Journal of Agricultural and Applied Economics, 36,1(April 2004):241–250

Risk and Fertilizer Use in the Rainfed Rice Ecosystem of Tarlac, Philippines

Abedullah and Sushil Pandey

The study analyzes the effect of risk aversion on the optimal level of fertilizer by employing a pooled time-series cross-sectional survey data collected from 46 rainfed rice farmers in Tarlac, Central Luzon, Philippines. Based on a heteroscedastic specification of production function, fertilizer was found to be a risk-increasing input, but the effect of risk aversion on the optimal fertilizer use was estimated to be moderate. Explanations for the low average rate of application of fertilizer under rainfed conditions thus need to be found elsewhere.

Key Words: expected utility, fertilizer, heteroscedastic production function, Just and Pope's and Antle's techniques, rainfed, risk aversion

JEL Classification: Q12

Farming is a risky enterprise, especially under rainfed conditions. Prices at the time of harvest, technological change, government action, and weather conditions can seldom be anticipated (Kalirajan and Huysman). Production risk arises mainly from the natural environment and is associated with uncertainties in climate, particularly precipitation and, to some extent, temperature. Production risk is one of the major constraints in the rainfed ecosystem that can retard technology adoption and lower the social welfare (Ahsan, Ali, and Kurian). It is believed that modern varieties (MVs) have not realized their full potential because year-to-year yield variability makes it risky for farmers to apply economically optimal levels of inputs (Barker; Pandey et al.). Crop response to fertilizer varies from year to year, even on the same plot, because of stochastic disturbances such as weather, pests, and diseases. It is frequently argued that aversion to risk and production risk make farmers hesitant to apply the profit-maximizing or optimal level of fertilizers. However, empirical evidence of this is somewhat ambiguous (Rosegrant and Roumasset). Most of the studies summarized by Rosegrant and Roumasset pertain to irrigated rice production. It would be useful to establish the extent to which risk and risk aversion lead to a reduced use of fertilizers in rainfed rice systems.

Risk and risk aversion are not the only potential sources of low investment or "underinvestment"; low investment could also result from generally low profitability or from credit constraints (Rosegrant and Roumasset; Roumasset). To establish the concept that it is risk and risk aversion that lead to underinvestment, empirical evidence is required. Riskiness or an increase in riskiness with input use will lead to underinvestment only if farmers are risk-averse (Ramaswami; Rosegrant and Roumas-

---

Abedullah is scientific project assistant, Institut für Agrarökonomie und Verfahrenstechnik, University of Rostock, Justus-von-Liebig-Weg 7, Germany. Sushil Pandey is agricultural economist and deputy head Social Sciences Division (SSD), International Rice Research Institute (IRRI), Manila, Philippines.

The authors wish to thank two anonymous reviewers of the *Journal* for their useful comments and insights.

set; Sandmo). It has been generally observed that farmers in low-income countries are in fact risk-averse (Anderson and Dillon; Antle 1988; Binswanger; Dillon and Scandizzo; Moscardi and de Janvry).

After Pope and Kramer's work, a considerable amount of theoretical literature has evolved on the impact of different kinds of insurance on input use (Babcock and Hennessy; Horowitz and Lichtenberg; Nimon and Mishra; Smith and Goodwin). However, these studies did not quantify the impact of risk itself on input use. Only a few studies attempted to estimate the effect of risk on the risk-neutral optimal level of fertilizers by employing experimental data from the irrigation system (Rosegrant and Roumasset; Smith and Umali). The level of risk faced by farmers in the rainfed system is expected to be higher than in experimental fields under irrigation conditions because of poorer environmental control under rainfed farmers' conditions. Therefore, risk measures derived from experimental data collected from the irrigated system might not be valid for the farmers' fields in rainfed areas. The purpose of this paper is to add empirical support to the presumed effect of risk on fertilizer use in rainfed conditions. The principal contributions of this paper are i) to apply the risk quantification models to estimate the marginal risk effects in rainfed environments under farmers' conditions, and ii) to compare the results of two popular models of risk estimation, the Just and Pope (1979) and Antle (1983) models. Because it is argued by Just and Pope (2002) that the method of estimation is important, this study examines whether the selection of estimation technique has any effect on the conclusion.

