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

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Investment portfolios of small farmers reflect their difficulties in smoothing consumption in the face of high risks. Improving farmers' ability to smooth consumption — perhaps through public employment schemes or increased consumption credit — would increase the overall profitability of their investments and would decrease inequality of earnings in high-risk areas.

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Despite the growing evidence that farmers in low-income environments are risk-averse, there ha. been little empirical evidence on the importance of risk in shaping the actual allocation of production resources among farmers differentiated by wealth.

Rosenzweig and Binswanger use panel data on investments in rural India to examine how the composition of productive and nonproductive asset holdings varies across farmers with different levels of total wealth and across farmers facing different degrees of weather risk.

Income variability is a prominent feature of the experience of rural agents in low-income countries. Rosenzweig and Binswanger report evidence, based on measures of rainfall variability, that the agricultural investment portfolio behavior of farmers in such settings reflects risk aversion, due evidently to limitations on consumption-smoothing mechanisms such as crop insurance or credit markets. The authors' results suggest that uninsured weather risk is a significant cause of lower efficiency and lower average incomes: A one-standard-deviation decrease in weather risk (measured by 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, rainfall variability induces a more unequal distribution of average incomes for a given distribution of wealth. Wealthier farmers are willing to absorb significant risk without giving up profits to reduce production risk. Smaller farmers have to invest their limited wealth in ways that reduce their exposure to risk at the cost of lower profit rates.

The authors found that at high levels of rainfall variability, differences in rates of profit per unit of agricultural assets were similar across classes of wealth. But over the sample range of rainfall variability, these rates of profit were always higher for the poorer farmers than for the wealthier ones, suggesting that the disadvantages of small farmers in risk diffusion are more than offset by their labor cost advantage.

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

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A major issue in the economic development literature has been the relationship between average productivity and the distribution of wealth, in particular the distribution of land. Attention has been focused on how features of rural labor markets in low-income settings, such as market segmentation and nutrition-wage interactions, imply that efficiency gains could arise from an equalizing distribution of land (e.g., Mazumdar, 1977; Dasgupta and Ray, 1984). These concerns have led to a large number of empirical tests of technical scale economies (e.g., Bardhan, 1973), of farm household "separability" (Lopez, 1986; Pitt and Rosenzweig, 1982; Benjamin, 1992), and of health-wage associations (Behrman and Deolalikar, 1987).

Studies related to the distribution-efficiency issue in 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 risk-averse (Moscardi and deJanvry, 1977; Dillon and Scandizzo, 1978; Binswanger, 1980, Antle, 1987 and 1989), 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. 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.

In this paper we utilize 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 levels of total wealth and across farmers facing different degrees of weather risk. In particular, we i) measure the riskiness of farmers' investment portfolios in terms of their sensitivity to weather variation, ii) 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, and iii) estimate how the influence of exogenous weather risk on portfolio riskiness and on farm profitability varies with total wealth.

We focus on weather-related risk for two reasons. First, there is a great deal of information on weather, so that this important and exogenous component of the riskiness of the environment can be measured along with the farmer responses to it.[1] Second, although weather is not the only factor exogenously affecting the variability in farm output and profits, it is the factor contributing to income variability that is most likely to influence welfare. This is because weather risk is spatially covariant. Unlike for idiosyncratic risk, it is difficult for farmers to undertake arrangements that insure against risks such as rainfall that affect everyone in their local community similarly. Risk will be reflected in ex ante investment and production decisions only to the extent that risk is not insurable, and weather risk appears to be uninsured in most low-income settings.

Prior studies of farmer risk aversion (Just and Pope, 1978; Antle, 1987 and 1989) assume that farmers cannot insure against any risk ex ante and cannot perform any consumption smoothing ex post. In these studies farmer utility depends on farm income, so that farmer consumption variability is isomorphic with farm profit variability. Recent evidence (Rosenzweig, 1988; Rosenzweig and Stark, 1989; Walker and Jodha, 1986), also based on the same data used in this paper, suggests, however, that rural agents employ a variety of formal and informal mechanisms that contribute to ex post consumption-smoothing. Moreover, the same data even suggests that such agents are successful in insuring against all non-covariant risk, in particular all risk that is not common to agents residing in a given village (Townsend, 1990). This evidence suggests that measuring risk preferences based on the relationship between moments of the distribution function of total farmer profits may not be appropriate because not all of profit riskiness affects utility, as is assumed in the farm-based studies. Estimates of consumption preferences cannot be obtained without specifying the constraints facing agents, in particular, the mechanisms they have established for ex post consumption-smoothing, inclusive of stock accumulation. We do not in this paper, therefore, attempt to directly measure risk preferences.[2]

In part one of the paper, we set out a framework for exploring the determination of the portfolio of agricultural investments under risk which explicitly incorporates the first two moments of the distribution of weather outcomes and takes account of farmers' differing ex post abilities to deal with weather risk. The model is based on the assumption that farmers, according to their risk preferences and ex post abilities to cope with risk, choose a set of assets differentially sensitive to weather-variability. The model provides a test for the existence of risk aversion and establishes the relationship between exogenous risk and portfolio choice by wealth class. Estimates of the production technology are shown to be sufficient in this framework to test for risk aversion and to measure portfolio riskiness among individual farmers.[3]

Section two contains a description of the data and a discussion of measurement issues, with particular attention to the measurement of weather, and a test of the relative importance of weather variability and other sources of income risk in actually influencing consumption. 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 weather risk and wealth on the riskiness and profitability of farmers' asset portfolios are estimated. These estimates are also used to test for the existence of heterogeneity in risk-preferences.

