Bulletin Number 89-4

June, 1989

ECONOMIC DEVELOPMENT CENTER

WEALTH, WEATHER RISK AND THE COMPOSITION AND PROFITABILITY: OF AGRICULTURAL INVESTMENTS

Mark R. Rosenzweig

Hans P. Binswanger

ECONOMIC DEVELOPMENT CENTER

Department of Economics, Minneapolis

Department of Agricultural and Applied Economics, St. Paul

UNIVERSITY OF MINNESOTA

Wealth, Weather Risk and the Composition and Profitability of Agricultural Investments

Mark R. Rosenzweig

University of Minnesota

Hans P. Binswanger

The World Bank

June 1989

A major issue in the literature concerned with economic development has been the relationship between average productivity and the distribution of wealth, in particular the distribution of land. Attention has primarily been focused on how features of rural labor markets in low-income settings, inclusive of market segmentation and nutrition-wage interactions, entail efficiency gains from an equalizing redistribution of land (e.g., Mazumdar, 1977; Dasgutpa and Ray, 1984). These concerns have in part spawned a large number of empirical tests of technical scale economies (e.g., Bardhan, 1973), farm household "separability" (Lopez, 1986; Pitt and Rosenzweig, 1986; Benjamin, 1988), and health-wage associations (Behrman and Deolalikar, 1987).

Studies related to the distribution-efficiency issue in the context of low-income rural areas have tended to ignore risk considerations, although the advantages of large landowners in obtaining credit has been recognized (Sen, 1966). Despite the growing evidence that farmers in low-income environments are characterized by aversion to risk (Moscardi and deJanvry, 1977; Dillon and Scandizzo, 1978; Binswanger, 1980, Antle, 1987), however, there has been little empirical evidence on the importance of risk in shaping the actual allocation of production resources among farmers differentiated by wealth.[1] Empirical work on contractual relations in low-income rural areas has also not been successful in obtaining credible or consistent empirical relationships between wealth and risk behavior (Bell and Srinivasan, 1985), in part because of population heterogeneity in risk attitudes.

While it might be thought that a principle impediment to obtaining better evidence on risk-related behavior in low-income countries is the unavailability of data, an advantage almost unique to the study of agricultural environments is that one of the major sources of risk, weather, has been recorded for long periods of time in most countries of the world. Despite this, the literature on agricultural risk has not exploited actual weather data to measure risk, although rainfall information has been fruitfully used to study intertemporal consumption behavior (Wolpin, 1982; Paxson, 1988).

In this paper we utilize unique panel data from rural India on investments, wealth and rainfall to examine how the composition of productive and non-productive asset holdings varies across farmers with different overall levels of total wealth holdings and across farmers facing different degrees of weather risk. In particular, we propose and implement a test of the central feature of an investment equilibrium characterized by risk-averse agents, namely the existence of a positive association between the average returns to individual production assets and their sensitivity to weather variability. We also estimate how the influence of weather risk on asset portfolios and farm profitability varies with measured risk preferences and with total wealth holdings.

In part one of the paper, we set out a simple framework for exploring the determination of agricultural investments under risk which explicitly incorporates the first two moments of the distribution of weather outcomes. The analysis rests on the estimation of a restricted profit function in which it is assumed that farmers choose a set of assets differentially sensitive to weather-variability based on their risk preferences but allocate resources to maximize profits after the resolution of uncertainty. Section two contains a description of the data and a discussion of measurement issues, with particular attention to the measurement of weather. In section three, the profit function estimates are presented and tests of scale economies, of the applicability of the two-moment distributional assumption, and of the risk-aversion investment equilibrium are reported. In the next section, estimates of the influence of experimentally-ascertained risk preferences, weather risk and wealth on the riskiness and profitability of farmers' portfolios of investments are estimated. These estimates are also used to test for the existence of risk-preference heterogeneity.

The empirical results reject the hypothesis that the composition of agricultural investments reflects technical scale economies but support the hypothesis that asset portfolios are influenced significantly by farmers' aversion to risk. The results also indicate that the trade-off between profit variability and average profit returns to wealth is significant and that the loss in efficiency associated with risk mitigation is considerably higher among the less wealthy farmers. Average incomes are thus not only lower but income inequality is exacerbated relative to the distribution of wealth as a consequence of uninsured weather risk. These results are shown to be consistent with decreasing relative and absolute risk aversion rather than solely with wealth-related credit market or other risk diffusion advantages. However, the results indicate that for farmers in the top quintile of the wealth distribution, increases in risk do not lead to reductions in the measured riskiness of investment portfolios and thus to decreased profits. A wealth-equalizing redistribution of land could thus increase average profitability, but only if land is acquired from the upper tail of the wealth distribution, although such a program may be less efficient than improving access to consumption credit or other means of insurance.

1. Theoretical Framework

We consider a farmer with total asset holdings W who allocates his n production assets prior to the realization of a random weather outcome ω in order to maximize his expected utility of consumption. Because we will be directly estimating the effects on the investment portfolio of measured characteristics of the distribution of the stochastic variable, it is particularly convenient to represent the farmer's expected utility rankings for consumption in terms of his preference ordering over moments of the consumption distribution. This is so because it is straightforward to map changes in the moments of the observed stochastic variable (weather) into changes in these characteristics of the consumption distribution. Moreover, Meyer (1987) has demonstrated the consistency of the two sets of rankings, for the first two moments of the distribution of payoffs, when the stochastic payoff variables differ from each other only by location and scale parameters. Under this condition, a wide variety of functional forms for expected utility models are consistent with models incorporating mean-standard deviation rankings. Since we utilize direct information on the stochastic variable we will be able to test for this condition.

The farmer maximizes

$$(1) \quad U = V(\mu_c, \sigma_c), \qquad V_\mu > 0, \; V_\sigma < 0,$$

where μ_c and σ_c are the mean and standard deviation of consumption. Meyer has also demonstrated that the quasi-concavity of (1) is sufficient to guarantee convexity of preferences, so that $V_{\mu\mu}$, $V_{\sigma\sigma} < 0$ and $V_{\mu\mu}V_{\sigma\sigma} - V_{\sigma\mu}^2 \geq 0$.

The farmer can influence the arguments in (1) by choosing an appropriate mix of production investments. Normalizing, arbitrarily, by the nth production asset and assuming a profit function linear homogenous (CRS) in the investment inputs, we can express the relationship between the mean and standard deviation of farmer profits, μ_Π and σ_Π, the productive investment portfolio vector $\tilde{\alpha}_i$, where the element α_i = value share of the ith investment input in total wealth, and the mean and standard deviation of the stochastic weather distribution, μ_ω and σ_ω, respectively, as:

(2) $\mu_\Pi = Wf(\tilde{\alpha}_i)\mu_\omega$ and

(3) $\sigma_\Pi = W\Gamma(\tilde{\alpha}_i)\sigma_\omega, \qquad f_{\alpha\alpha}, \Gamma_{\alpha\alpha} < 0.$[2]

Note that in (2) the mean and standard deviation of profits per unit of wealth are homogenous of degree 0 in total wealth, reflecting the CRS assumption, but are of degree 1 in the first two moments, respectively, of the weather distribution. The homogeneity assumption for the weather variable is similar to most specifications of stochastic output in the theoretical literature on agricultural risk utilizing the expected utility framework (see Feder 1977). We have also for simplicity assumed that there is one source of stochastic variability in profits. It is straightforward to consider multiple weather shocks, and we test for these below. With one source of profit variability, Γ measures the riskiness of the asset stock composition.

The mean of consumption is given by

(4) $\mu_c = \mu_\Pi$.