The scheme of the paper is as follows. In the next section, a heteroscedastic production function with a measurable stochastic input (i.e., rainfall) is specified and is applied to the farm-level survey data collected from rainfed rice areas of Tarlac, Philippines. The second section delineates the methodology used to estimate the effect of risk on the risk-neutral optimum level of fertilizer under the expected utility maximization framework. Empirical results are presented, and implications are derived in the subsequent sections.

Analytical Framework

Just and Pope (1979) showed that conventional formulations of production functions with multiplicative random error are inappropriate, as they impose *a priori* restrictions on the marginal risk—i.e., if the marginal contribution of an input to the mean output is positive, then a positive marginal effect on the variance of output is also imposed (Just and Pope 1978).

However, not all inputs are risk increasing—i.e., some inputs, such as irrigation, pesticide, equipment, and others, are likely to reduce risk in production (Carlson 1970, 1979, 1984; Pingali and Roger; Rola and Pingali). In general, erroneous conclusions could be drawn from evaluating policies if the conventional specification is used. To segregate the effect of inputs on the mean and variance of output, a heteroscedastic production function featuring flexible risk effects is needed (Anderson and Griffiths; Just and Pope 1978, 1979).[1] This alternative specification with additive error (Equation (1)) does not restrict the sign of the marginal risk coefficient *a priori.*

$$(1) \qquad Y = F(X) + h^{1/2}(X)\varepsilon, \qquad E(\varepsilon) = 0, \qquad V(\varepsilon) = \sigma^2,$$

where Y is the output, and the X's are independent variables (physical inputs and management factors). F and h represent the functional forms, where $F(X)$ is the deterministic component (representing the mean value of output), $h^{1/2}(X)\varepsilon$ is the stochastic component (capturing the variability of output), and ε is the random error with zero mean and constant variance.

Different techniques are available to esti-

---

[1] The production function is heteroscedastic in the sense that its variance depends on the measured input levels. This suggests that the likely magnitude of farm-specific effects that are not included as inputs, such as managerial ability and quality of land, as well as drought and disease, will be influenced by the measured inputs (Griffiths and Anderson).

Table 1. Per Hectare Output and Input Use and Their Coefficient of Variation (CV) in Tarlac, Central Luzon, Philippines[a]

Explanatory Variables	Mean Value	CV
Parcel Area (ha)	0.9	62
Yield (tons)	3.4	33
Seed (kg)	110	42
Labor (days)	55	28
NPK[c] (kg)	94	43
Herbicide (kg/ai/ha)	0.14	118
Pesticide (kg/ai/ha)	0.09	154
Rainfall (in mm)[b]	1,625	23

[a] All values represent the average of input use estimated from 420 observations (parcels).

[b] Rainfall is the average of 4 months, July–October, for 1990–1995.

[c] NPK represents fertilizer nutrients N, P, and K.

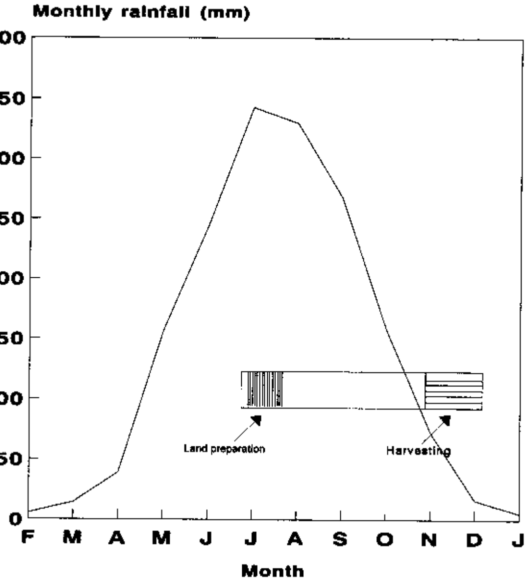

Figure 1. Average Monthly Rainfall for 1977–1995, Victoria, Tarlac, Philippines

mate Equation (1). Just and Pope (1979) proposed a maximum likelihood method of estimating the variance function. Antle (1983) developed a more general approach to obtain consistent and asymptotically efficient parameters of first, second, and higher moments of output. He suggested a Generalized Least Squares estimation technique to estimate all the moments of output. This paper employs both the Just and Pope and the Antle approaches of estimation to study the effect of risk on fertilizer use. The comparison helps us examine whether the choice of estimation technique makes a difference in the conclusion.