The empirical results reject the hypothesis that the composition of agricultural investments reflects technical scale economies. They support the hypothesis that the composition of asset portfolios are influenced significantly by farmers' aversion to risk, by their wealth and by the degree of rainfall variability. In particular, farmers in riskier environments select portfolios of assets that are less sensitive to rainfall variation and thus less profitable. 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 poorer farmers. As a consequence of uninsured weather risk, average incomes are thus not only lower but income inequality is exacerbated relative to the distribution of wealth. The results also indicate that average profit losses for wealthier farmers are smaller than for less-wealthy farmers in rainfall-variable environments and differentials in rates of profit per unit of productive wealth by wealth class shrink as rainfall variability increases. Nevertheless, in our sample, rates of profits for small farmers always exceeded those of the wealthiest farmers over the sample range of rainfall variability.

1. Theoretical Framework

We consider a farmer with total asset holdings (wealth) W who allocates his n production assets prior to the realization of a random weather outcome w 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 weather 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 distribution of consumption. This is so because it is straightforward to map changes in the moments of the observed stochastic variable (weather) into changes in the moments 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) $U = V(\mu_c, \sigma_c), \qquad V_\mu > 0,\ V_\sigma < 0,$

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

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

Note that in (2) and (3) the mean and standard deviation of profits per unit of wealth are homogenous of degree 0 in total wealth W, reflecting the CRS assumption. They are homogeneous of degree one 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 portfolio.[4]

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 $\sigma_c = \sigma_\Pi$, as is assumed in farm risk studies (e.g., Just and Pope, 1978 and 1979; Antle, 1987 and 1989). On the other hand, if farmers are fully insured against income fluctuations, $\sigma_c = 0$, as is assumed in, for example, studies of savings based on the permanent income hypothesis (e.g. Wolpin, 1980; Paxson, 1992). 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 influenced by total wealth:

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

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

The set of first order conditions are given by

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

where $f_{\alpha_i} = f_i - f_n$ and $\Gamma_{\alpha_i} = \Gamma_i - \Gamma_n$, with f_j and Γ_j marginal contributions of the jth production capital to the mean and to the standard deviation, respectively, of profits. The profit maximization condition is $f_{\alpha_i} = 0$. Therefore, 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 were able to maximize (expected) profits.

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 make higher-than-average contributions to profit variability in equilibrium ("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.

Implications can also be derived from this framework concerning the wealth-differentiated effects of weather risk on the riskiness of farmer portfolios and their profitability. These are derived in the Appendix. First, it can be shown that the effect of a mean-preserving change in the standard deviation of the weather distribution leads to a reduction in Γ, portfolio riskiness, and therefore in farm profitability. The magnitude of the effect of an increase in weather riskiness, however, declines with the total wealth of the farmer if i) there is declining relative and absolute risk aversion or ii) $\kappa' < 0$, wealth facilitates ex post consumption smoothing. Thus, wealthy or "large" farmers may possibly be more efficient than small farmers (and exhibit more variable incomes) in areas in which weather risk is sufficiently high, even if risk aversion does not depend on wealth, as long as the more wealthy are better able than the less wealthy to smooth consumption. Because the responsiveness of asset portfolios to risk depends on both preferences and on constraints, it is clear that the observed relationship between the moments of the profit distribution (profitability and riskiness in this case) by wealth class cannot alone be used to characterize preferences, as in Antle (1989). More importantly, the overall profitability of farmer asset portfolios and the inequality in the distribution of profits can be improved via interventions that do not necessarily require a redistribution of wealth; in particular those that reduce constraints on ex post consumption-smoothing; e.g., credit market improvements, weather insurance, or employment schemes may be as effective. However, as discussed in Binswanger and Rosenzweig (1976), covariance and moral hazard make the establishment of credit programs and insurance particularly difficult in rural areas, and the poor experience of such schemes is testimony to this difficulty (Hazell et al., 1986).

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 portfolios 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. In addition, on approximately July 1 of each year a complete asset survey was undertaken for all survey households. As part of the survey, daily rainfall information was also obtained. 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. It is thus possible with these data to construct a number of alternative measures of rainfall incidence and variability, and to measure asset portfolios, total farmer wealth and farm profits.

The semi-arid tropics in which the ICRISAT study villages reside are characterized by 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.[5] 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. 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 buffalos; 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, imposing as little structure as possible on the technology, we characterize the profit function using the normalized quadratic form, where we normalize by total wealth holdings W. Thus profits for each farmer k in period t are given by

$$\Pi_{kt} = \sum_i \beta_i \alpha_{ikt} + \tfrac{1}{2}\sum_i \sum_j \delta_{ij}\alpha_{ikt}\alpha_{jkt} + \sum \gamma_i \alpha_{ikt}\omega_t + \gamma_\omega \omega_t + \epsilon_{kt} + v_k, \tag{8}$$

where ϵ_{kt} is an i.i.d. error and v_k is a time-invariant error. The parameters in (8) are assumed to pertain to all farmers and solely reflect technology. The latter will be so as long as pre-harvest variable inputs are allocated in fixed proportion to assets and farmers maximize short-run profits, given the set of α_is, based on the weather outcome realized after all investments have been undertaken.[6]

One advantage of the quadratic form (8) is that statistical tests of global quasi-concavity (in the α_i) can be readily implemented (Lau, 1976), because the relevant Hessian matrix of second partials consists only of the estimated δ_is. If (8) 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 (8) is of a simple form:

(9) $\Gamma = \mathrm{sqrt}((\sum_i \gamma_i \alpha_i + \gamma_\omega)^2)$.

