value is 0.0003).

planting period unemployment rates and those of harvesting period are positively correlated (c) male share of off-farm work increases in the harvest period on average[10]-- the household stands to incur more losses more from a prospective harvest period male unemployment compared to a prospective harvest period female unemployment (also a high correlation exists between the two unemployment rates in the regression, the Pearson coefficient of correlation is 0.9195, N=438). In that case a higher planting period male unemployment rate would lead households to turn to conservative crop choices. Male and female planting period wage rates, taken as proxy for harvest period male and female wage rates respectively, show similar sign patterns. These four labor market regressors are jointly significant. The household share of irrigated land and rainfall uncertainty terms are statistically significant and are of expected signs. A higher share of irrigated land, one would expect, leads to lower share of land allocation to safer crops whereas a higher value for the rainfall shock terms such as standard deviation of monsoon onset date and total monsoon rainfall as well as yearly deviation of monsoon onset date lead to increased uncertainty in the production environment-- thereby a higher land allocation to safer crops is expected. On the other hand, the coefficients of the valuation of household non-financial assets, household characteristics terms and the crop price ratio term are not statistically significant. The household characteristics terms are not jointly significant.

5.B. Fixed Effects Tobit Estimation

For fixed effects Tobit regressions, particularly with a panel data where T is short but N is large such as the ICRISAT-India data set, a suitable estimator is one provided by Honore (1992). Here we have used Honore estimator to estimate a fixed effects Tobit model.

Table 2 presents the fixed effects Tobit estimates and for comparison the corresponding coefficients from the random effects Tobit model are also presented. Since a fixed effects regression does not take into account variables with small variations over the years-- a number of variables, such as standard deviation of monsoon onset date, standard deviation of total monsoon rainfall and some

[10] Over 6 years period and 17 kharif season observations from 3 villages, average male share of total off-farm work in the planting period is 0.4376 and that of female is 0.5624 and average male share of total off-farm work in the harvesting period is 0.4734 and that of female is 0.5260.

household characteristics variables were dropped as compared to the random effects Tobit estimates in Table 1. One point to note is that the fixed effects coefficients and standard errors are generally of smaller magnitudes as compared to their random effects counterparts. In most of the cases the signs of the coefficients are also same. The joint hypothesis test results also show similar patterns in both sets of estimations.

5.C. Random Effects and Fixed Effects Estimations

In this section, we consider two alternatives to a Tobit specification, as in Tables 1 and 2. The objective is to avoid full dependence on arbitrary crop groupings and censoring issue. One specification considers household crop returns as the relevant dependent variable-- this excludes any consideration of crop grouping and this also eliminates the censoring issue. The second one considers differences in household land allocation to "low" crop group and "high" crop group-- this, though still dependent on crop grouping, avoids the censoring issue. Tables 3 and 4 report the regression results from these two specifications, respectively.

The household crop income earnings from the current crop season reflect decision-making by the household at the start of the planting season-- particularly the crop choice decision. In case the household decides to grow crops with lower means and lower variances of returns in stead of crops with higher means and higher variances of returns, this is expected to reflect on the year-end household crop returns. Since this data set follows the same households over a number of years it is possible to control for household unobserved effects and obtain some valuable information from the season-end crop returns data. The factors that lead households to choose a higher share of its land for less risky crops are expected to lead them to obtain lower amount of season-end crop returns. The second alternative approach is to consider the difference in household land allocation between the groups-- in this case, the difference between the total amounts of land allocated to the "low" crop group and the "high" crop group.

In Table 3, regression coefficients have been reported from cross-sections and time-series random effects and fixed effects estimations for comparison. Male planting period labor unemployment has the expected negative signs for both random effects and fixed effects estimations and are statistically significant at least at the 10% level. Higher male and female planting period real wage rates are expected to assure the household of a vibrant off-farm labor market at the harvest period-- thereby reducing its incentive to allocate land to less riskier crops-- this is expected to lead to a higher season-end household crop returns. Similar to the cases of random effects Tobit estimation, the two real wages show different signs with the female ones showing expected positive signs. Similar to other estimations, the share of irrigated land share shows the expected (positive) and statistically significant signs. In the fixed effects estimation, a number of rainfall uncertainty terms and household characteristics terms are dropped from the equation because of lack of variations within the group. Household valuation of assets shows the expected (positive) and is significant in case of the random effects estimation. In the case of random effects estimation the correlation between the unobserved effect and the regressors is assumed to be zero while it case of fixed effects estimation this correlation is allowed to take any arbitrary value (in this regression it is –0.789).