Data Source

The study uses pooled time-series and cross-section survey data for 6 years (1990–1995) from Tarlac, Central Luzon, Philippines. The monitoring of rice production practices of 46 randomly selected farmers in the municipality of Victoria began in 1990. Farm records were developed to record data on farm operations by parcel. A team of researchers visited the study area twice a year to interview the farmers. Details of the survey design can be found in the study by Pandey et al. Input-output data on rice for each parcel of land, defined as a contiguous block of land, were analyzed. The database consists of 70 parcels in which rice is grown in each of the 6 years. In the production function, each parcel is considered an observation, and there are (70 × 6) 420 observations for all 6 years. The means and coefficients of variation of output and input variables are reported in Table 1.

Rainfall

The wet season usually starts in late May and ends quite abruptly in mid-October. Farmers grow rice during the wet season, transplanting their crop from the last week of July until the last week of August. The mean annual rainfall in Victoria is 1,924 mm, but the average for the crop production season (July–October) is 1,625 mm. From July to October, the minimum rainfall fluctuated from 156 mm in October to 344 mm in July (Figure 1), and this amount is sufficient for rice.[2] Unless irrigation facilities are available, only crops such as mungbean can be grown during the dry season, which starts in November.

---

[2] The optimum water requirement for rice is about 200 mm/mo. When rainfall is less than 100 mm/mo, crop growth is seriously retarded, especially if the deficit happened during the flowering and grain-filling stages (Syamisiah, Suprapto, and Bhuiyan).

Empirical Representation of Production Functions

The empirical representations of the production function (estimated by Just and Pope's and Antle's methods) employed to estimate the effect of risk on the risk-neutral optimum level of fertilizer use are defined as follows:

$$Y = \theta X_1^{\alpha_1} X_2^{\alpha_2} Z^{\alpha_3} e^{(V^*\alpha_4)} + [\beta_0 X_1^{\beta_1} X_2^{\beta_2} Z^{\beta_3} e^{(V^*\beta_4)}]^{1/2}\varepsilon, \tag{2}$$

where

Y = yield in tons.
X_1 = total labor in person-days/ha.
X_2 = fertilizer nutrients (total of N, P, and K)/ha.
Z = total rainfall during July to October (for the years 1990–1995). This produces only one observation for each year.
V = dummy variable for rice variety. It has a value of 1 for MVs such as IR64 and IR72 and 0 otherwise.
ε = stochastic error term.

Transplanting is the dominant method of crop establishment, and the seeding rate for transplanted rice varies little across households. Therefore, we decided not to include the seeding rate as an explanatory variable. Herbicides and pesticides were initially included as independent variables in our model, but they were subsequently dropped, as their effects were statistically insignificant. The use of insecticides and herbicides is uncommon, as only a few parcels were treated with small quantities of these chemicals. All variables were expressed on a per hectare basis (imposing the condition of constant return to scale); therefore, farm area was not included in the model.

Labor, fertilizer, variety dummy, and total rainfall during the rice production period were the major variables included in the production function estimation. As the analysis is based on parcel-level data on yield and input use, it would have been ideal to have parcel-level data on rainfall also. However, parcel-level rainfall data were not collected in this survey that covered 420 parcels for 6 years. For biological reasons, it would have been more appropriate to specify rainfall as a weekly or monthly total *vis-à-vis* the seasonal total. We used the seasonal total, because a reliable estimation of yield responses to rainfall for each month would not have been possible from the available data for 6 years only due to limited degrees of freedom. Rainfall is the only measurable stochastic variable specified in the production function. The effect of all other stochastic variables is captured in the residual. Year dummies were not included, as rainfall captures the specific-year effect.

Despite its shortcomings as a description of choice under uncertainty, the expected utility model has remained dominant in the analysis of problems involving choice under uncertainty. Therefore, in this study, the effect of risk on the optimum level of fertilizer was explored by means of a constant partial risk aversion (CPRA) utility function using the expected utility framework. This form of utility function has been widely used in applied research (Rosegrant and Roumasset; Sillers; Smith and Umali). The expected utility is derived by substituting the mean and variance of profit (first and second moment) in the Taylor series expression of the CPRA utility function.

$$E[U(\pi)] = (1 - S)(\bar{\pi})^{(1-S)} + (1/2!)\sigma_\pi^2[(-S)(1 - S)^2\bar{\pi}^{-(1+S)}]. \tag{3}$$

In the above formulation, π, $U(\pi)$, and σ_π^2 stand for stochastic profit, utility of profit, and variance of profit, respectively, while S is the risk-aversion parameter. The degree of risk aversion increases with an increase in S. Empirically estimated values of risk-aversion coefficients for the CPRA utility function for Filipino farmers are available from Sillers' study. Several values of risk-aversion coefficients were used to examine the sensitivity of model results to the risk-aversion parameter.