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 e_{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 products) on the monsoon onset date and then on all six weather variables, using all farm households in the ten ICRISAT villages.

Reduced-form random effects estimates of the influence of the rainfall variables on profits are presented in Table 1.[7] 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 (average sample profits from crop production, in 1983 rupees, is 3700). 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 both this measure of rainfall and the onset date as weather variables in our estimation of (8), 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.[8]

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

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.

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 ex post by utilizing locally-supplied credit or via other village-based risk-sharing arrangements. Binswanger and Rosenzweig (1987) and Rosenzweig (1988) 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 ex ante risk reduction through altering the portfolio of investments which differ in their sensitivity 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

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 (1.53)[a]	-71.9 (1.35)
Age squared	.438 (0.78)	.373 (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.

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 $\bar{\alpha}_i$. This residual measure of household-specific income, orthogonal to income determined by the weather, has an effect on food consumption that is only 0.6 of a percent that of actual profits. Common weather shocks to income appear to have substantially greater consequences for consumption than does idiosyncratic risk, a result consistent with Townsend's findings (1990), based on the same data, that only village-level shocks affected the individual movements in consumption.[9] These results also suggest that estimates of risk preferences based on the assumption that farmers have to absorb all income risk are misleading.

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

Table 3 reports test statistics based on our estimates of the normalized restricted profit function (8). In addition to the eight investment types (excluding consumer durables as part of the normalization) and the two weather measures, we included in the specification total wealth and its square, to test for scale effects, the number of adult male 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

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

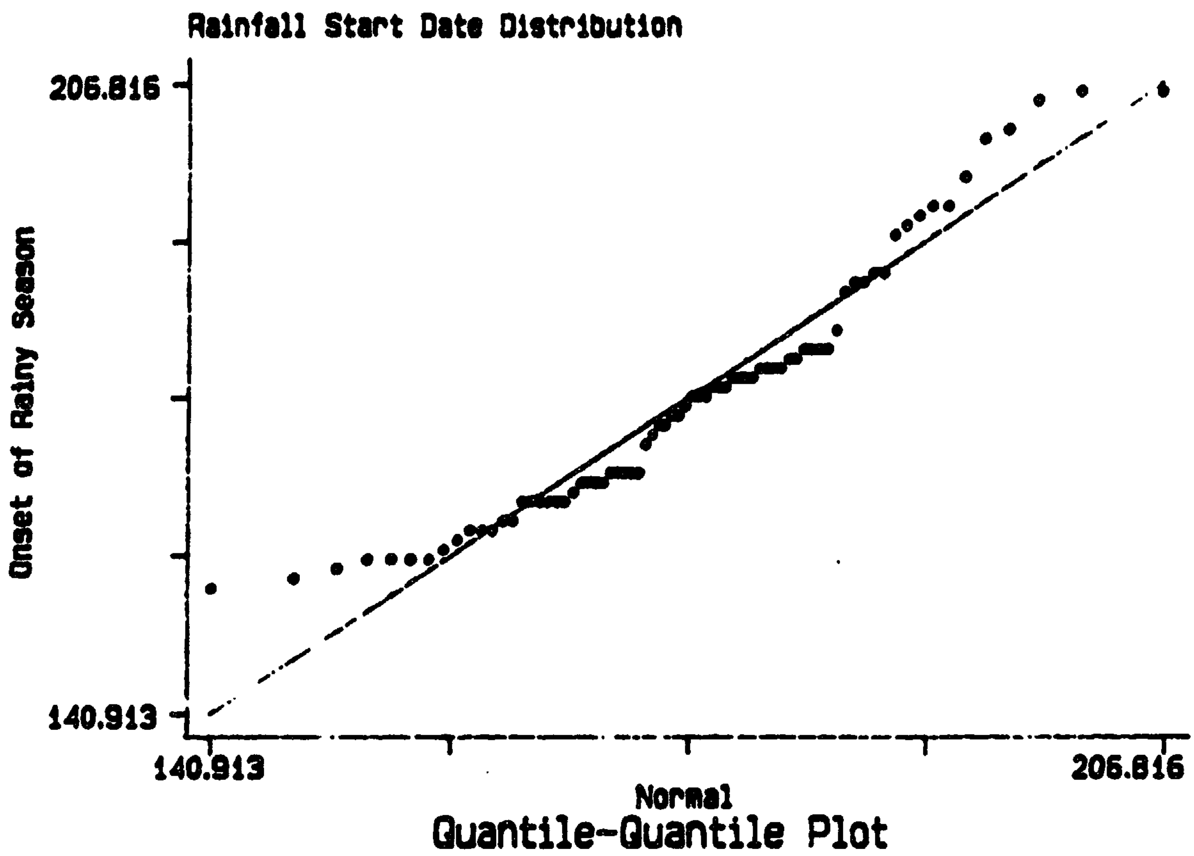
a. Estimation procedure: fixed effects.