The mapping of the standard deviation in profits to that of consumption depends on what is assumed about capital market constraints. If assets cannot be sold and borrowing is not possible then $\sigma_c = \sigma_\Pi$, while if farmers are fully insured against income fluctuations, $\sigma_c = 0$. Most likely, the situation is somewhere in between these extreme cases. Moreover, the sensitivity of consumption variability to ex post profit variability may depend on the total level of asset holdings, for which there may be a limited market and which may serve as collateral for loans. Rosenzweig and Stark (1989), for example, report that the association between the variances of intertemporal profits and consumption was significantly lower for Indian farmers with greater inherited wealth, and Binswanger and Rosenzweig (1986) report that wealthier Indian farmers were substantially heavier borrowers. Both of these studies utilized the same survey data to be employed in this study. Accordingly, we express the relationship between consumption and profit variability as

(5) $\sigma_c = \kappa(W)\sigma_{\Pi}$,

with $\kappa'(W) < 0$.

The set of first order conditions are given by

(6) $V_\mu f_{\alpha_i} = -V_\sigma \Gamma_{\alpha_i} \sigma_\omega \kappa$, $\quad i=1,\ldots,n-1$,

where $f_{\alpha_i} = f_i - f_n$ and $\Gamma_{\alpha_i} = \Gamma_i - \Gamma_n$, with f_j and Γ_j the marginal contributions of the jth production capital to the mean and standard deviation, respectively, of profits. Expression (6) indicates that if farmers are risk-averse and capital assets differ in their contributions to profit variability ($\Gamma_{\alpha_i} \neq 0$), then as long as farmers' incomes are not perfectly insured, ($0 < \kappa \leq 1$) (mean) profits will be lower than mean profits would be if farmers maximized (expected) profits, since the profit maximization condition is $f_{\alpha_i} = 0$.

A readily testable implication of an investment equilibrium characterized by risk-aversion, embodied in (6), is the existence of a positive association across all production assets between marginal contributions to the mean and to the variability of profits, as for any two assets i and k,

(7) $f_{\alpha_i}/f_{\alpha_k} = \Gamma_{\alpha_i}/\Gamma_{\alpha_k}$.

A second implication of imperfectly insured consumption combined with risk-averse investment behavior that follows from the positive relationship between Γ_{α_i} and f_{α_i} is that a shift to assets that in equilibrium make higher-than-average contributions to profit variability ("risky" assets) induces a rise in mean profits, since risky assets must have higher average returns. Farmers more willing or more able to bear risk thus should not only hold high-Γ investment portfolios but should exhibit higher average profits per unit of wealth.

To establish the conditions under which the efficiency and portfolio riskiness of farmers changes with total wealth holdings and to assess how the sensitivity of profits to changes in weather risk is altered as wealth levels increase, we first note, from Meyer (1987):

1. Farmers exhibit decreasing, constant, or increasing relative risk aversion as $R = (V_{\sigma\mu}\mu_c + V_{\sigma\sigma}\sigma_c)V_\mu^{-1} - (V_{\mu\mu}\mu_c + V_{\sigma\mu}\sigma_c)V_\sigma/V_\mu^{2} = aV_\mu^{-1} + bV_\sigma V_\mu^{-2} \gtreqless 0$.

2. Farmers exhibit decreasing, constant, or increasing absolute risk aversion as $A = V_{\sigma\mu}V_\mu^{-1} - V_{\mu\mu}V_\sigma/V_\mu^2 \gtreqless 0$.

For simplicity, assume that there are only two types of capital i and j and that in equilibrium f_{α_i} and $\Gamma_{\alpha_i} > 0$, i.e. investment good i is the risky asset, and thus high-α_i portfolios are both riskier and more profitable. The effect of a mean-preserving change in the standard deviation of the weather distribution on the choice of the risky asset is given by:

$$(8) \quad \frac{d\alpha_i}{d\sigma_\omega} = -\kappa[(V_{\sigma\mu}f_{\alpha_i} + V_{\sigma\sigma}\Gamma_{\alpha_i}\sigma_\omega\kappa)W\Gamma + V_\sigma\Gamma_{\alpha_i}]\Phi^{-1}$$

$$= -\kappa[SW\Gamma + V_\sigma\Gamma_{\alpha_i}]\Phi^{-1}$$

where, suppressing subscripts, $\Phi = V_\mu f_{\alpha\alpha} + V_{\mu\mu}f_\alpha^2 W + V_\sigma\Gamma_{\alpha\alpha}\sigma_\omega\kappa + V_{\sigma\sigma}\Gamma_\alpha^2\sigma_\omega^2\kappa W + 2V_{\sigma\mu}f_\alpha W\sigma_\omega\kappa < 0$ by second order conditions.

The first term in brackets in (8), $SW\Gamma$, is the effect on the riskiness of investment due to a a wealth-independent increase in the variability of consumption, and is negative; the second bracketed term is negative as long as α_i is the risky asset. Thus, ceteris paribus, when farmers are not fully insured ($\kappa \neq 0$) an increase in weather risk reduces the riskiness of their portfolios of production capital and mean profitability.

The effect of a change in the level of wealth on α_i is:

$$(9) \quad \frac{d\alpha_i}{dW} = -[R + \frac{d\alpha_i}{d\sigma_\omega}\sigma_\omega\kappa']\Phi^{-1}.$$

Because of the homogeneity assumptions embodied in (2) and (3), an increase in wealth increases by the same proportion both the mean and standard deviation of profits and consumption. It is thus relative risk aversion (R) that matters in determining the relationship between the profitability or riskiness of the capital portfolio and total wealth, as shown in (9). The second term in brackets reflects the extent to which wealth directly reduces the variability in consumption for given variability in farm profits via the asset or credit market. Thus, if $\kappa' = 0$, farmers cannot save or barter, decreasing relative aversion is necessary and sufficient for wealthier farmers to be holding more risky portfolios of production capital and to be more efficient. However, with wealth accumulation being advantageous in the credit market and/or with asset resale possibilities, so that $\kappa' < 0$, decreasing relative risk aversion is not a necessary condition for consumption riskiness and profitability per unit of wealth to rise with total wealth.

The relationship between total wealth and the impact of weather riskiness on the riskiness (and profitability) of the stock of capital inputs, assuming third derivatives of (1) are small, is given by

$$(10)\quad d(d\alpha_i/d\sigma_\omega)/dW = -\kappa[\Gamma_{\alpha_i} a + \Gamma S]\Phi^{-1}$$

$$- \frac{d\alpha_i}{d\sigma_\omega}[-f_{\alpha_i}A + \Gamma_{\alpha_i}\kappa\sigma_\omega S + a\Gamma_{\alpha\alpha}\sigma_\omega\kappa + bf_{\alpha\alpha}]\Phi^{-1}$$

$$+ \frac{\kappa'}{\kappa}[\frac{d\alpha_i}{d\sigma_\omega} - \kappa' V_{\sigma\sigma}\Gamma_{\alpha_i}\sigma_\Pi\Phi^{-1}].$$

In expression (10), both absolute (A) and relative risk aversion matter. The first bracketed term is positive if a is non-negative, which is true when farmers are characterized by non-increasing constant relative risk aversion; similarly, the second bracketed term must be positive if farmers are characterized by non-increasing absolute and relative risk aversion ($A, a, b \geq 0$) and f and Γ are concave. The last bracketed term in (10) arises from the potential effect of wealth in facilitating consumption smoothing <u>ex post</u> ($\kappa' < 0$) and contributes unambiguously to wealth diminishing the effect of weather variability on portfolio riskiness and profitability. Thus, non-increasing absolute and relative risk aversion are sufficient, but not necessary, for the investments of wealthier farmers to be less influenced by weather risk.