Framework to Estimate the Effect of Risk on Fertilizer Use

Profit is estimated after deducting the cash and noncash costs of inputs from the gross revenue. Gross revenue (*GR*) refers to the total monetary value (including crop share) that goes to the landlord and harvester/thresher as well as the output retained at home. It is computed by multiplying the yield by the product price. The cash cost (*CC*) includes the cost of hired labor, fertilizer, pesticide, and herbicide; the noncash cost (*NCC*) covers the cost of family labor, planting material, harvester, and thresher. The farm-specific gross revenue, cost, and profit are calculated as follows:

$$GR = P_y Y \tag{4}$$

$$CC = P_1 z_1 + P_2 X_2 + C_1 + C_2 \tag{5}$$

$$NCC = P_1 z_2 + P_3 X_3 \quad \text{but} \tag{6}$$

$$X_1 = z_1 + z_2 \quad \text{and}$$

$$GC = CC + NCC \tag{7}$$

$$\pi = P_y Y - P_1 X_1 - P_2 X_2 - P_3 X_3 - C_1 - C_2, \tag{8}$$

where all inputs and outputs are defined on a per hectare basis as shown below:

Y = output in tons,
X_1 = total labor in person-days,
z_1, z_2, = hired and family labor in person-days, respectively,
X_2 = fertilizer nutrients (total of N, P, and K in kg); farmyard manure is converted into N (1 ton of farmyard manure produces 10 kg of active nutrient of N) (Ali). It is evaluated at the average market price of N from urea,
X_3 = planting material in kg,
GC = gross cost, includes the cash and noncash costs,
π = net profit, estimated after deducting all costs from *GR*,
P_y = real price in pesos/t of output, estimated by dividing each year's actual output price by the consumer price index (with a base year of 1990). For farmers who did not sell output in the market, the opportunity value of output is computed at the average market price,
P_1 = real wage rate in pesos per person-day estimated as the actual wage rate divided by the consumer price index. Family labor is evaluated at the average market wage of the respective year,
P_2 = real price of fertilizer nutrients (NPK) in pesos/kg, estimated as actual prices divided by the consumer price index,
P_3 = real price of planting material in pesos/kg, estimated as actual prices divided by the consumer price index. For farmers who did not buy planting material from the market, the opportunity cost of planting material is estimated at the average market price of the planting material,
C_1 = the sum of real pesticide cost, herbicide cost, and tractor cost, estimated as actual costs divided by the consumer price index,
C_2 = the sum of real harvester and thresher costs, estimated as actual costs divided by the consumer price index.

All costs, gross revenues, and net profits are estimated on a per hectare basis. Risk-neutral farmers are assumed to maximize the expected profit. Under the assumption that input-output quantities and their respective prices are identically distributed random variables, the expected value of profit ($\bar{\pi}$) can be written as follows[3]:

$$\begin{aligned} \bar{\pi} = {} & \bar{P}_y \bar{\overset{*}{Y}} + \mathrm{Cov}(P_y, \overset{*}{Y}) - \bar{P}_1 \bar{X}_1 \\ & - \mathrm{Cov}(P_1, X_1) - \bar{P}_2 \bar{X}_2 - \mathrm{Cov}(P_2, X_2) \\ & - \bar{P}_3 \bar{X}_3 - \mathrm{Cov}(P_3, X_3) - \bar{C}_1 - \bar{C}_2, \end{aligned} \tag{9}$$

where $E(\overset{*}{Y}) = \bar{\overset{*}{Y}}$, which is the expected value

---

[3] The expected value of the addition of two variables (dependent or independent) is equal to the sum of the expected values of each variable (Kmenta). The expected value of the product of two independent variables is equal to the product of the expected value of each variable, while the expected value of the product of two dependent variables is equal to the product of the expected value of each variable plus the covariance of the variables (Mood, Franklin, and Duane).