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.[10]

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 in weather and very slow technological change, experience, but not formal schooling, has real payoffs, as found in Rosenzweig and Wolpin (1985).[11] The tests also reject the hypothesis that the size of the family labor force does not influence profits. This result appears to contradict the findings by Pitt and Rosenzweig (1986) and by Benjamin (1992), based on Indonesian data, indicating the perfect substitutability of hired and family labor.

A necessary and sufficient condition for the global quasi-concavity of the profit function (8) 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 (8) replacing the matrix of δ_{ij}s by parameters corresponding to the Cholesky

Figure 1.



Rainfall Start Date Distribution
206.816
140.913
Onset of Rainy Season
140.913
206.816
Normal
Quantile-Quantile Plot

factorization of that matrix. Non-linear least squares estimates of (8), with Cholesky factor terms replacing the δ_{ij}, yield direct estimates of the Cholesky factors, which also should be non-positive. These results indicated 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.

Based on the normalized profit function parameter estimates, we present in Table 4 for all eight investment inputs the computed marginal profit level effects, evaluated at the sample means, and the marginal profit variance effects, with their associated asymptotic t-ratios. 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

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.

that specific capital items may be more or less useful in smoothing consumption *ex post*. With the k-function having as arguments not only total wealth but α^*_i as well, the equilibrium condition (6) becomes

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

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, evidence in Rosenzweig and Wolpin (forthcoming) based on the ICRISAT data suggests that bullocks play a predominant role in consumption smoothing among the other durable agricultural stocks. Given evident constraints on borrowing and the liquidity of bullocks, most farmers are unable to sustain profit-maximizing bullock stocks, which thus exhibit high marginal profit level returns.

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

Based on the estimates of the profit function and on the actual asset portfolios α^*_i of the household we can construct individual measures of portfolio riskiness Γ_k, from (9), for each farm household k. 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 household 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 riskiness or weather sensitivity is thus 9.3.

The risk framework suggests that portfolio riskiness should vary with the first two moments of the weather distribution and with total wealth. Moreover, the effect of an increase in weather risk (a mean-preserving shift in the variability of weather) on the riskiness and profitability of the portfolio is likely to depend on the total level of household wealth. 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 may vary across the farmers in our sample.[12] 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.

The ICRISAT data enable us to use two procedures that may circumvent the bias due to risk-preference heterogeneity. First, to the extent that preferences 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. 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.

Based on the data from the six original villages where the longer time-series of weather are available, we report in Table 5 estimates of i) the

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

Variable/ Estimation Procedure	Random Effects	Fixed Effects	Random Effects
Coefficient of variation in onset (CV)	-.884	-	-.551
	(4.14)[a]		(2.85)
CV·total wealth ($x10^{-4}$)	.133	.0693	-
	(7.68)	(6.30)	
CV·inherited wealth ($x10^{-4}$)	-	-	.0731
			(5.32)
Total wealth ($x10^{-4}$)	-7.10	-4.13	-
	(5.72)	(4.93)	
Inherited wealth ($x10^{-4}$)	-	-	-5.13
			(4.78)
Mean onset date	.471	-	.132
	(0.26)		(0.08)
Age	.590	.351	.490
	(1.72)	(1.64)	(1.57)
Constant	76.3	-	69.1
	(2.13)		(2.13)
F	42.9	8.80	43.8
χ^2 (Breusch-Pagan, d.f.=1)	328.8	-	176.5
χ^2 (Hausman, d.f.=3)	103.0	-	0.74

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

effects on portfolio riskiness Γ of changes in the village-specific mean and coefficient of variation (expressed as a percentage) of the monsoon onset date (CV), ii) household total wealth and iii) the onset CV interacted with wealth. In the first column, the coefficients obtained using the random effects estimation procedure are reported.[13] 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 weather risk (the onset CV) significantly decreases portfolio riskiness. And the effect of weather risk on portfolio riskiness declines significantly with wealth.

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 therefore we report the fixed effects estimates of the determinants of Γ. This procedure only permits 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 column, 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. The Hausman test indicates that for this specification, we cannot reject the hypothesis that the inherited wealth variables are orthogonal to the error term.

The results in Table 5 thus indicate that farmers not only reduce the responsiveness of the returns of their asset portfolio to rainfall variation when there is greater expected rainfall variability but that this response is attenuated as wealth increases. To assess how changes in weather variability affect profit variability via the portfolio response, and how this relationship changes with wealth level, we used the inherited-wealth coefficients in Table 5 to predict Γ for the range of values of the standard deviation in the monsoon onset date in the six ICRISAT villages, from 9.4 to 25.1 weeks, and for quintiles of the wealth distribution. These predicted Γ's were then used to compute profit variability induced by rainfall, measured by the CV of profits (expressed as a percentage). The CV of profits at each wealth level is based on the relationship (3) between the standard deviations in profits and weather. Dividing both sides of (3) by profits yields:

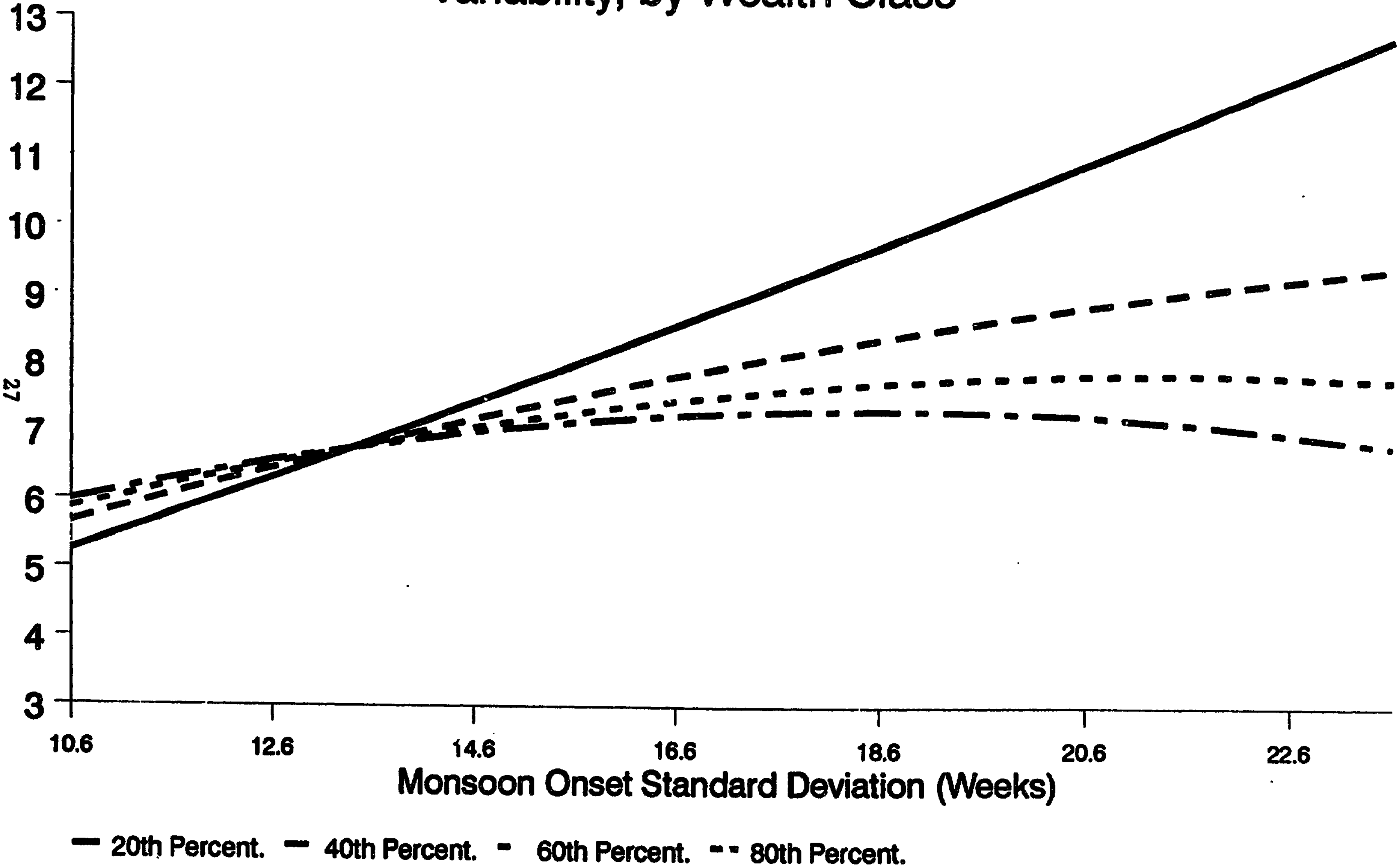
(10) $CV_{\Pi} = R\Gamma(\bar{\alpha}_i)\sigma_{\omega}$

where R is the inverse of the profit rate expressed in terms of total wealth (Π/W). We fixed the profit rate at the sample mean of 0.11.

Figure 2 displays the predicted relationships between the onset standard deviation and the profit CV for four farmer wealth classes. As can be seen, for farmers at wealth levels below the top 20 percent, increases in rainfall variability increase the variability of profits less than proportionally, with the least wealthy farmers attenuating the effects of weather risk to the greatest extent as weather risk increases. The top 20 percent of farm households, however, are evidently able or willing to completely absorb all rainfall-induced profit risk, as reflected in the linearity of the profit-rainfall variability plot for this wealth group. As a consequence of the differential response of portfolio riskiness by wealth, differences in profit variability by wealth class widen as rainfall variability increases. While the rainfall-induced CV in profits is approximately the same for all wealth classes at the sample average of the onset standard deviation (13.6), at a rainfall standard deviation of 19, for

Figure 2.

Profit Variability (CV) and Weather Variability, by Wealth Class



example, the rainfall component of the profit CV for the top 20 percent of farmers is 50 percent greater than that of the bottom 20 percent (10.7 versus 7).