2. The Data

The preceding framework indicates that to test for the existence of an investment equilibrium conditioned by risk and to assess the interactions between total wealth holdings, agricultural risk and the composition of investment holdings requires time-series data on investments, wealth and weather. The ICRISAT Indian village surveys (Singh et al., 1985) provide detailed time-series information on agricultural production and investments for farm households over a period of up to ten years. Begun in the crop year 1975-76 in six villages in three agroclimatic regions of the Indian semi-arid tropics, the survey collected longitudinal information approximately every three weeks on all transactions (purchases, sales, production, investment) for 40 households in each village, 30 of which were cultivating households. At the conclusion of the survey, there were ten years of information collected for three of the villages, seven years for one, and nine years of information for two of the original six villages. In 1980-81, two other villages (each with 40 households) were added to the survey and were surveyed for four years; another two villages (80 households) were added in 1981-82 and were surveyed for three years.

In addition to the transaction information, in each year on approximately July 1 a complete inventory of the households' asset holdings was taken. All of the information was obtained by resident village investigators. The ICRISAT wealth and investment portfolio data are thus likely to be substantially more accurate than in most surveys, particularly those occurring at one point in time. As part of the survey, daily rainfall information was also obtained. It is thus possible to construct a number of alternative measures of rainfall incidence and variability.

Two other features of the ICRISAT village survey make it particularly well-suited for studying the consequences of agricultural risk for investment. First, the separation theorem (Tobin (1958)) does not appear to be applicable to the villages. That is, farmers are not generally able to invest in a riskless asset. In principle, farmers could alter the riskiness of their investment portfolios by merely changing the proportion of their holdings that they lease out at a fixed rental rate, while arranging productive assets on the self-cultivation portion of their portfolios so as to maximize profits. In that case, the composition of production portfolios (but not leasing behavior) would be invariant to risk. While the ICRISAT data do not provide information on the contractual terms for leased-out land, in less than seven percent of the observations (household-years) are farmers renting in any land at fixed rental rates.[3] Very few farmers are thus able or willing to absorb the risk entailed by taking on a fixed-rent contract, leaving almost all farmers fully exposed to weather risk. In approximately 21 percent of the observations, farmers are share renting land; this contractual form, of course, mitigates but does not eliminate risk.

A second advantage of the ICRISAT survey is that the farmers in six of the villages were subject to an experiment designed to directly elicit their aversion to risk (Binswanger, 1980). It is thus possible to test whether our non-experimentally obtained measures of portfolio riskiness are related to these independently-ascertained measures of subjective risk-aversion.

The semi-arid tropics in which the ICRISAT study villages reside are characterized by very low levels of erratically-distributed rainfall. As a consequence, agricultural incomes are low and quite variable--in the six original villages for which there is from seven to ten years of information, the average coefficient of variation in total farm profits (net of the value of family labor) was 127. In contrast, our analysis of the earnings of U.S. white males aged 25-29 in 1971, surveyed in seven rounds of the National

Longitudinal Survey of Youth, indicated that the average coefficient of variation in earnings was only 39. The variability in agricultural income is not due to technical change; the crops grown in the survey areas - millet, pigeon-pea, cotton--were not affected by the Indian Green Revolution. Agricultural risk is thus predominantly weather-based in this environment, and it is possible to utilize all sample years to estimate the technology of production.

Finally, total wealth holdings in the six villages are very unequally distributed. Based on sample-period averages of real wealth for each farm household, the top 20 percent of farmers own over 54 percent of all wealth. Mean total wealth holdings (in 1983 rupees) was 54,158 rupees, with a median of 33,265 rupees. The minimum average value of wealth holdings was 4,154; the highest was 453,581 rupees. Mean farm profits, also in 1983 rupees, was 5,825.

3. Specification of the Technology and the Measurement of Weather

To estimate the profitability and riskiness of asset portfolios, we aggregated the detailed information on (annual) asset holdings into nine categories, by value, using 1983 prices: unirrigated landholdings; irrigated landholdings, inclusive of the value of irrigation equipment; draft animals, including bullocks and water buffalo; milk animals; other animals, including chickens and goats; traditional farm implements, including manual plows, carts, blades, hoes; modern machinery, including tractors; liquid capital, including financial assets and food stocks, and consumption assets, including consumer durables and housing.

To estimate the relationship between the two moments of the weather distribution and profits, we assume that the profit function is a normalized quadratic, where we normalize by total wealth holdings. Thus profits for each farmer k in period t are given by

$$(11)\quad \Pi_{kt} = \sum_i \beta_i\alpha_{ikt} + \tfrac{1}{2}\sum_i\sum_j \delta_{ij}\alpha_{ikt}\alpha_{jkt} + \sum \gamma_i\alpha_{ikt}\omega_t + \gamma_\omega\omega_t + \epsilon_{kt} + v_k$$

where ϵ_{kt} is an i.i.d. error and v_k is a time-invariant error. We thus assume that farmers maximize short-run profits, given the set of α_is, based on the weather outcome realized after all investments have been undertaken. The advantage of the quadratic form (11) is that statistical tests of global quasi-concavity (in the α_i) can be readily implemented (Lau, 1976), since the relevant Hessian matrix of second partials consists only of the estimated δ_is. If (11) is quasi-concave in the α_i, it is then possible to solve for the expected profit-maximizing investment portfolio for each weather environment and thus to measure farmer-specific deviations in investment portfolios from their expected-profit optimum. Moreover, the riskiness Γ of each farmer's portfolio of investments based on (3) and (11) is of a simple form:

$$(12)\quad \Gamma = \mathrm{sqrt}((\sum_i \gamma_i\alpha_i)^2).$$

The appropriate procedure to obtain estimates of the β_i, δ_i, and γ_i depends on what is assumed about the error terms. If the time-invariant error v_k is correlated with the investments, then a farmer fixed effects estimator (Mundlak, 1978) provides consistent parameter estimates. As the portfolio of α_i's is measured at the beginning of the crop season, we assume that neither ω_t, the realization of weather in period t, nor ϵ_{kt}, the unobserved shock to production, is known to the farmer prior to the implementation of his asset plan for period t. The orthogonality between actual weather in period t and the ex ante investment portfolio, net of the permanent distributional characteristics of weather, is testable and we test it below.

The remaining issue in obtaining estimates of the technology parameters is the characterization of weather. We take an empirical approach. We used the daily rainfall information to construct six measures of rainfall: the beginning and end dates of the rainy season (monsoon), where the monsoon onset is determined as the date after which there has been at least 20 mm of rain within several consecutive days after June 1; the fraction of days within the season with rain; the average rain per day during the season, and the length of up to two intraseasonal drought periods. Village "folklore" suggests that the timing of the monsoon is the most important aspect of weather (and uncertainty). We therefore first regressed total (real) profits from crop production and total farm profits (crop profits plus profits from animal by-products) on the monsoon onset date and then on all six weather variables, using all farm households in the ten ICRISAT villages.