The Breusch-Pagan test is the Lagrange multiplier test which tests for random effects. The null hypothesis of this test is that the variance of the *unobserved effect* is zero-- which by default is a fixed effects specification. The random effects specification is appropriate in case the null hypothesis is rejected; this is the case in this regression with a chi-square test statistic of 284.16 (p-value=0.00). Therefore the Breusch-Pagan test in this regression suggests the use of a random effects specification (Table 3).

A Hausman test contrasts the appropriateness of random effects versus fixed effects estimation. The test in this regression is ordered in a way that a fixed effects specification is considered to be *consistent* under both null and alternative hypotheses while a random effects estimation is considered to be *inconsistent* under the alternative but *efficient* under the null. The Hausman test statistic is based on the difference in coefficients from the two regressions-- the null hypothesis is that this difference in coefficients is not systematic. The chi-square value for the Hausman test in this regression is 27.73 with a p-value of 0.036. This implies that a fixed effects estimation would be appropriate one with a significance level of 0.036 and higher (Table 3).

We find similar results for Table 4. The Breusch-Pagan test result in Table 4 again supports use of random effects estimation as the chi-square value is 126.12 (p-value=0.00) while the Hausman test this time supports the use of random effects estimation since we fail to reject the null hypothesis (with chi-square value of 12.07 and p-value of 0.359) (Wooldridge (2002:288)). Overall, evidence is there for support of use of random effects specification for this particular data.

6. Concluding Remarks

A two period stochastic dynamic programming model is developed here. It has been shown that under some conditions, particularly under expectation of a negative rainfall shock, risk-averse farmers' expectations of a lower depth of the market or a lower wage rate in that market at the next period would lead them to allocate more of their land to safe crops as a particular form of *risk-management strategy*. In the extension to the basic model the farmers are also shown to be encouraged to take risky crop choice decisions in the presence of some risk-mitigating factors in their production environment, such as a higher share of irrigated land.

The estimation results on data from the ICRISAT survey in India support the link between household crop choice decisions and labor market unemployment and wage terms as modeled in the theoretical model section. The results indicate a significant impact of household expectation of the harvesting period male unemployment rate on crop choices, taking planting period male unemployment rate as a proxy. The results indicate the strong influence of irrigation on crop choices, also modeled here.

The panel data set used for estimation is a short one and it suffered from the problem of missing information and partly unusable information as well as attrition. A more accurate and updated data set for investigating the issues raised in this paper remains an objective for future research. It remains to be investigated whether the basic ideas behind this paper will extend to other places where some other form of off-farm income source plays the role of *insurance* for crop income shocks-- such as remittance earnings or transfer payments.

Random Effects Tobit Estimation[1] *Dependent Variable: Household Land Share to "Low" Crop Group*		
Independent Variable(s)	Coefficient /Marginal Effect at Mean Value dy/dx (*Standard Error*)	*Elasticity at Mean Value d(lny)/d(lnx)* (*Standard Error*)
Labor Market Wage and Unemployment:		
Male Planting Period Labor Unemployment	3.902*** (*0.818*)	1.468*** (*0.326*)
Female Planting Period Labor Unemployment	– 3.009*** (*0.562*)	– 1.281***(*0.256*)
Male Planting Period Real Wage Rate	0.517** (*0.248*)	0.8** (*0.39*)
Female Planting Period Real Wage Rate	– 1.811*** (*0.341*)	– 1.75*** (*0.355*)
Irrigation:		
Share of Irrigated Land	– 1.415*** (*0.149*)	– 0.303*** (*0.04*)
Rainfall Uncertainty:		
Standard Deviation: Monsoon Onset Date	0.09*** (*0.012*)	2.07*** (*0.33*)
Standard Deviation: Total Monsoon Rainfall	0.02*** (*0.002*)	6.79*** (*0.955*)
(Village) Yearly Deviation: Monsoon Onset Date	0.005*** (*0.002*)	0.01***(*0.003*)
Household Assets:		
Log of Value of Household Non-financial Assets[2]	– 0.108 (*0.112*)	– 0.842 (*0.873*)
Household Characteristics:		
Number of Household Males Within Age of 15-45	0.03 (*0.037*)	0.105 (*0.129*)
Number of Household Females Within Age of 15-45	– 0.015 (*0.036*)	– 0.055 (*0.133*)
Number of Remittance Members Per Household	0.053 (*0.039*)	0.039 (*0.029*)
Age of Household Head	0.033 (*0.021*)	3.405 (*2.118*)
Age of Household Head Squared	– 0.0003* (*0.0001*)	– 1.904*(*1.033*)
Education Level of Household Head	0.067 (*0.043*)	0.255 (*0.167*)
Caste Index: Behrman	– 0.002 (*0.002*)	– 0.202 (*0.201*)
Crop Price Ratio[3]:		
Jower/Sorghum (HYV)-Jower/Sorghum (Local)	– 0.314 (*0.198*)	– 0.547 (*0.348*)
Joint Hypothesis Tests: Chi-square test for joint significance of unemployment rates: chi-sq= 28.62 and pr>chi-sq= 0.000 Chi-square test for joint significance of wage rates: chi-sq= 35.60 and pr>chi-sq= 0.000 Chi-square test for joint significance of unemployment and wage rates: chi-sq= 64.75 and pr>chi-sq= 0.000 Chi-square test for joint significance of rainfall uncertainty terms: chi-sq= 134.11 and pr>chi-sq= 0.000 Chi-square test for joint significance of household characteristics: chi-sq= 10.48 and pr>chi-sq= 0.163		
N=428 Number of Households= 98 Log Likelihood= –259.228 Wald chi-sq = 244.04 Pr> chi-sq= 0.0000 Observations: Uncensored= 208 Left-censored= 106 Right-censored= 114		