The central proposition of the portfolio model, as expressed in equilibrium condition (6), is that farmers trade-off income variability with profitability. The results in Table 5 and Figure 2, therefore, suggest that profit levels should not only be less affected by weather risk among wealthier farmers but, at least in environments with high rainfall variability, the profitability of wealthier farmers per unit of wealth may exceed that of the less wealthy, given the evident higher ability or willingness of the wealthy to tolerate profit variability. To examine relationships between farm profits, weather variability, and wealth we use the same procedures and specifications as employed in obtaining estimates of the determinants of portfolio riskiness, except that the current-year onset date is also included, because the current weather state affects profit realizations (but not the pre-season composition of assets).[14] 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 farm profit levels. In the specifications based on contemporaneous wealth levels, the coefficient estimates are similar in sign patterns to those of Table 5, as expected. The estimates also appear to be robust to estimation procedure. In particular, the statistically significant wealth and CV-wealth interaction 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 specification employing inherited rather than current wealth, reported in the last column of Table 6, is estimated less precisely, but the CV/inherited wealth

Table 6
Determinants of Profit Levels: Six ICRISAT Villages

Variable/ Estimation Procedure	Random Effects	Fixed Effects	Random Effects
Coefficient of variation in onset (CV)	-24.7	-	-11.2
	(1.33)[a]		(1.06)
CV·total wealth ($x10^{-4}$)	2.91	3.28	-
	(2.35)	(2.03)	
CV·inherited wealth ($x10^{-4}$)	-	-	2.11
			(2.89)
Total wealth ($x10^{-4}$)	440.8	308.2	-
	(5.15)	(2.84)	
Inherited wealth ($x10^{-4}$)	-	-	25.1
			(0.44)
Onset date	-14.2	-13.2	-15.9
	(2.11)	(1.93)	(1.17)
Mean onset date	247.8	-	-229.1
	(1.46)		(2.46)
Age	24.4	40.1	394.6
	(0.95)	(1.13)	(3.88)
Constant	194.0	-	1990
	(0.06)		(0.54)
F	66.6	29.2	34.0
χ^2 (Breusch-Pagan, d.f.=1)	1924	-	2769
χ^2 (Hausman, d.f.=3)	15.2	-	0.53

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

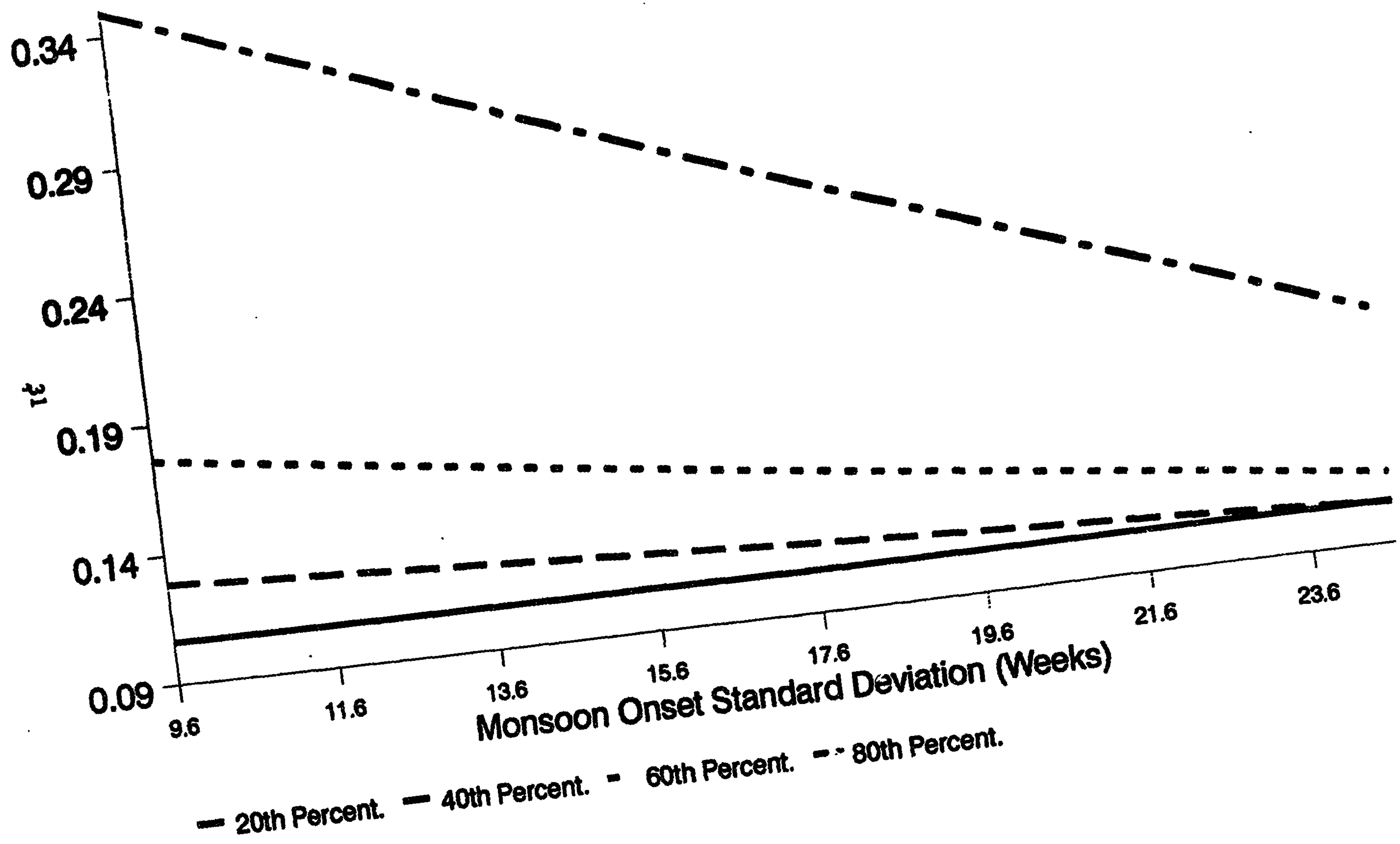
interaction term also indicates that in response to increases in weather variability less-wealthy farmers are significantly more willing to sacrifice profit levels than are wealthier farmers.