Random effects estimates of the influence of the rainfall variables on profits are presented in Table 1. The initiation date of the monsoon does significantly affect both crop and total profits--a one standard deviation delay (16 days) in the start of the monsoon reduces crop (total) profits by 222 (150) rupees, or by approximately 6 (3) percent. We could not reject the hypothesis that the five other measures of rainfall, included in the specification reported in the second column for each profit variable, do not add to the explanatory power of the profit regressions. Moreover, inclusion of the other rainfall variables does not appreciably alter the effect of the onset variable. Of the other rainfall measures, the only potentially important candidate is the fraction of days with rain. Accordingly, we use

Table 1

Random Effects Estimates: Effects of Rainfall Measures on Profits (1983 Rupees) from Crop Production and Total Farm Profits in Ten ICRISAT Villages

	Crop Profits		Total Profits	
Weather Variable	(1)	(2)	(1)	(2)
Monsoon onset date	-13.9	-15.7	-9.35	-12.4
	(2.68)[a]	(2.78)	(1.68)	(2.05)
End of monsoon	-	-1.29	-	-.357
		(0.37)		(0.10)
Fraction of days in season with rain	-	1993	-	1722
		(2.25)		(1.81)
Rain per day in season	-	-85.1	-	-108
		(1.44)		(1.70)
Consecutive days of intraseasonal drought - first episode	-	-2.67	-	-4.95
		(0.35)		(0.61)
Consecutive days of intraseasonal drought - second episode	-	-2.59	-	-8.41
		(0.33)		(0.99)
Constant	7054	7619	7440	8219
	(7.13)	(5.72)	(6.89)	(5.70)
F	82.0	25.2	87.7	26.9
χ^2 (Breusch-Pagan)	7886	7809	8438	8394
n	2168	2168	2168	2168

a. Absolute values of asymptotic t-ratios in parentheses.

both this measure of rainfall and the onset date as weather variables in our estimation of (11), and undertake additional tests of their importance. That the quantity of rainfall is far less important than its timing is consistent with the well-known difficulties experienced by researchers using rainfall quantities to explain yield (Herdt, 1972) or the allocative behavior of farmers (McGuirk and Boissert, 1988) based on aggregate Indian data.[4]

The village-level rainfall variables explain a small proportion of the variability in individual profits. This might suggest that an investigation of the influence of the riskiness of these variables on farmer behavior would not yield significant results--unmeasured variability in profits, due to sources orthogonal to rainfall, might be a far more important source of risk. However, even if all of the residual variability in profits were not merely measurement error, it is not necessarily true that such variability significantly alters behavior. To the extent that non-weather-induced income variability is not covariant across farmers within the village, such risk might be considerably mitigated <u>ex post</u> by utilizing locally-supplied credit or via other village-based risk-sharing arrangements. Binswanger and Rosenzweig (1987) have shown that most loans in the ICRISAT villages are acquired from local informal sources without access to external funds. Moreover, loans appear to be less available when the local economy is subject to a common shock, such as a late monsoon (Rosenzweig, 1988). Thus weather-induced profit variability may be far less insurable than idiosyncratic or household-specific profit variability, necessitating <u>ex ante</u> risk reduction through altering the portfolio of investments differentially sensitive to weather outcomes. Investments would then be predominantly responsive to weather risk.

To assess the relative importance of weather-induced and other sources of income variability on consumption, we utilized the information on household food consumption (85 percent of total consumption) that is available for nine years in three of the ICRISAT villages. In column (1) of Table 2 we report a fixed effects regression of food consumption on total farm profits and the age of the household head. The results indicate that household (food) consumption is not wholly independent of current farm profits--a 100 rupee decrease in profits reduces food consumption by seven rupees. In the second column of Table 2 we regress, again using fixed effects, food consumption on farm profits measured net of the effects of the weather variables. This profit measure is the residual obtained from the regression of farm profits on the weather variables. These profit-weather regressions were run separately for each household, since the risk framework suggests that weather should differentially affect profits according to the individual farmer's composition of assets $\tilde{\alpha}_i$. This residual measure of household-specific income, orthogonal to income determined by the weather, has an effect on food consumption that is only .6 of a percent that of actual profits. Common weather shocks to income appear to have substantially greater consequences for consumption than does idiosyncratic risk.[5]

4. Estimates of the Technology and Tests of the Risk-Aversion Investment Equilibrium

Table 3 reports some test statistics based on our estimates of the normalized restricted profit function (11). We included in the specification, in addition to the eight investment types (excluding consumer durables as part of the normalization) and the two weather measures, total wealth and its square, to test for scale effects, the number of adult male

Table 2

Fixed Effects Estimates: Effects of Total Farm Profits, Inclusive and Exclusive of the Effects of Weather, on Food Consumption in Three ICRISAT Villages, 1975-1984

Variable	(1)	(2)
Age of household head	-85.5	-71.9
	(1.53)[a]	(1.35)
Age squared	.438	.373
	(0.78)	(0.70)
Farm profits	.0694	-
	(5.76)	
Farm profits net of effects of weather[b]	-	.00047
		(0.02)
F	13.6	2.86
n	720	720

a. Absolute values of asymptotic t-ratios in parentheses.

b. Residual from household-specific fixed-effects regression of total farm profits on onset of monsoon in the village.

Table 3

Test Statistics: Normalized Quadratic Profit Function[a]

Hypothesis	Test Statistics	
No effect of monsoon onset date	$F(13,1742) = 6.73$	
No effect of fraction of days with rain	$F(13,1742) = 2.01$	
No scale effect	$F(2,1742) = 2.09$	
No effect of adult male family members	$F(14,1742) = 6.99$	
No effect of adult female family members	$F(14,1742) = 3.39$	
No effect of schooling of head of household	$F(14,1742) = 1.49$	
No effects of age of head of household	$F(14,1742) = 2.79$	
	Cholesky Values	
Function quasi-concave in 7 capital stocks (Cholesky factor ≤ 0[b])	-2.16	t = 3.41
	-.0133	t = 0.33
	-.0623	t = 0.33
	-1.24	t = 0.36
	0.792	t = 0.032
	-.146	t = 0.006
	27.9	t = 0.018

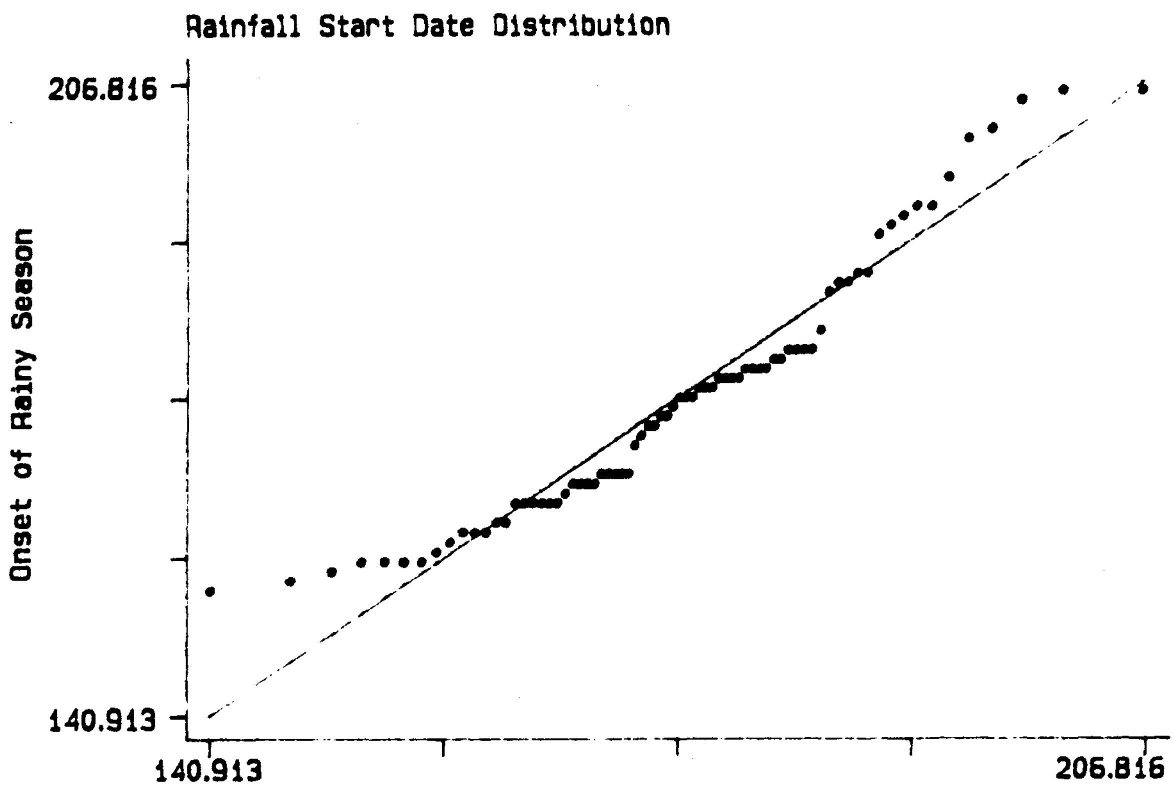
a. Estimation procedure: fixed effects.