Note: [1] ***significant at 1% level, **significant at 5% level and *significant at 10% level.
[2] at 1983 constant prices. [3] prices at the harvest period, one year earlier.

Table 1. Random Effects Tobit Estimation: Household Land Share to "Low" Crop Group

Fixed Effects Tobit Estimation *Dependent Variable: Household Land Share to "Low" Crop Group*		
Independent Variable(s)	Fixed Effects Tobit Coefficient *(Standard Error)*	Random Effects Tobit Coefficient *(Standard Error)*
Labor Market Wage and Unemployment:		
Male Planting Period Labor Unemployment	2.388*** (*0.513*)	3.128*** (*0.819*)
Female Planting Period Labor Unemployment	– 1.682 *** (*0.369*)	– 2.538 *** (*0.564*)
Male Planting Period Real Wage Rate	0.266 (*0.194*)	– 0.098 (*0.206*)
Female Planting Period Real Wage Rate	– 1.181*** (*0.218*)	– 1.609*** (*0.298*)
Irrigation:		
Share of Irrigated Land	– 0.924 *** (*0.073*)	– 1.325*** (*0.129*)
Rainfall Uncertainty:		
(Village) Yearly Deviation: Monsoon Onset Date	0.003* (*0.002*)	0.005*** (*0.002*)
Household Assets:		
Log of Value of Household Non-financial Assets	0.034 (*0.101*)	0.074 (*0.122*)
Household Characteristics:		
Age of Household Head	0.065* (*0.036*)	0.087*** (*0.02*)
Age of Household Head Squared	– 0.0007** (*0.0003*)	– 0.0007*** *(0.0002)*
Crop Price Ratio:		
Jower/Sorghum (HYV)- Jower/Sorghum (Local)	– 0.147 (*0.136*)	0.022 (*0.196*)
N Number of Observations	428	428
Joint Hypothesis Tests: Chi-square test for joint significance: (*Fixed Effects*) chi-sq= 359.9 p-value= 0.000 Chi-square test for joint significance of unemployment rates: (*Fixed Effects*) chi-sq= 22.6 p-value= 0.000; *(Random Effects)* chi-sq= 20.82 p-value= 0.000 Chi-square test for joint significance of wage rates: (*Fixed Effects*) chi-sq= 31.2 p-value= 0.000; *(Random Effects)* chi-sq= 43.9 p-value= 0.000 Chi-square test for joint significance of unemployment and wage rates: (*Fixed Effects*) chi-sq= 55.3 p-value= 0.000; *(Random Effects)* chi-sq= 66.87 p-value= 0.000 Chi-square test for significance of share of irrigated land: (*Fixed Effects*) chi-sq= 320.9 p-value= 0.000; *(Random Effects)* chi-sq= 105.29 p-value= 0.000 Chi-square test for joint significance of household characteristics: (*Fixed Effects*) chi-sq= 5.4 p-value= 0.02; *(Random Effects)* chi-sq= 21.31 p-value= 0.000		

Table 2. Fixed Effects Tobit Estimation: Household Land Share to "Low" Crop Group