The statistically-acceptable first-column parameter estimates suggest 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.

Does the reduced sensitivity of wealthy-farmer profit levels to rainfall risk implied by our estimates suggest that wealthier farmers in rainfall-risky areas have higher profits per unit of wealth than smaller farmers? For each of the four wealth groups depicted in Figure 2 figure 3 plots the predicted rates of profit per unit of productive wealth (wealth less the value of consumer durables) for different values of the standard deviation in the rainfall onset date, based on the first column profit-level estimates in Table 6. These results show that profit rates fall considerably faster for the less wealthy farmers as rainfall variability increases, and that for the top group they do not fall at all. The

Figure 3.

Profit-Wealth Ratios and Weather Variability, by Wealth Class



wealth-specific differences in the slopes of the profit rate curves are quite sharp, resulting in a tendency to convergence in profit rates as rainfall variability increases. At the sample mean standard deviation, the difference between the profit rate of the bottom (second) quintile farmers and that of the top quintile is 20 (5) percentage points; this differential shrinks to 15 (2) percentage points when the standard deviation is 19. However, at all of the sample values of the onset standard deviation smaller farmers exhibit higher rates of profit than larger farmers.

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, 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 weather risk (measured by 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, rainfall 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 significantly more risk while reaping higher average returns than less-wealthy farmers, is evidence against the common supposition that smaller farms are always more efficient than larger farms, a presumption that tends to ignore the returns to agricultural investment holdings. In our data, we found that at high levels of rainfall variability differences in rates of profit per unit of agricultural assets were similar across wealth classes. However, over the sample range of rainfall variability these rates of profits were always higher for the poorer farmers than for the wealthier ones.

The results suggest that improvements in the abilities of farmers to smooth consumption, perhaps via increased consumption credit, would increase the overall 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 do we not observe a market for it? While the supply of insurance against the vagaries of rainfall should be less afflicted by moral hazard among farmers than yield insurance, our results indicate that the demand for rainfall insurance may be quite weak. First, a substantial proportion of profit risk is idiosyncratic, and evidently well-diffused. 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* weather 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, as would data with a larger number of agro-climatic environments. 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 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 where consumption-smoothing opportunities are limited may shed additional light on the determination of agricultural investments (Rosenzweig and Wolpin, forthcoming). Such an approach may also be a more appropriate framework with which to study savings behavior and to characterize risk attitudes in low-income rural settings, where investment and consumption decisions are closely linked.

References

Antle, John M., "Econometric Estimation of Producers' Risk Attributes," Journal of Agricultural Economics 69, August 1987, 505-522.

--------------, "Nonstructural Risk Attitude Estimation," Journal of Agricultural Economics 71, December 1989, 774-784.

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 Compos[illegible]ion, Labor Markets, and Labor Demand: A Testing for Separation in Agricultural Household Models," Econometrica 60, March 1992, 287-322.

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.

__________, Hans P. and Mark R. Rosenzweig, "Behavioural and Material Determinants of Production Relations in Agriculture," The Journal of Development Studies 22, April 1986, 503-539.

__________, 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 1987.

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.

Hazell, Peter, Carlos Pomaseda and Alberto Valdez, eds., Crop Insurance for Agricultural Development: Issues and Experiences. Baltimore: Johns Hopkins Press, 1986.

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

Just, R. E. and R.D. Pope, "Stochastic Specification of Production Functions and Economic Implications," Journal of Econometrics 7, May 1978, 67-86.

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., "Using Weather Variability to Estimate the Response of Savings to Transitory Income in Thailand," American Economic Review 82, March 1992, 15-33.

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.

__________ and Kenneth I. Wolpin, "Credit Market Constraints, Consumption Smoothing and the Accumulation of Durable Production Assets in Low-Income Countries: Investments in Bullocks in India," Journal of Political Economy, forthcoming.

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.

Townsend, Robert M., "Risk and Insurance in Village India," mimeo, University of Chicago, 1990.

Walker, Thomas S. and Narpat S. Jodha, "How Smaal Farm Households Adapt to Risk," in Hazell, Peter, Carlos Pomaseda and Alberto Valdez, eds., Crop Insurance for Agricultural Development: Issues and Experiences. Baltimore: Johns Hopkins Press, 1986, 17-35.

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.

Footnotes

We are grateful to an anonymous referee and an Associate Editor for helpful comments on an earlier draft of this paper. Useful comments were also received from participants at workshops at the Universities of Chicago, Minnesota, and Virginia; Brown, Northwestern and Harvard Universities and the Technion University, Israel.