b. Estimation procedure: fixed effects non-linear least squares. Specification excludes scale, schooling, age and milk animals to conserve parameter space. Test statistic for milk animals ($F(14,1742) = 1.68$).

and female family members, and the schooling and age of the household head. The test statistics indicate the timing of the monsoon has a statistically significant effect on total farm profitability, while the set of 13 coefficients associated with the proportion of days with rain is not statistically significant at even the ten percent level. In subsequent tests, therefore, we only consider the influence of the monsoon onset variable.

Does the principle measured risk variable, the monsoon onset date, conform to the location and scale transform assumption of the mean-standard deviation analysis of risk? As noted, if the onset date is normally distributed, this property holds. Figure 1 presents a normal quantile plot of this rainfall measure, based on 75 observations. The plot suggests some conformity to the normal, with perhaps fatter tails. The Kolmogorov-Smirnov test statistic is .119, which is only statistically significant at the 20 percent level of significance. We thus cannot reject the assumption that the monsoon onset date has a normal distribution.

Of the other test statistics, the results indicate the absence of technological scale effects on profits. Differences in investment portfolios across wealth classes evidently do not arise from technical scale economies. The results also indicate that schooling has no effects on profits, but reject the hypothesis that the age of the farmer does not affect profits (the marginal return is positive at sample mean values). These latter results are consistent with the hypothesis that in environments subject to risk but characterized by stationarity, experience, but not formal schooling, has real payoffs, as found in Rosenzweig and Wolpin (1985). The tests also reject the hypothesis that the size of the family labor force does not influence profits. This result appears to contradict



Quantile-Quantile Plot

the findings by Pitt and Rosenzweig (1986) and by Benjamin (1988), based on Indonesian data, indicating the perfect substitutability of hired and family labor.[6]

A necessary and sufficient condition for the global quasi-concavity of the profit function (11) in the α_i is that the Hessian matrix of second partials with respect to the α_i, consisting solely of the δ_{ij}s, be negative semi-definite. This in turn implies that all of the eigenvalues of the Hessian be non-positive. Based on our set of point estimates of the δ_{ij}, six of the eight eigenvalues were negative. To test if the non-negative eigenvalues indicate rejection of quasi-concavity, we implemented the test proposed by Lau (1978). We reestimated (11) replacing the matrix of δ_{ij}s by parameters corresponding to the Cholesky factorization of that matrix. In particular, if D is the Hessian matrix of δ_{ij}s, then the Cholesky factorization is

(13) $D = LCL'$,

where C is a diagonal matrix of Cholesky factors, L is a unit lower triangular matrix, and L' is its transpose. Non-linear least squares estimates of (11), with (13) replacing the δ_{ij}, yield direct estimates of the Cholesky factors, which also should be non-positive.

The bottom part of Table 3 reports the estimates of the Cholesky factors for seven of the eight investment inputs. We dropped all variables indicated not to be statistically significant in Table 3 and milk animals, which also had no statistically significant effect in the linear specification of (11), to conserve parameters (249 parameters needed to be estimated). These results indicate that we cannot reject quasi-concavity at any reasonable level of statistical significance, due to the two non-negative Cholesky factors being measured with very little precision. However, our point estimates of the δ_{ij} make it impossible to find a set of α_i that maximize expected profits.

In Table 4 we present the computed marginal profit level effects, evaluated at the sample means, and the marginal profit variance effects, with their associated asymptotic t-ratios, for all eight investment inputs based on the normalized profit function parameter estimates. Sample mean investment shares are reported in the leftmost column, with their standard deviations. All estimated effects, reported in columns two and three, are relative to the effects of consumer durables and housing. The results reject the hypothesis that the investment inputs have identical profit variance or profit level effects. The Spearman rank correlation across the eight types of capital stocks between level and variance effects is positive, in conformity to expression (6), but not statistically significant at the 15 percent level. The principle deviants from the risk-aversion investment equilibrium condition are the liquid assets and draft animal categories--there appears to be severe underinvestment in both assets despite their not contributing, on the margin, to increasing profit variability. Exclusion of draft animals leads to a rank correlation between level and variability effects of .68, which is statistically significant at the .01 level. Exclusion of both draft animals and liquid assets yields a rank correlation of .83, which is also statistically significant at the .01 level.

What may account for the underinvestment in both liquid assets and draft animals? The framework set out in section 1 does not accommodate the possibility that specific capital items may be more or less useful in smoothing consumption *ex post*. With the κ-function having as arguments not

Table 4

Estimated Normalized Profit Level and Profit Variance Effects of Changes in the Shares of Productive Capital Items Relative to Consumer Durable and Housing Wealth[a]

Capital Item	Share of Total Wealth (α_i)	Marginal Profit Level Effect ($\partial\pi/\partial\alpha_i$)	Marginal Profit Variance Effect ($\partial\Gamma^2/\partial\alpha_i$)
Irrigated land	0.132	0.0656	0.0645
	(0.226)[b]	(2.45)[c]	(0.80)[c]
Dry land	0.591	0.0289	-.0496
	(0.317)	(1.62)	(0.78)
Traditional implements	0.0073	1.285	1.184
	(0.013)	(3.87)	(1.20)
Modern implements	0.00376	0.127	3.891
	(0.0403)	(0.63)	(8.86)
Draft animals	0.0223	1.167	-0.644
	(0.0312)	(10.6)	(1.34)
Milk animals	0.0249	0.00234	-0.152
	(0.0433)	(0.02)	(0.47)
Other livestock	0.0174	0.156	0.568
	(0.0381)	(1.35)	(2.39)
Liquid assets	0.0806	0.0928	-2.45
	(0.0826)	(2.22)	(1.40)
Consumer durables and housing	0.121	-	-
Spearman rank correlation, level and variance effects		.262	
Spearman rank correlation, excluding draft animals		.679	
Spearman rank correlation, excluding draft animals and liquid assets		.829	

a. Computed from normalized restricted profit function estimates at sample means of α_i.

b. Standard deviation in parentheses in column.

c. Absolute values of asymptotic t-ratios in parentheses in column.

only total wealth but $\tilde{\alpha}_i$ as well, the equilibrium condition (6) becomes

$$(6') \quad V_\mu f_{\alpha_i} = V_\sigma \sigma_\omega [\Gamma_{\alpha_i} \kappa + \kappa_{\alpha_i} \Gamma].$$

If (6′) is the correct characterization of the equilibrium, then without prior knowledge of the association between the profit variability and ex post consumption smoothing effects κ_{α_i} for each α_i, it is no longer possible to know how profit level and profit variability effects will be correlated.