Random Effects & Fixed Effects Estimation *Dependent Variable: Household Income Earnings from Crop Cultivation*		
Independent Variable(s)	Coefficients (*Standard Errors*)	
	Random Effects	Fixed Effects
Labor Market Wage and Unemployment:		
Male Planting Period Labor Unemployment	– 8307.276** (*3888.8*)	– 7418.05* (*3849.573*)
Female Planting Period Labor Unemployment	2213.719 (*2643.635*)	1573.305 (*2603.662*)
Male Planting Period Real Wage Rate	– 4951.241***(*1171.184*)	– 6446.996***(*1317.803*)
Female Planting Period Real Wage Rate	6045.181*** (*1599.471*)	3032.14*** (*1966.75*)
Irrigation:		
Share of Irrigated Land	1373.522*** (*644.948*)	1667** (*670.892*)
Rainfall Uncertainty:		
Standard Deviation: *Monsoon Onset Date*	– 275.221*** (*86.522*)	-
Standard Deviation: *Total Monsoon Rainfall*	– 57.358*** (*15.77*)	-
Yearly Deviation: *Monsoon Onset Date*	15.545* (*8.991*)	27.782*** (*10.103*)
Household Assets:		
Log of Value of Household Non-financial Assets	2358.126*** (647.28)	755.591(*797.241*)
Household Characteristics:		
Number of Household Males, Age 15- 45	– 212.602 (*298.729*)	-
Number of Household Females, Age 15-45	– 62.372 (*262.492*)	857.746 (*548.821*)
Number of Remittance Members Per Household	1206.074*** (*329.073*)	-
Age of Household Head	433.361** (*149.527*)	287.556 (*282.243*)
Age of Household Head Squared	– 3.446* (*1.363*)	1.575 (*2.666*)
Education Level of Household Head	775.291** (*298.856*)	-
Caste Index: Behrman	12.437 (*13.773*)	-
Crop Price Ratio:		
Jower/Sorghum (HYV)-Jower/Sorghum (Local)	724.007*(946.617)*	799.012 (*928.418*)
N Number of Observations	428	428
R-Squares		
Within	0.147	0.185
Between	0.577	0.001
Overall	0.552	0.006
Correlation (u_i, *Xb*) Unobserved Effect and Regressors	0 (Assumed)	– 0.789
Model Significance	Wald chi-sq= 186.78 Pr>chi-sq= 0.000	F-statistic= 6.59 Pr>F= 0.000
Rho Fraction of Variance Due to Unobserved Effects	0.653	0.935
F test Null Hypothesis: All Unobserved Effects= 0		F(97,319)=8.87 Pr>F=0.000
Breusch-Pagan test Lagrange Multiplier Test for Random Effects Null Hypothesis: Var(u)= 0	chi-sq= 284.16 Pr>chi-sq= 0.0000	
Hausman test Null Hypothesis: Difference in Coefficients Not Systematic	chi-sq= 27.73 Pr>chi-sq= 0.036	

Table 3. Random and Fixed Effects Estimation: Income Earnings from Crop Cultivation.

Random Effects & Fixed Effects Estimation *Dependent Variable: Household Land Allocation Difference* *Between "Low" Crop Group and "High" Crop Group*		
Independent Variable(s)	Coefficients (*Standard Errors*)	
	Random Effects	Fixed Effects
Labor Market Wage and Unemployment:		
Male Planting Period Labor Unemployment	45.676*** (*8.611*)	46.682***(*8.726*)
Female Planting Period Labor Unemployment	–29.545*** (*5.866*)	–29.866*** (*5.902*)
Male Planting Period Real Wage Rate	4.314*(*2.537*)	6.377**(*2.987*)
Female Planting Period Real Wage Rate	–17.916*** (*3.488*)	–16.918***(*4.458*)
Irrigation:		
Share of Irrigated Land	– 6.094*** (*1.337*)	– 7.184***(*1.521*)
Rainfall Uncertainty:		
Standard Deviation: *Monsoon Onset Date*	0.76*** (*0.131*)	-
Standard Deviation: *Total Monsoon Rainfall*	0.191*** (*0.024*)	-
Yearly Deviation: *Monsoon Onset Date*	0.048**(*0.02*)	0.043* (*0.023*)
Household Assets:		
Log of Value of Household Non-financial Assets	– 4.104*** (*1.171*)	–1.751 (*1.807*)
Household Characteristics:		
Number of Household Males, Age 15- 45	0.04 (*0.424*)	-
Number of Household Females, Age 15-45	0.746* (*0.388*)	1.575 (*1.244*)
Number of Remittance Members Per Household	–2.736*** (*0.461*)	-
Age of Household Head	–0.627*** (*0.233*)	0.196 (*0.64*)
Age of Household Head Squared	0.005** (*0.002*)	-0.006 (*0.006*)
Education Level of Household Head	-0.818* (*0.452*)	-
Caste Index: Behrman	0.034* (*0.02*)	-
Crop Price Ratio:		
Jower/Sorghum (HYV)-Jower/Sorghum (Local)	–2.235 (*2.108*)	–2.312 (*2.105*)
N Number of Observations	428	428
R-Squares		
Within	0.284	0.3
Between	0.713	0.003
Overall	0.618	0.0001
Correlation (u_i, Xb) Unobserved Effect and Regressors	0 (Assumed)	–0.615
Model Significance	Wald chi-sq= 366.93 Pr>chi-sq= 0.000	F-statistic= 12.45 Pr>F= 0.000
Rho Fraction of Variance Due to Unobserved Effects	0.372	0.832
F test Null Hypothesis: All Unobserved Effects= 0		F(97,319)= 3.72 Pr>F= 0.000
Breusch-Pagan test Lagrange Multiplier Test for Random Effects Null Hypothesis: Var(u)= 0	chi-sq= 126.12 Pr>chi-sq= 0.000	
Hausman test Null Hypothesis: Difference in Coefficients Not Systematic	chi-sq= 12.07 Pr>chi-sq= 0.359	