1. Rainfall information has been used to study intertemporal consumption behavior in the context of models in which there are no constraints on farmers' abilities to smooth consumption (Wolpin, 1982; Paxson, 1992).

2. Rosenzweig and Wolpin (forthcoming) estimate a fully-specified dynamic structural model of stock accumulation incorporating credit-market constraints and informal insurance based on the data set used here. These permit identification of farmer preference orderings, and indicate that farmers are risk averse. Tractability constraints limited the model to one asset (bullocks) and one wealth class, however.

3. Antle (1989), in an innovative and careful study based on a subset of the same data used here and that became known to us after we had completed our study, also employs the insight that if farmers optimally manage their asset portfolios information can be learned from technology estimates about risk behavior. Based on the additional assumption that farmers cannot smooth consumption, however, Antle attempts to estimate the distribution of risk preferences without estimating the rest of the demand structure. We do not believe that this latter assumption is supported by the data and that therefore reliable inferences can be made about the derivatives of farmer preference functions based on this method, at least from the data used here. Moreover, no attempt in that study is made to relate risk preferences, even if they were identified, to the wealth position of farmers nor to quantify the costs of the constraints on consumption smoothing or their distribution.

4. For (2) and (3) to be interpreted as reflecting a profit function, variable inputs must be allocated so as to maximize profits or in fixed proportion to the farm assets. The former assumption is clearly plausible for inputs allocated after the resolution of uncertainty. Antle's (1987) results suggest that some pre-harvest inputs reflect farmer's risk attitudes (and lack of <u>ex post</u> protection) but this would also be true if such inputs are allocated in fixed proportions with assets and the asset portfolio reflects risk factors. Rosenzweig and Wolpin (forthcoming) test the fit of a model which assumes pre-harvest input proportionality with one important farm asset, bullocks.

5. Profits are computed by subtracting from agricultural receipts all paid out costs and the total cost of family labor used in agricultural production, where days of family labor are valued at the relevant age and sex-specific market wage rates.

6. See note 3.

7. The theoretical framework (equation (2)) suggests that the effects of rainfall on profits will differ across farmers to the extent that they choose different asset portfolios. The estimated gross or reduced-form effects of rainfall on profits reflect the average effects in the population. The theoretically-more appropriate specification from which to infer rainfall effects is equation (8), which is estimated below. The results indicating the

importance of the monsoon timing are not sensitive, however, to specification.

8. 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.

9. 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.

10. Antle (1987 and 1989) finds that the distribution of profits is not normal. However, as noted, it is not the characteristics of the distribution of total profits that matter for allocative decisions, only that for the part of profits that is reflected in consumption variability, which in this case is that determined by rainfall.

11. The lack of significance of schooling is not due to the fact that schooling does not change over time. The time-invariant schooling variable is interacted with all time-varying variables (assets and rainfall), which vary significantly over time and have significant effects on profits. Of course, the profit-function schooling result does not mean that schooling has no return in the context of the semi-arid tropics of India. Walker et al. (1990) show that schooling augments wage earnings (inclusive of non-agricultural earnings).

12. By heterogeneity in preferences we mean inter-farmer variation in preference mappings. The evidence on "risk-preference" heterogeneity in Binswanger's experiments (1980) and Antle's econometric studies (1987 and 1989) does not distinguish between variability in preference mappings and variations in preferences that may be due to differences in constraints. If all or most of the variation in the measures of subjective risk aversion are due to constraint variation, then we need be less concerned about the endogeneity of total wealth holdings.

13. The estimation procedure takes into account the non-independence of the observations. The number of farmers in the sample used to obtain the estimates in Tables 5 and 6 is 135. The total number of observations is 1407. The standard Lagrange multiplier test (Breusch-Pagan) indicates rejection of the hypothesis of the independence of the errors. The statistic is reported at the bottom of the tables (the critical chi-square value at the .005 level of significance, for one degree of freedom, is 7.88).

14. 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.

Appendix

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

The first term in brackets in (8), $SW\Gamma$, is the effect on the riskiness of investment due to a 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, <u>ceteris paribus</u>, when farmers are not fully insured ($\kappa > 0$) 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 wealth and portfolio behavior thus cannot be used to make inferences about preferences.

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[1], is given by

$$(10)\quad d(d\alpha_i/d\sigma_\omega)/dW = i\kappa[\Gamma_{\alpha_i} a + \Gamma S]\Phi^{-1} - \frac{d\alpha_i}{d\sigma_\omega}[-f_{\alpha_i} A + \Gamma_{\alpha_i} \kappa\sigma_\omega S + a\Gamma_{\alpha\alpha}\sigma_\omega\kappa + bf_{\alpha\alpha}]\Phi^{-1} + \frac{\kappa'}{\kappa}[\frac{d\alpha_i}{d\alpha_\omega} - \kappa' V_{\sigma\sigma}\Gamma_{\alpha_i}\sigma_{\Pi}\Phi^{-1}].$$

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 >=

0) and f and Γ are concave. The last bracketed term in (10) arises from the potential effect of wealth in facilitating consumption smoothing ex post ($\kappa' < 0$) 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.

1. Antle (1987 and 1989) reports evidence that the third derivative of the utility function is not small. However, as noted, this evidence is based on the assumption that no farmers can shed any income risk.

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