It is not surprising that liquid assets (financial assets and food stocks) play a role in smoothing consumption as well as provide a source of funds for purchasing variable inputs. However, our analysis of the transaction records from the original six villages covering the entire survey period also indicates that the purchase and sale of draft animals accounted for 72.9 percent of all market transactions involving investment durables. The high turnover rate for draft animals suggests that this capital item may also be playing a role in consumption smoothing predominant among the other durable agricultural stocks. If so, then in periods in which weather has been particularly poor, both the level of liquid assets and stocks of draft animals may be depleted and thus exhibit high marginal profit level returns.[7] For given profit variability effects, however, overinvestment in conventionally-characterized liquid assets and in draft animals in normal periods may be observed, given their consumption smoothing role. An investigation of optimal stock behavior is beyond the scope of this paper, but is considered in Rosenzweig and Wolpin (1989) in the context of a dynamic stochastic model.

5. Weather Risk, Wealth and the Riskiness and Profitability of Farm Investment Portfolios

Based on the estimates of the profit function and the actual asset portfolios $\tilde{\alpha}_i$ of the household we can construct individual measures of portfolio riskiness Γ, from (13), for each farm household. There is considerable inter-household variability in Γ--based on survey-period averages for each household, the sample mean of Γ is .000632 and the standard deviation is .000539. At the sample mean of wealth, the mean estimate of Γ implies an average standard deviation in total profits of 544 rupees at the mean standard deviation of the monsoon onset; the average coefficient of variation in profits associated with the average Γ measure of portfolio weather sensitivity is thus 9.3. At the same (mean) wealth level, a one standard deviation increase in Γ raises the coefficient of variation of profits to 17.3.

To directly assess whether portfolio riskiness and profitability per unit of wealth are positively associated in the sample, as should be true in the risk-averse investment equilibrium, we regressed, using fixed effects, farm profits divided by total wealth (Π/W) on the Γ measure of riskiness and the farmer's age and age squared. The results were:

$$(14)\quad \Pi/W = \underset{(4.31)}{5.54\,\Gamma} + \underset{(2.36)}{.00593\cdot \text{age}} - \underset{(2.24)}{.000056\cdot \text{age squared}} \qquad n = 2130 \quad F(3,1825) = 8.54$$

where t-ratios are in parentheses. Farm households with production asset portfolios less sensitive to weather variability sacrifice profitability, in conformity to the investment risk framework--a one standard deviation decrease in portfolio riskiness lowers average profits by 162 rupees at the mean level of wealth.

The risk framework suggests that the variation in portfolio riskiness across farm households and over time should be related to the first two moments of the weather distribution and to total wealth. Moreover, the

Table 5

Determinants of Gamma (x10^5): Six ICRISAT Villages

Variable/ Estimation Procedure	Random Effects	Random Effects	Fixed Effects	Random Effects	Random Effects
Coefficient of variation in onset (CV)	-.884	-.267	-	-.551	-.0783
	(4.14)[a]	(0.76)		(2.85)	(0.27)
CV·total wealth (x10^{-4})	.133	.138	.0693	-	-
	(7.68)	(7.75)	(6.30)		
CV·inherited wealth (x10^{-4})	-	-	-	.0731	.0834
				(5.32)	(6.07)
Total wealth (x10^{-4})	-7.10	-7.07	-4.13	-	-
	(5.72)	(5.63)	(4.93)		
Inherited wealth (x10^{-4})	-	-	-	-5.13	-5.69
				(4.78)	(5.32)
Mean onset date	.471	.368	-	.132	.130
	(0.26)	(0.20)		(0.08)	(0.08)
Risk aversion parameter	-	7.50	-	-	6.33
		(1.27)			(1.25)
CV·risk aversion parameter	-	-.138	-	-	-.102
		(1.89)			(1.66)
Age	.590	.432	.351	.490	.299
	(1.72)	(1.26)	(1.64)	(1.57)	(0.99)
Constant	76.3	33.0	-	69.1	36.9
	(2.13)	(0.72)		(2.13)	(0.95)
F	42.9	16.8	8.80	43.8	20.3
χ^2 (Breusch-Pagan)	328.8	287.8	-	176.5	117.4
χ^2 (Hausman)	103.0	99.9	-	0.74	4.51

a. Absolute values of asymptotic t-ratios in parentheses.

effect of a mean-preserving shift in the standard deviation of weather on portfolio riskiness and profitability may depend on the total level of wealth holdings. A problem with testing for wealth effects is that at any given point in time both accumulated wealth as well as the investment portfolio will reflect the farm household's subjective risk preferences, which, as shown in Binswanger (1980), vary across the farmers in our sample. The observed cross-household association between wealth and the risk characteristics of the asset portfolio, given heterogeneity in risk preferences, does not conform to the result that would be obtained by randomly assigning wealth levels across farmers. To the extent that preferences for risk are time-invariant, a fixed effects procedure will provide consistent estimates of wealth effects on portfolio allocations. However, because the moments of the weather distribution are also time-invariant (under stationarity), use of the fixed effects procedure does not allow the identification of the direct effects of the characteristics of the weather distribution on portfolio choice.

The ICRISAT data allow two alternative procedures that may circumvent the bias due to risk-preference heterogeneity. First, we can exploit the farmer-specific measures of (partial) risk aversion revealed in the experimental lottery games reported in Binswanger (1980); that is, we can treat risk preferences as observables and "control" for them. An alternative procedure is to use inherited wealth, also available in the data, instead of current wealth. To the extent that the wealth inherited by a farmer is orthogonal to his preferences for risk, use of inherited rather than current wealth reduces biases associated with heterogeneity.

In Table 5 we report reduced-form estimates of the effects on portfolio riskiness Γ of changes in the village-specific mean and coefficient of variation (CV) of the monsoon onset date, household total wealth and the onset CV interacted with wealth, based on the data from the six original villages where the longer time-series of weather are available. In the first column, the coefficients obtained using the random effects estimation procedure are reported. The results conform to the risk-aversion model in which farmers are characterized by decreasing relative risk aversion and/or in which wealth contributes to ex post consumption smoothing. At the sample median of wealth, an increase in the onset CV significantly decreases portfolio riskiness--a one standard deviation increase in the CV (29.5) lowers Γ by 20 percent. The set of coefficients also indicate that the effect of the weather CV on portfolio riskiness declines sharply with wealth--at the mean wealth level, Γ is lowered by only 7.6 percent when the CV is higher by one standard deviation. Indeed, above wealth levels corresponding to the top quintile of the wealth distribution (75,376 rupees), there is no negative effect of weather variability on portfolio riskiness. The top 20 percent of farm households are evidently able or willing to completely absorb profit risk.

The Hausman test indicates rejection of the hypothesis that the right-hand-side variables in the specification reported in the first column of Table 5 are uncorrelated with the residual. In the second column we report estimates that attempt to correct for preference heterogeneity by including the measure of each farmer's partial risk aversion parameter, from the five rupees level in game nine reported in Binswanger (1980). These estimates are similar to those obtained without the risk preference measures. They also provide support for the hypothesis that the investment portfolio is related to preferences for risk. At the sample mean of the onset CV, farmers with greater aversion to risk according to the experimental games do have lower-Γ investment portfolios, and increases in the variability in the start of the monsoon induces more risk-averse farmers to lower the riskiness of their portfolios more strongly than less risk-averse farmers. However, the Hausman test statistic still indicates the existence of heterogeneity bias.