Table 4. Random and Fixed Effects Estimation: Household Land Allocation Differences.

Appendix

Appendix 1. Crop Grouping

Classification of Crops In terms of Return and Riskiness	Name of Crops	Total Number of Crops
High	Groundnuts Castor (HYV) Bajra/Pearl Millet (HYV) Jowar/Sorghum (HYV) Maize (Local) Paddy (Local) Paddy (HYV) Wheat (HYV) Cotton (Local) Cotton (HYV) Lemon Sugarcane Onion Chillies Other Vegetables Green Fodder Crops	16
Low	Sesamum Castor Sunflower Safflower Bajra/Pearl Millet (Local) Jowar/Sorghum (Local) Wheat (Local) Other Cereals Other Fruits Redgram (Tur)/Pigoen pea Greengram (Mung) Blackgram (Urad) Bengalgram (Chenna)/Chick pea Other Pulses Other Spices (Salt, Tamarind etc.)	15
Total		31

Appendix 2. Summary Statistics of the Variables Used in Estimations

Variable(s)	N	Mean	Standard Deviation	Min.	Max.
Household land share to "low" crop group	467	0.461	0.408	0	1
Household income earnings from crop cultivation	467	2894.936	5456.586	– 4728.11	39026.24
Household land allocation difference ("low" group minus "high" group)	467	– 2.127	9.293	– 48.6	23.2
Male planting period labor unemployment rate (village-specific)	438	0.192	0.087	0.037	0.361
Female planting period labor unemployment rate (village-specific)	438	0.217	0.118	0.049	0.516
Male planting period real wage rate (village-specific) (Rs/hr)	467	0.794	0.177	0.521	1.177
Female planting period real wage rate (village-specific) (Rs/hr)	467	0.493	0.117	0.341	0.766

Household share of irrigated land	467	0.105	0.234	0	1
Standard deviation of monsoon onset date (village-specific)	467	11.395	4.095	7.324	16.51
Standard deviation of total monsoon rainfall (village-specific)	467	174.878	20.449	155.574	208.262
(Village) Yearly deviation of monsoon onset date (village-specific)	476	1.205	13.881	– 16.818	44.182
Log of value of household non-financial assets	464	3.955	0.397	2.948	5.263
Number of household males within the age of 15 to 45	466	1.768	1.080	0	5
Number of household females within the age of 15 to 45	466	1.891	1.122	0	5
Number of remittance-earning members per household	466	0.386	1.136	0	7
Age of household head	466	51.425	11.964	27	90
Age of household head squared	466	2787.352	1326.939	729	8100
Education level of household head	466	1.961	1.251	1	5
Caste Index: Behrman	460	54.543	26.193	5	97.5
Jower/sorghum (HYV)-Jower/sorghum (local), previous harvest price ratio	467	0.877	0.125	0.591	1.186

Appendix 3. The Second Period Problem: Comparative Statics

Totally differentiating equation (2) with respect to L_1 and k one obtains,

$\partial L_1/\partial k = \{\partial^2 f^{(1)}(.)/\partial L_1\partial k + [\partial^2 h^{(1)}(.)/\partial L_1\partial k]\,\gamma\}/\,[\,-\{\partial^2 f^{(1)}(.)/\partial L_1^2 + [\partial^2 h^{(1)}(.)/\partial L_1^2]\,\gamma\}]$ (A1)