Table 2. Estimates of First and Second Moments of Output from Production Function with Just and Pope's and Antle's Techniques in Tarlac, Central Luzon, Philippines[a]

Explanatory Variables	Just and Pope's Technique		Antle's Technique	
	First Moment	Second Moment	First Moment	Second Moment
Intercept	0.159*	−5.382ns[b]	0.185*	0.023ns
	(0.089)	(4.438)	(0.084)	(0.028)
Labor	0.349***	0.346ns	0.372***	0.112ns
	(0.058)	(0.445)	(0.062)	(0.613)
Fertilizer	0.213***	0.223ns	0.234**	0.205*
	(0.040)	(0.233)	(0.041)	(0.103)
Rainfall	0.087*	0.246ns	0.075*	0.452*
	(0.047)	(0.235)	(0.039)	(0.259)
Variety	0.72*	−0.20*	0.96*	−0.34**
	(0.39)	(0.13)	(0.51)	(0.18)
R^2	0.21	0.05	0.25	0.09

[a] The results are estimated from production function as explained in Equation (2) (from the parcel-level data set, 70 × 6 = 420 observations, 70 observations for each of the 6 years). Numbers in parentheses are asymptotic standard errors.

[b] ns is not significant.

*** Significant at 1%.

** Significant at 5%.

* Significant at 10%.

of the first moments of output for a parcel-specific level of resources (X's). The parcel-specific information related to soil and land quality was not available; hence, such information could not be included. All variables are as defined in Equations (4)–(8). To estimate the risk-neutral optimum level of fertilizers, all variables in Equation (9) were fixed at the mean levels (except for fertilizer), and various profits were estimated by changing the levels of fertilizer. The risk-neutral optimum level of fertilizer was derived by solving for the fertilizer rate that maximized the expected profit in Equation (9). The optimal solution under risk aversion was derived by solving for the fertilizer rate that maximized the expected utility in Equation (3). The difference between the two rates at any particular level of risk aversion is the effect of risk on the optimum level of fertilizer use.

Results of the Production Function Analysis

The Breusch-Pagan test was applied to test for the presence of heteroscedasticity. The null hypothesis of homoscedasticity was rejected at the 5% level.[4] Labor, fertilizer, and total rainfall from July to October (the critical time for rainfed rice production in the study area) are included as explanatory variables in the production function specification. The results of the first and second moments of output estimated by employing the Just and Pope (1979) technique are reported in Table 2 (columns 1 and 2). The signs of labor and fertilizer for the first moment of output are as expected, and both are statistically significant at the 1% level. The rainfall and variety variables are significant only at the 10% level. In the variance function (second moment of output), the effect of labor is positive but not statistically significant. Fertilizer and rainfall are also not statistically significant in the second moment of output. Rice variety is the only variable significant at the 10% level, with the negative sign indicating that MVs reduce risk.

The results of the first and second moments

---

[4] This is based on the simple idea that, if the hypothesis of homoscedasticity is true, the ordinary least-squares estimates of the regression coefficients should not differ significantly from the maximum likelihood estimates that allow the possible heteroscedasticity (Breusch and Pagan).

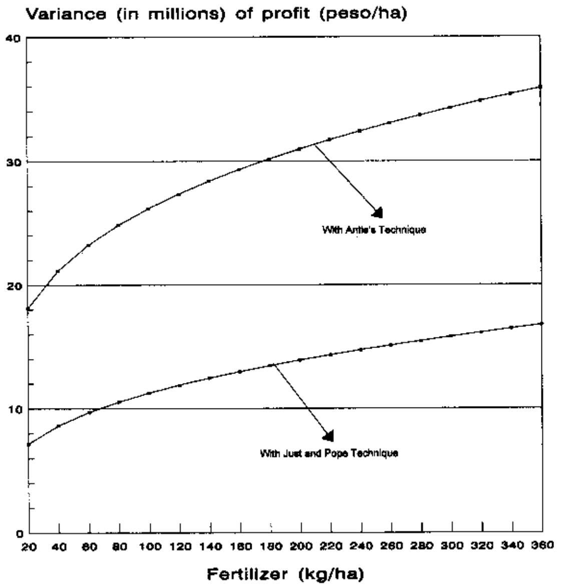

Figure 2. Fertilizer Variance Response from Just and Pope's (1979) and Antle's (1983) Estimation Techniques

of output estimated by employing Antle's (1983) flexible moment-based approach are reported in Table 2 (columns 3 and 4). The signs of labor and fertilizer are positive and highly significant in the first moment of output. However, rainfall and variety variables are significant only at the 10% level. Generally, labor is expected to have a risk-reducing effect, as it can be flexibly allocated to suit the environmental conditions of rice production (Anderson and Griffiths; Budiman). Labor, however, had a positive effect on the variance of output, but the coefficient was not statistically significant. Both fertilizer and rainfall have positive effects on the variance of output, indicating that both have a risk-increasing effect, but the coefficients of both variables are significant only at the 10% level. MVs have a risk-reducing effect, and the coefficient is significant at the 5% level. Once again, results indicate that MVs are less risky. This could have resulted from their having more tolerance of and resistance to pests and diseases.