The third column of Table 5 reports the fixed effects estimates of the determinants of Γ, which only permit the identification of the direct wealth and the CV-wealth interaction effects. These are highly statistically significant and conform in sign pattern to their random effects counterparts, indicating decreases in the effects of the weather CV on Γ as wealth levels rise; the magnitudes are approximately half those estimated using random effects. In the last two columns, we replace contemporaneous wealth with inherited wealth (in 1983 rupees). These results are similar in magnitude to those obtained with current wealth levels, and also indicate that farmers shift to less risky investment portfolios in response to increases in weather variability, but only among farmers with inherited wealth levels below the top 30th percentile of the <u>inherited</u> wealth distribution. And, again, particularly so among farmers that the experimental data indicate are more risk averse.

The steep fall in the effects of weather variability on portfolio riskiness as wealth levels rise indicated in Table 5 does not appear to be solely accounted for by wealth differences in <u>ex post</u> consumption smoothing capabilities. The estimates in Rosenzweig and Stark (1989) indicate that a unit increase in the standard deviation of profits is associated with a .333 rise in the standard deviation in food consumption for households at the bottom 25th percentile of the wealth distribution. The effect of profit variability on consumption variability only declines to .321 for households at the top 80th percentile. While this fall in the sensitivity of consumption to profit volatility by wealth level is statistically significant, it cannot account for our findings of a steep decline in the response of the weather sensitivity of investment portfolios to weather variability as wealth levels increase. The estimates of Table 5 thus suggest that farmers are characterized by decreasing relative risk aversion.

Although we cannot compute the profit-maximizing portfolio based on the profit-function parameter estimates, as discussed, we can estimate the reduced-form relationships between farm profits, weather variability, and wealth using the same procedures as employed in obtaining estimates of the determinants of portfolio riskiness. And the equilibrium condition (6) implies that the coefficient sign patterns for profits should be the same as those for Γ. Table 6 reports the estimates of the reduced-form determinants of profits. The specifications employed in obtaining the profit estimates are identical to those in Table 5 except that the current-year onset date is also included, since the current weather state affects profits (but not the pre-season composition of assets).[8]

In the specifications employing contemporaneous wealth levels, the coefficient estimates are similar in sign patterns to those of Table 5. The estimates appear to be robust to estimation procedure, however. In particular, the CV-wealth interaction and onset date coefficients are almost identical when estimated using random or fixed effects, and the Hausman test indicates only marginal rejection (.06 level) of the hypothesis that heterogeneity may be biasing the set of profit-level coefficients, in contrast to the strong rejection for the Γ estimates. The experimentally-obtained risk aversion variables also do not appear to be related to profits.

Table 6

Determinants of Profit Levels: Six ICRISAT Villages

Variable/ Estimation Procedure	Random Effects	Random Effects	Fixed Effects	Random Effects	Random Effects
Coefficient of variation in onset (CV)	-24.7	-29.2	-	-11.2	-34.8
	(1.33)[a]	(0.88)		(1.06)	(0.75)
CV·total wealth ($x10^{-4}$)	2.91	2.65	3.28	-	-
	(2.35)	(2.09)	(2.03)		
CV·inherited wealth ($x10^{-4}$)	-	-	-	2.11	.755
				(2.89)	(0.34)
Total wealth ($x10^{-4}$)	440.8	448.9	308.2	-	-
	(5.15)	(5.15)	(2.84)		
Inherited wealth ($x10^{-4}$)	-	-	-	25.1	136.9
				(0.44)	(0.79)
Onset date	-14.2	-14.4	-13.2	-15.9	-14.5
	(2.11)	(2.13)	(1.93)	(1.17)	(2.05)
Mean onset date	247.8	254.4	-	-229.1	-194.4
	(1.46)	(1.41)		(2.46)	(0.72)
Risk aversion parameter	-	156.9	-	-	260.5
		(0.27)			(0.33)
CV risk aversion parameter	-	-.355	-	-	-6.34
		(0.05)			(0.64)
Age	24.4	26.9	40.1	394.6	47.6
	(0.95)	(1.03)	(1.13)	(3.88)	(1.56)
Constant	194.0	-1408	-	1990	5321
	(0.06)	(0.32)		(0.54)	(1.39)
F	66.6	27.7	29.2	34.0	8.50
χ^2 (Breusch-Pagan)	1924	1823	-	2769	2750
χ^2 (Hausman)	15.2	14.9	-	0.53	0.61

a. Absolute values of asymptotic t-ratios in parentheses.

The first-column parameter estimates indicate that at wealth levels up to 84,830 rupees, corresponding to the top 19 percent of the sample farmers ranked by wealth, higher variability in the monsoon onset date is associated with significantly lower average profits. The wealth distribution cutoff point, where weather variability no longer depresses mean profits, is remarkably similar to the wealth cutoff at which weather variability no longer decreases portfolio riskiness. The costs of decreased riskiness are not small and are borne significantly more heavily by the less wealthy. At the mean wealth level, a one standard deviation increase in the onset date coefficient of variation (29.5) lowers average profits by 264 rupees, or by 4.5 percent. At the wealth median, profits are lower by 443 rupees for every one standard deviation increase in the onset date CV, a reduction in mean profits of 15 percent, while for farmers with wealth holdings below the 25th percentile, average profits are lowered by 555 rupees. This cost of risk reduction represents 35 percent of average profits for the lowest quartile of farmers.

The specifications employing inherited rather than current wealth, reported in the last two columns of Table 6, are estimated less precisely but also indicate that less-wealthy farmers are significantly more willing to sacrifice profit levels than are wealthier farmers in response to increases in weather variability. The estimated cutoff is 53,081 rupees, corresponding to the 55th percentile of the inherited wealth distribution.

6. Conclusion

Income variability is a prominent feature of the experience of rural agents in low-income countries. In this paper, we have obtained evidence, based on measures of rainfall variability, indicating that the agricultural investment portfolio behavior of farmers in such settings reflects risk aversion, due evidently to limitations on ex post consumption-smoothing mechanisms. Our results suggest that uninsured weather risk is a significant cause of lower efficiency and lower average incomes--a one standard deviation decrease in the standard deviation of the timing of the rainy season would raise average profits by up to 35 percent among farmers in the lowest wealth quartile. Moreover, weather variability induces a more unequal distribution of average incomes for a given distribution of wealth. This latter feature, resulting from the evident willingness of wealthier farmers to absorb more risk while reaping higher average returns, is evidence against the common supposition that smaller farms are more efficient than larger farms, a presumption that tends to ignore the returns to agricultural investment holdings. However, we also found that among the top quintile of farmers increased weather risk does not reduce profitability. This suggests that there is some scope for efficiency gains from an equalizing redistribution of land. The results also suggest that improvements in the abilities of farmers to smooth consumption, perhaps via increased consumption credit, would increase the profitability of agricultural investments; similarly, the availability of rain insurance would both raise overall profit levels in high-risk-areas and decrease earnings inequality within those areas.

Given the apparent private and social gains from weather insurance, specifically for monsoon timing insurance, why we do not observe a market for it? While the supply of insurance against the vagaries of rainfall should not be afflicted by moral hazard among farmers, our results indicate that the demand for rainfall insurance may be quite weak. First, a substantial proportion of profit risk is idiosyncratic, and evidently welldiffused. Second, demand for weather insurance would come primarily, if not exclusively, from poor farmers. Wealthy farmers are evidently unwilling to pay a premium, via reduced averaged profits, to reduce their exposure to *ex ante* risks.

Our study has only been concerned with behavior responsive to the first two moments of the weather distribution. Although this appears to be supported by the data, longer time-series on rainfall (and other aspects of weather) may permit richer models of risk behavior. Our analysis has also taken the distribution of total wealth holdings as given, although our empirical analysis accommodated heterogeneity in risk preferences and its consequences for the accumulation of wealth levels. Finally, our model was concerned solely with the role of assets in mitigating risk *ex ante* and assumed away the dynamic behavior, in particular the holding of assets to smooth consumption *ex post*. Indeed, we obtained some evidence that in the environment studied, conventionally-defined liquid assets and draft animals appeared to be traded intertemporally in response to realized income fluctuations. A dynamic analysis of investment and consumption smoothing incorporating weather risk may shed additional light on the determination of agricultural investments. Such an approach may also be a more appropriate framework with which to study savings behavior in low-income rural settings, where investment and consumption decisions are closely linked.