Similarly, totally differentiating equation (3) with respect to L_2 and $(1 - k)$ one obtains,

$\partial L_2/\partial(1-k) = \{\partial^2 f^{(2)}(.)/\partial L_2\partial(1-k) + [\partial^2 h^{(2)}(.)/\partial L_2\partial(1-k)]\gamma\}/\,[\,-\{\partial^2 f^{(2)}(.)/\partial L_2^2 + [\partial^2 h^{(2)}(.)/\partial L_2^2]\gamma\}]$ (A2)

The terms in the numerator in equation (7), $\partial^2 f^{(1)}(.)/\partial L_1\partial k$ and $\partial^2 h^{(1)}(.)/\partial L_1\partial k$, are positive by their specifications. In order for the numerator term to be always positive, the positive first term $\partial^2 f^{(1)}(.)/\partial L_1\partial k$ must always outweigh the second term $[\partial^2 h^{(1)}(.)/\partial L_1\partial k]\gamma$, even in the case of the later term being negative under negative rainfall shocks $\gamma<0$. This requirement is similar to the requirement in the case of the second order condition of the second period problem The term inside the bracket in the denominator is negative following the second order condition of the second period problem. Therefore the sign of the term the term $\partial L_1/\partial k$ (similarly $\partial L_2/\partial(1-k)$) is positive. Since off-farm labor supply is a residual of a given total family labor time over and above labor applications to crops 1 and 2, and since an increase in k will increase the on-farm labor allocated to crop 1 but that will also reduce $(1- k)$ which will act to reduce the on-farm labor allocated to crop 2, the sign of ∂(off-farm labor supply)/∂k can not be ascertained *a priori*.

Appendix 4. Extension of the Model

The first order conditions for the second period problem of the extended model are as follows,

With respect to L_1, $\partial I/\partial L_1 = p_1[\partial f^{(1)}(.)/\partial L_1 + [\partial h^{(1)}(.)/\partial L_1]\,\gamma(1-a)] - [\,\overline{w_k} + (1-d_k)\gamma] = 0$ (A3)

With respect to L_2, $\partial I/\partial L_2 = p_2[\partial f^{(2)}(.)/\partial L_2 + [\partial h^{(2)}(.)/\partial L_2]\,\gamma(1-a)] - [\,\overline{w_k} + (1-d_k)\gamma] = 0$ (A4)

The second order conditions for the second period problem of the extended model are as follows,

With respect to L_1, $\partial^2 I/\partial L_1^2 = p_1[\partial^2 f^{(1)}(.)/\partial L_1^2 + [\partial^2 h^{(1)}(.)/\partial L_1^2]\,\gamma(1-a)] <0$ (A5)

With respect to L_2, $\partial^2 I/\partial L_2^2 = p_2[\partial^2 f^{(2)}(.)/\partial L_2^2 + [\partial^2 h^{(2)}(.)/\partial L_2^2]\,\gamma(1-a)] <0$ (A6)

The second order cross partial derivative terms are (derived from (A5) or (A6)),

$\partial^2 I/\partial L_1\partial L_2 = \partial I^2/\partial L_2\partial L_1 = 0$ (A7)

The other second order condition of the second period problem is also satisfied,

$[\partial^2 I/\partial L_1^2]\,[\partial^2 I/\partial L_2^2] - [\partial^2 I/\partial L_1\partial L_2]^2 > 0$,

since $[\partial^2 I/\partial L_1^2] <0$ (from (A5)), $[\partial^2 I/\partial L_2^2] <0$ (from (A6)) and $[\partial^2 I/\partial L_1\partial L_2] = 0$ (from (A7)).

One special case of the first order conditions is to be mentioned here. That is the marginal products of second period labor allocation to crops 1 and 2, at a=1 and d_k =1, are,

$\partial f^{(1)}(.)/\partial L_1 = p_1^{-1}\overline{w_k}$ and $\partial f^{(2)}(.)/\partial L_2 = p_2^{-1}\overline{w_k}$.

--rainfall uncertainty does not affect optimal choices of labor if the village off-farm labor market is fully diversified (d_k = 1) and share of irrigated land for the cultivator household is unity (a=1).

The first order condition for the first period problem of the extended model is as follows.