Figure 2 compares the fertilizer variance response functions in the Just and Pope and Antle estimation techniques. The intercept and slope in Antle's technique are higher than those derived from the Just and Pope technique, implying that, at each fertilizer level, the variance response is higher in the latter technique. The Just and Pope estimation technique has the same weaknesses in computing the second, third, and higher moments of output as the conventional Cobb-Douglas production function has in estimating the first moment. The use of a multiplicative error term while estimating the second and higher moments of output in the Just and Pope model causes this difficulty. As a result, the Just and Pope estimation technique failed to relate the second, third, and higher moments with inputs, as it does not satisfactorily address the underlying problem of heteroscedasticity while estimating the coefficients of these higher moments. Antle used a more general approach to these problems to obtain consistent and asymptotically efficient estimates for the second and higher moments. Our empirical results also indicate that the estimation technique matters.

The Impact of Risk on Fertilizer Use

When farmers were assumed to be extremely risk-averse ($S = 1.8$), the effect of risk on fertilizer use was 36 and 73 kg lower than the risk-neutral optimum level, but in percent terms, the effect was 9% and 19% lower for Just and Pope's and Antle's techniques, respectively (Table 3). Under the assumption that farmers are moderately risk-averse ($S = 0.8$), the effect of risk on fertilizer use was 20 and 38 kg, but in percent terms, the effect was 5% and 10% for the two estimation techniques, respectively. The application of risk-neutral and risk-averse decision-making models predicted that moderately risk-averse farmers would apply only 5% and 10% less fertilizer than risk-neutral farmers. The effect of risk aversion on fertilizer use derived here falls within the range estimated by Rosegrant and Roumasset, but it is slightly below that obtained by Smith and Umali. The effect of risk because of less use of fertilizer on yield varied from 14 to 97 kg/ha for the Just and Pope method and from 22 to 188 kg/ha for the Antle technique, depending on the degree of

Table 3. The Reduction in the Risk-Neutral Optimum Level of Fertilizer Use with Different Estimation Techniques in Tarlac, Central Luzon, Philippines

	Reduction Compared with Risk-Neutral Optimal			
Risk-Aversion Level	Just and Pope's Method (kg)	Antle's Method (kg)	Just and Pope's Method (%)	Antle's Method (%)
When $S = 1.8$	36	73	9	19
When $S = 1.3$	28	52	7	14
When $S = 0.8$	20	38	5	10
When $S = 0.5$	17	28	4	7
When $S = 0.3$	13	20	3	5

risk aversion. The effects of risk on fertilizer use for Antle's technique are almost double those for Just and Pope's technique at all values of risk-averse attitude. The effect of risk on yield was also higher for Antle's technique than for Just and Pope's technique. This was expected, as the intercept and fertilizer response in the variance function for Antle's technique were higher than those derived from Just and Pope's model (Figure 2). Therefore, it should be noted that, in risk-related studies, the choice of production function estimation technique is important. However, given our empirical findings, we failed to conclude that risk has a substantial effect on the optimum level of fertilizer use in the study area.

For sensitivity analysis, we arbitrarily doubled the coefficient of fertilizer in the variance function. The effect of risk on fertilizer use can be seen in Table 4. For the Just and Pope technique, the effect of risk on fertilizer use did not change substantially, but for Antle's technique, the effect of risk increased drastically at all values of the risk-aversion coefficient.

Table 4. The Percent Reduction in the Risk-Neutral Optimum Level of Fertilizer Application After Doubling the Coefficient of Fertilizer (as Estimated in Table (2)) in the Second Moment of Just and Pope's and Antle's Estimation Techniques in Victoria, Tarlac, Philippines

	Reduction Compared with Risk-Neutral Optimal	
Risk-Aversion Level	Just and Pope's Method (%)	Antle's Method (%)
When $S = 1.8$	15	31
When $S = 1.3$	13	28
When $S = 0.8$	10	24
When $S = 0.5$	7	18
When $S = 0.3$	5	14

Rosegrant and Herdt found a substantial effect of risk on fertilizer use (i.e., up to 42% of the risk-neutral optimum level). While these differences in results could have been caused by differences in the nature of the data and the rice environments analyzed, improved pest tolerance of the more recently released MVs may be a contributing factor. Scientists have incorporated many new traits—greater pest resistance, shorter crop duration, and improved grain quality—in the more recent MVs. A majority of farmers in the study area grow MVs such as IR64 and IR72. Long-term experimental trials conducted at International Rice Research Institute show that IR64 and IR72 have a greater tolerance to insects and diseases than the earlier varieties (Mackill, Coffman, and Garrity), and our results also indicate that MVs have risk-reducing effects.