Footnotes

1. Antle (1987) is one of the only econometric studies to investigate actual risk behavior. He employs a random coefficients procedure to estimate the pre-harvest labor allocation rules of Indian rice farmers, thus assuming that risk attitudes are randomly distributed, rather than reflective of actual wealth holdings. In that study, the strong assumption is also made that a farmer's allocation of inputs for a particular crop are independent of the risks and other technological factors associated with other crops grown.

2. An important assumption, embedded in (2) and (3), is that the $\tilde{\alpha}_i$ are chosen prior to the realization of the stochastic variables, but once uncertainty is resolved, all other (variable) inputs are allocated to maximize profits. Under this assumption, functions (2) and (3) reflect solely the technology of production and the impact of the weather variable on input and output prices (as in Antle, 1987). Risk preferences influence only the allocation of the $\tilde{\alpha}_i$. The model is thus separable in variable inputs, but not in capital stocks.

3. Thus, we cannot test the separation theorem with these data.

4. We also regressed, using random effects, the total value of crop output on the rainfall variables. These estimates also indicated the importance of rainfall timing relative to quantity. Moreover, the monsoon onset date explained significantly more of the variability in output than in profits, with a one standard deviation in the onset date reducing real output value by 8.4 percent. The stronger effect of the timing of the monsoon on output compared to profits reflects the ex post adjustment of variable input costs by farmers after the resolution of the timing of the rainy season. The

scope for _ex post_, profit-maximizing input adjustment thus reduces profit risk relative to output or yield risk.

5. The residual also contains measurement error so that it is not possible to quantify the effect of the true variability in profits net of weather shocks.

6. Our estimates of the marginal returns to male and female family members, at the sample means, indicates a return for males 25 percent higher than that for females. This almost wholly reflects male/female differences in labor force participation.

7. Village informants have suggested that the sample period was characterized by worse-than-average rainfall levels; sample-period variability in rainfall was not extraordinary.

8. Inclusion of the current onset data in the reduced-form Γ equations, based on the investment portfolios, did not add significantly to the explanatory power of those equations, as expected.

References

Antle, John M., "Econometric Estimation of Producers' Risk Attributes," Journal of Agricultural Economics, August 1987, 505-522.

Bardhan, Pranab K., "Size, Productivity and Returns to Scale: An Analysis of Farm-Level Data in India Agriculture," Journal of Political Economy 81, November/December 1973, 1370-1386.

Behrman, Jere and Anil Deolalikar, "Wages and Labor Supply in Rural India: The Role of Health, Nutrition and Seasonality," in Sahn, D. E., ed., Causes and Implications of Seasonal Variability in Household Food Insecurity, Washington, DC: International Food Policy Research Institute, 1987.

Bell, Clive, and T. N. Srinivasan, "The Demand for Attached Farm Servants in Andhra Pradesh, Bihar and Punjab," 1985, mimeo.

Benjamin, Dwayne, "Household Composition and Labor Demand: A Test of Rural Labor Market Efficiency," Woodrow Wilson School, Princeton University, RPDS Discussion Paper No. 140, November 1988.

Binswanger, Hans P., "Attitudes Towards Risk: Experimental Measurement in Rural India," American Journal of Agricultural Economics 62, August 1980, 395-407.

__________, "Attitudes Towards Risk: Theoretical Implications of an Experiment in Rural India," Economic Journal 91, September 1981, 867-889.

__________ and Mark R. Rosenzweig, "Credit Markets, Wealth and Endowments in Rural South India," Agriculture and Rural Development Department, World Bank Discussion Paper No. ARU59, October 1986.

Dasgupta, Partha, and D. Ray, "Inequality, Malnutrition and Unemployment: A Critique of the Market Mechanism," 1984, mimeo.

Dillon, J. and Peter Scandizzo, "Risk Attitudes of Subsistence Farmers in Northeast Brazil," American Journal of Agricultural Economics 60, September 1978, 425-435.

Feder, Gershon, "The Impact of Uncertainty in a Class of Objective Functions," Journal of Economic Theory 16, December 1977, 504-512.

Herdt, R. W., The Impact of Rainfall and Irrigation on Crops in Punjab, 1907-1948," Indian Journal of Agricultural Economics, March-May 1972.

Lau, Lawrence J., "A Characterization of the Normalized Restricted Profit Function," Journal of Economic Theory 12, 1976, 131-163.

__________, "Testing and Imposing Monotonicity, Convexity and Quasi-Convexity Constraints," in Production Economics: A Dual Approach to Theory and Applications 1978, 409-453.

Lopez, Ramon E., "Structural Models of the Farm Household that Allow for Interdependent-Utility and Profit-Maximization Decisions," in Singh, Inderjit, Lyn Squire and John Strauss, eds., Agricultural Household Models, Baltimore: The Johns Hopkins Press, 1986, 306-325.

Mazumdar, Dipak, "The Theory of Sharecropping, with Labor Market Dualism," Economica 42, August 1975, 261-271.

McGuirk, Anya M. and Richard N. Boisvert, "A Dynamic Model of Acreage Allocation Decisions with Endogenous Land Quality," December 1988, mimeo.

Meyer, Jack, "Two-Moment Decision Models and Expected Utility Maximization," American Economic Review 77, June 1987, 428-430.

Moscardi, E. and Alain de Janvry, "Attitudes Towards Risk Among Peasants: An Econometric Approach," American Journal of Agricultural Economics 59, August 1977, 710-716.

Mundlak, Yair, "On the Pooling of Time Series and Cross Section Data," Econometrica 46, January 1978, 69-85.

Paxson, Christina H., "Household Savings in Thailand: Responses to Income Shocks," Woodrow Wilson School, Princeton University, RPDS Discussion Paper No. 137, February 1988.

Pitt, Mark M. and Mark R. Rosenzweig, "Agricultural Prices, Food Consumption, and the Health and Productivity of Indonesian Farmers," Agricultural Household Models, Baltimore: The Johns Hopkins Press, 1986, 153-182

Rosenzweig, Mark R., "Risk, Implicit Contracts and the Family in Rural Areas of Low-Income Countries," Economic Journal 98, December 1988, 1148-1170.

__________ and Oded Stark, "Consumption Smoothing, Migration and Marriage," Journal of Political Economy 97, August 1989.

__________ and Kenneth I. Wolpin, "Specific Experience, Household Structure and Intergenerational Transfers: Farm Family Land and Labor Arrangements in Developing Countries," Quarterly Journal of Economics 100, Supplement, 1985.

Sen, Amartya K., "Peasants and Dualism with or without Surplus Labor," Journal of Political Economy 74, June 1966, 425-450.

Singh, R. P., Hans P. Binswanger, and N. S. Jodha, Manual of Instructions for Economic Investigators in ICRISAT's Village Level Studies, International Crop Research Institute for the Semi-Arid Tropics, Hyderabad, India, May 1985.

Tobin, James, "Liquidity Preferences as Behavior Towards Risk," Review of Economic Studies 25, February 1958, 65-86.

Wolpin, Kenneth I., "A New Test of the Permanent Income Hypothesis: The Impact of Weather on the Income and Consumption of Farm Households in India," International Economic Review 23, October 1982, 583-594.