With respect to *k*,

$$E_\gamma [U'\{I\}\{p_1[\partial f^{(1)}(.)/\partial k + \partial h^{(1)}(.)/\partial k\gamma(1-a)] - p_2[\partial f^{(2)}(.)/\partial(1-k) + \partial h^{(2)}(.)/\partial(1-k)\gamma(1-a)]\}] = 0. \quad (A8)$$

Here $I = p_1[f^{(1)}(k, L_1) + h^{(1)}(k, L_1)\gamma(1-a)] + p_2[f^{(2)}(1-k, L_2) + h^{(2)}(1-k, L_2)\gamma(1-a)] + [\overline{w_k} + (1-d_k)\gamma][T - L_1 - L_2]$.

The second order condition for the first period problem of the extended model requires that the total differential of equation (A8) be negative,

$$\begin{aligned} &E_\gamma [U''\{I\} \\ &*\{p_1[\partial f^{(1)}(.)/\partial k + \partial h^{(1)}(.)/\partial k\,\gamma(1-a)] - p_2[\partial f^{(2)}(.)/\partial(1-k) + \partial h^{(2)}(.)/\partial(1-k)\gamma(1-a)]\}^2] \\ &+ E_\gamma [U'\{I\}\{ p_1[\partial^2 f^{(1)}(.)/\partial k^2 + \partial^2 f^{(1)}(.)/\partial k\partial L_1 * \partial L_1/\partial k] \\ &\quad + p_1[\partial^2 h^{(1)}(.)/\partial k^2 + \partial^2 h^{(1)}(.)/\partial k\partial L_1 * \partial L_1/\partial k]\gamma(1-a) \\ &\quad + p_2[\partial^2 f^{(2)}(.)/\partial(1-k)^2 + \partial^2 f^{(2)}(.)/\partial(1-k)\partial L_2 * \partial L_2/\partial(1-k)] \\ &\quad + p_2[\partial^2 h^{(2)}(.)/\partial(1-k)^2 + \partial^2 h^{(2)}(.)/\partial(1-k)\partial L_2 * \partial L_2/\partial(1-k)]\gamma(1-a)\}] < 0 \end{aligned} \quad (A9)$$

In this extended model we are particularly interested in one comparative static result. That is $\partial k/\partial a$, the effect of changes in household share of irrigated land on the land allocation term *k* taken by the cultivator household. One would expect a reduced urgency on behalf of the household to resort to costly *ex ante* risk-management strategies in the form of crop choice decisions if some risk-mitigating mechanisms are already in place. By totally differentiating equation (A8) with respect to *k* and a,

$$\partial k/\partial a = [\partial^2 E_\gamma U'\{I\}/\partial k\partial a] / -[\partial^2 E_\gamma U'\{I\}/\partial k^2] \quad (A10)$$

The denominator term is expression (A9). The numerator term in equation (A10) can be expressed as,

$$\begin{aligned} &[\partial^2 E_\gamma U'\{I\}/\partial k\partial a] = E_\gamma [U''\{I\}* \\ &\{p_1[\partial f^{(1)}(.)/\partial k + \partial h^{(1)}(.)/\partial k\gamma(1-a)] - p_2[\partial f^{(2)}(.)/\partial(1-k) + \partial h^{(2)}(.)/\partial(1-k)\gamma(1-a)]\} \\ &\quad *\{(-1)\, p_1 h^{(1)}(k, L_1)\gamma + (-1)p_2 h^{(2)}(1-k, L_2)\gamma\}] \\ &- E_\gamma [U'\{I\}*\{ p_1[\partial h^{(1)}(.)/\partial k]\gamma - p_2[\partial h^{(2)}(.)/\partial(1-k)]\gamma \}]. \end{aligned}$$

The term $U''\{I\}$ is negative everywhere, the term $\{(-1)p_1 h^{(1)}(k, L_1)\gamma + (-1)p_2 h^{(2)}(1-k, L_2)\gamma\}$ is positive under negative rainfall shocks $\gamma<0$, and the middle term can be shown to be positive following the discussion of the term $\partial k/\partial d_k$. Therefore the first term in the expression is negative. In the second term, $\{p_1[\partial h^{(1)}(.)/\partial k]\gamma - p_2[\partial h^{(2)}(.)/\partial(1-k)]\gamma\}$ can be shown to be positive under negative rainfall shocks following the discussion in the aforementioned case. Since $U'\{I\}$ is positive, the second term is therefore negative under negative rainfall shocks. This implies the numerator term $[\partial^2 E_\gamma U'\{I\}/\partial k\partial a]$ is negative. The denominator expression $[\partial^2 E_\gamma U'\{I\}/\partial k^2]$ is negative from the discussion of the second order condition of the first period problem of the extended model. Therefore,

$\partial k/\partial a \leq 0$, under a negative rainfall shock (focus question (3)).