Concluding Remarks

This study shows that the effect of risk aversion on optimal fertilizer use in rainfed rice production is generally small in the Philippines. Our empirical results also indicate that the choice of estimation technique has an impact on the optimal dose.

Although poorer environmental control under farmer conditions is likely to result in higher production risk than on experimental farms, the effect of risk and risk aversion appears to be small. However, this conclusion may be valid only for more favorable rainfed environments such as Tarlac, where the average rainfall during the rice-growing season is substantially higher than the minimum rainfall required for rice production. It may not hold true for unfavorable rainfed rice areas where climatic variability is high. Further analysis is required for less-favorable environmental conditions where risk aversion may have a greater impact on input use.

[Received September 2002; Accepted July 2003.]

References

Ahsan, S., A.N. Ali, and J. Kurian. "Towards a Theory of Agricultural Insurance." *American Journal of Agricultural Economics* 64(1982): 502–29.

Ali, M. "Quantifying The Socio-Economic Determinants of Sustainable Crop Production: An Application to Wheat Cultivation in the Tarai of Nepal." *Agricultural Economics* 14(1996):45–60.

Anderson, J.R., and J.L. Dillon. *Risk Analysis in Dryland Farming Systems.* Rome: Food and Agriculture Organization of the United Nations, Farm Systems Management Ser. 2, 1992.

Anderson, J.R., and W.E. Griffiths. "Production Risk and Input Use: Pastoral Zone of Eastern Australia." *Australian Journal of Agricultural Economics* 25(1981):149–59.

Antle, J.M. "Testing the Stochastic Structure of Production: A Flexible Moment-Based Approach." *Journal of Business and Economic Statistics* 1(1983):192–201.

———. "Pesticide Policy, Production Risk and Producer Welfare: An Econometric Approach to Applied Welfare Economics." Washington, DC: Resources for the Future, 1988.

Babcock, A.B., and D.A. Hennessy. "Input Demand Under Yield and Revenue Insurance." *American Journal of Agricultural Economics* 78(1996):416–27.

Barker, R. *Economics Aspects of High-Yielding Varieties of Rice with Special Reference to National Rice Policies.* Manila, Philippines: IRRI Report, FAO Study Group on Rice, March 1969.

Binswanger, H.P. "Attitude Towards Risk: Experimental Measurement in Rural India." *American Journal of Agricultural Economics* 62(1980): 395–407.

Breusch, T.S.A., and A.R. Pagan. "A Simple Test for Heteroskedasticity and Random Coefficient, Variation." *Econometrica* 47(1979):1287–94.

Budiman, H. "An Assessment of Farm-Level Input Demand and Production Under Risk on Rice Farms in the Cimanuk River Basin, Jawa Barat, Indonesia." Ph.D. Dissertation, University of Iowa State, Ames, 1985.

Carlson, G.A. "A Decision Theoretic Approach to Crop Disease Prediction and Control." *American Journal of Agricultural Economics* 52(1970):216–23.

———. "The Role of Pesticides in Stabilizing Agricultural Production." *Pesticides: Contemporary Roles in Agriculture, Health and the Environment.* J. Sheets and D. Pimental, eds. Totowa, NJ: Humana Press, 1979.

———. "Risk Reducing Inputs Related to Agricultural Pests." *Risk Analysis for Agricultural Production Firms: Concepts, Information Requirements, and Policy Issues.* Southern Research Project, S-180, Department of Agricultural Economics, University of Illinois, Urbana, 1984.

Dillon, J.S., and P. Scandizzo. "Risk Attitude of Subsistence Farmers in Northeast Brazil." *American Journal of Agricultural Economics* 60(1978):425–35.

Griffiths, W.E., and J.R. Anderson. "Using Time-Series and Cross-Section Data to Estimate a Production Function with Positive and Negative Marginal Risks." *Journal of the American Statistical Association* 77(1982):529–36.