Appendix 5. Crop Grouping

We concentrated on two pieces of information that are reported, for all the crops from 1975 to 1984-- these are "(crop) net income" and "(crop) net return"[11].

First, we converted the "net income" and "net return" from crop return figures per plot for crops planted in the *kharif* season into 1983 constant prices. Second, we converted into "net income per acre" and "net return per acre" terms. Third, for one particular crop, one particular village, one particular year,

Net income= ∑(plot area)(net income per acre from the plot)/ ∑ (plot area).

Fourth, for one particular crop, one particular year,

[11] "Net income" from a plot of land in a season is calculated as total output value (the sum of main product value and byproduct value) minus total input value (the sum of values of seed, fertilizer, sheep penning, manure, tank, pesticides, family labor, hired labor, own bullock labor and hired bullock labor). On the other hand "net return" from a plot of land in a season is calculated in the same way except that it does not include values for family labor and own bullock labor. While "net return" are more suited for discussions since they do not involve evaluation of family labor and bullock labor participation costs calculated by the ICRISAT researchers-- "net income" can provide an indication of the true costs associated with crop production activities.

Net income= ∑(plot area from one village)(weighted average in step 3 from that village)/
∑ (plot area from one village).

Fifth and final, for one particular crop,

Net income= ∑ (plot area from one year)(weighted average in D from that year)/
∑ (plot area from one year).

For measuring standard deviations of net income and those of net return for each of the crops, we followed the following steps. First, we convert the "net income" and "net return" per plot for crops into 1983 constant prices. Second, we converted into "net income per acre" and "net return per acre" terms.

Third, for one particular crop, one particular village, one particular year,

Standard deviation of net income=

squared root of "∑ (net income per acre − weighted average of net income)^2 / (N −1)"

-- where N is the number of observations.

Fourth, for one particular crop, one particular year,

Standard deviation of net income=

∑(plot area from one village)(weighted average of standard deviation of net income as in step 3 from that village)/ ∑ (plot area from one village).

Fifth and final, for one particular crop,

Standard deviation of net income=

∑ (plot area from one particular year)(weighted average of standard deviation of net income as in step 4 from that year)/ ∑ (plot area from one particular year).

The abovementioned formula has been applied to calculate crop returns for a total of 31 crops that were listed as first crops in the plots planted in the study villages during 1975 to 1984. The crops that were planted in only one plot in a particular village in a particular year have been excluded because of small numbers of observations. The returns are measured in four categories such as weighted average of net income, weighted average of net return, weighted average of standard deviation of net income and weighted average of standard deviation of net return. The measurements show statistically significant positive correlations between each other. These positive and statistically significant correlation coefficients between mean and standard deviation measurements imply that it is possible to classify the crops in the study villages in categories such as crops with "*high means and high variances*" and crops with "*low means and low variances*."

We ranked *kharif* season crops planted in the study villages in terms of the abovementioned return measurements in descending orders. The crops for which all four of their return measurements showed rankings above or equal to 15 or 16 (upper half of the list) were placed in the "high" crop group category and the crops for which all four of their return measurements showed rankings below or equal to 15 or 16 (lower half of the list) were placed in the "Low" crop group category.

Appendix 6. Labor Employment Categories

We constructed two village-level variables as indicators of ongoing conditions in the village off-farm labor market in the *kharif* season planting period. These are as follows.

(1) The Involuntary Off-farm Unemployment Rate. This is calculated as following:

Village-level off-farm unemployment rate=

[total involuntary unemployment days]/[total demand for off-farm employment days].

The total demand for off-farm employment days is calculated as:

[total demand for off-farm employment days]=

[total involuntary unemployment days] + [total (off-) farm work days] +

[total off-farm non-government work days] + [total off-farm government work]

--summed across all the sample households in that particular study village.

(2) The Share of Non-agricultural Work in Total Off-farm Work, calculated as:

Village-level share of non-agricultural work (in total off-farm work)=

[total off-farm work (non-agricultural sources)]/ [total off-farm work (all sources)].

The total off-farm work (from non-agricultural sources) is calculated as:

[total off-farm work (non-agricultural sources)]=

[total off-farm non-government work days] + [total off-farm government work].

The total off-farm work (from all sources) is calculated as:

[total off-farm work (all sources)]= [total (off-) farm work days] +

[total off-farm non-government work days] + [total off-farm government work].

-- summed across all the sample households in that particular study village.

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