Horowitz, K.J., and E. Lichtenberg. "Insurance, Moral Hazard, and Chemical Use in Agriculture." *American Journal of Agricultural Economics* 75(1993):926–35.

Just, R.E., and R.D. Pope. "Stochastic Specification of Production Functions and Economic Implications." *Journal of Econometrics* 7(1978):67–86.

———. "Production Function Estimation and Related Risk Considerations." *American Journal of Agricultural Economics* 61(1979):249–57.

———. *A Comprehensive Assessment of the Role of Risk in Agriculture.* Boston: Kluwer Academic Publishers, 2002.

Kalirajan, K., and A. Huysman. "An Econometric Analysis of Production Risk Using Farm Level Panel Data in the Philippines." *Indian Journal of Agricultural Economics* 39(1984):614–29.

Kmenta, J. *Elements of Econometrics.* New York: Macmillan Publishing Co., 1986.

Mackill, D.J., W.R. Coffman, and D.P. Garrity. *Rainfed Lowland Rice Improvement.* Manila, Philippines: International Rice Research Institute (IRRI), 1996.

Mood, M.A., G.A. Franklin, and B.C. Duane. *Introduction to the Theory of Statistics,* 3rd ed. New York: McGraw-Hill Kogakusha, Ltd., 1974.

Moscardi, E., and A. de Janvry. "Attitude Towards Risk Among Peasants: An Econometric Approach." *American Journal of Agricultural Economics* 59(1977):710–16.

Nimon, R.W., and A.K. Mishra. "Revenue Insurance and Chemical Input Use Rate." Paper presented at the annual meeting of the American Agricultural Economics Association, Chicago, IL, August 5–8, 2001.

Pandey, S., P. Masicat, L.E. Velasco, and V. Renato. "Risk Analysis of Rainfed Rice Production System in Tarlac, Central Luzon, Philippines." *Experimental Agriculture* 35(1999):225–37.

Pingali, P.L., and P.A. Roger. *Impact of Pesticides on Farmer Health and the Rice Environment.* Boston: Kluwer Academic Publishers, and Los Baños, Laguna, Philippines: International Rice Research Institute, 1995.

Pope, R., and R. Kramer. "Production Uncertainty and Factor Demands for the Competitive Firm." *Southern Economic Journal* 46(1979):743–48.

Ramaswami, B. "Production Risk and Optimal Input Decisions." *American Journal of Agricultural Economics* 74(1992):860–69.

Rola, A.C., and P.L. Pingali. *Pesticide, Rice Productivity, and Farmers' Health: An Economic Assessment.* Washington, DC: World Resources Institute, and Los Baños, Laguna, Philippines: International Rice Research Institute, 1993.

Rosegrant, M.W., and R.W. Herdt. "Simulating the Impacts of Credits Policy and Fertilizer Subsidy on Central Luzon Rice Farms in the Philippines." *American Journal of Agricultural Economics* 63(1981):655–65.

Rosegrant, M.W., and J.A. Roumasset. "The Effect of Fertilizer on Risk: A Heteroscedastic Production Function with Measurable Stochastic Inputs." *Australian Journal of Agricultural Economics* 29(1985):107–21.

Roumasset, J.A. *Rice and Risk: Decision-Making Among Low-Income Farmers.* Amsterdam: North-Holland Publishing Co., 1976.

Sandmo, A. "On the Theory of the Competitive Firm Under Price Uncertainty." *American Economic Review* 61(1971):65–73.

Sillers, D.A. "Measuring Risk Preferences of Rice Farmers in Nueva Ecija (Philippines), An Experimental Approach." Ph.D. Dissertation, University of Yale, New Haven, CT, 1980.

Smith, J., and G. Umali. "Production Risk and Optimal Fertilizer Rates: An Application of the Random Coefficient Model." *American Journal of Agricultural Economics* 67(1985):654–59.

Smith, V., and B. Goodwin. "Crop Insurance, Moral Hazard, and Agricultural Chemical Use." *American Journal of Agricultural Economics* 78(1996):428–38.

Syamisiah, I., D. Suprapto, and S. Bhuiyan. "Rainwater Collection and Conservation for Alleviation of Drought and Increasing Productivity of Rainfed Ricelands in Indonesia." Paper presented at the International Symposium on Rainfed Lowland, Semarang, Central Java, Indonesia, February 8–13, 1993.