Risks and returns from soil conservation: evidence from low-income farms in the Philippines

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Abstract

This paper examines risks and returns associated with soil conservation on hillside farms in the Philippines. Stochastic efficiency analysis is combined with a heteroskedastic regression model to assess the impacts of contour hedgerows on low-income corn farms. Regression analysis indicates that, over time, contour hedgerows can improve yields up to 15% compared with conventional practices. The analysis also provides weak support for a hypothesis that hedgerows are variance reducing. However, results show that the reduction in yield variability afforded by hedgerows is modest, and that yield variability may increase by as much as 5% as hedgerow intensity rises. Tests for stochastic dominance show that, compared with the conventional tillage system, hedgerows do not constitute an unambiguously dominant production strategy. Stochastic efficiency with respect to a function is used to identify a range for the coefficient of relative risk aversion within which hedgerows dominate conventional tillage. Results suggest this range would be rather high; hedgerows dominate the conventional cropping strategy only for decision-makers with relative risk aversion coefficients in the range 3–5.5. Implications for soil conservation adoption in low-income settings are discussed. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

Soil erosion resulting from hillside farming is an important problem in developing regions of the world (World Bank, 1992)[1]. Soil erosion reduces yields and incomes, and poses a threat to household food security

in many areas (Blakie, 1985; Anderson and Thampapillai, 1990). Sedimentation arising from upland erosion is associated with a range of off-farm costs including downstream flooding, damage to hydroelectric and irrigation systems, and reduced productivity in coastal ecosystems (Magrath and Doolette, 1990; OECD, 1993). In response, substantial effort has been directed toward finding appropriate soil conservation measures for low-income farmers. Studies from both experimental trials and farmers' fields have been encouraging and demonstrate that, given sufficient time, soil conservation measures can both reduce rates

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[1]In the Philippines, area above 18% slope constitutes 60% of total land area. Currently much of this area is devoted to highly erosive annual crops such as corn and rice.

of soil erosion and increase crop yields (Lal, 1990; Lutz et al., 1994; Partap and Watson, 1994; Shively, 1997). In most cases, however, yield improvements occur with some delay, and returns are often negative in the short run — especially when financial and opportunity costs of establishing soil conservation structures are high (e.g. Nelson et al., 1998). Under these conditions, the present value of net benefits from investing in soil conservation may be small. An implication is that the potential impact of soil conservation on yield variability may be a key factor influencing the value of soil conservation investments to low-income farmers. These risk considerations constitute the focus of this paper.

Understanding the impacts of soil conservation on yield risk is important for two reasons. One, production risk influences incentives for adoption (Just, 1974; Just and Pope, 1979; Feder, 1980; Feder and O'Mara, 1981). As a result, understanding how soil conservation measures might change yield or income variability can help to explain patterns of soil conservation adoption. An additional reason for investigating the risk properties of soil conservation is that soil conservation measures are widely promoted for use by low-income farmers, many of whom have limited opportunities to reduce their exposure to risk. For these reasons, researchers and policy makers must remain cognizant of the fact that efforts to promote specific soil-conservation methods will have important implications for farmer welfare via impacts on agricultural risk.

To provide some insight into the risk properties of a widely used soil conservation method, this paper examines agricultural outcomes among a sample of hillside corn farms in the Philippines. Outcomes observed on plots using contour hedgerows for soil conservation are compared with outcomes on plots using conventional tillage practices. Given the widespread importance of corn as a staple crop among sample farms, this analysis focuses on how hedgerows affect the characteristics of corn production[2]. The outline of the paper is as follows. In the next section contour hedgerows are briefly described and data used

in the study are presented. Yields, net present values, and tests of stochastic dominance are reported. Results from tests of first- and second-degree stochastic efficiency reveal no unambiguous dominance of one technique over the other. However, stochastic efficiency with respect to a function identifies a risk aversion range within which hedgerows dominate conventional farming methods. To complement the stochastic efficiency analysis an econometric model of yield variability is introduced in Section 3. Heteroskedastic regression models are used to measure the impacts of hedgerows on yield and yield risk while conditioning on observable features of production — something that is not possible using stochastic efficiency analysis[3]. Regression results are reported in Section 4 and show that after controlling for input use and plot-specific factors, hedgerow implementation is correlated with an increase in effective yield. The change in yield variance that accompanies use of hedgerows is shown to depend — both in sign and magnitude — on the intensity of their use. Section 5 provides a discussion of results, their implications for hedgerow adoption, and prospects for sustaining incomes while simultaneously reducing risks in low-income settings.

2. Characteristics and impacts of hedgerow investments

2.1. Costs and returns for hedgerows

Contour hedgerows are defined as a spatially zoned agroforestry practice (Kang and Ghuman, 1991). Comprehensive reviews of hedgerows are provided by Young (1989), Kang and Wilson (1987) and Lal (1990). Hedgerows are widely promoted as an effective and low-cost method of erosion control for annual crop cultivation on steeply sloping fields. They are constructed as permanent vegetative barriers — typically grasses or densely spaced shrubs — planted

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[2]The combined value of marketed and non-marketed (home-consumed) corn among sample farms represented approximately 50% of total income and 80% of agricultural income at the time of the survey.

[3]Despite the analytical appeal of stochastic dominance — and its distribution-free assumptions — it has one important drawback in the context of this study, namely that it precludes one from accounting for yield differences that arise for reasons other than choice of technique. Differences in yield distributions that arise from differences in input use and plot-specific characteristics remain 'imbedded' in the distributions being compared.

along the contour of a field in rows 5–10 m apart. The barriers restrict soil and water movement, and annual crops are grown in alleys between the hedgerows. Compared with structural methods of erosion control — such as terracing — hedgerows can be constructed at low cost. For example Nelson et al. (1998) report a median labor requirement of approximately 60 days per hectare to establish contour hedgerows on sloping land in the Philippines, compared with 500 days per hectare for bench terraces (e.g. Cruz et al., 1988). As a result of their relatively low establishment requirements, contour hedgerows have been widely promoted and adopted by farmers throughout Asia, Africa, and Latin America. In some settings nitrogen-fixing species are used to form the hedgerows and plant trimmings are applied as green manure to enhance nutrient recycling. This practice can enhance soil fertility and reduce the need for commercial fertilizers (Cosico, 1990; Rosecrance et al., 1992). However, because rates of soil loss increase with slope steepness, hedgerows must be more closely spaced on steep fields to control soil erosion. As hedgerow use intensifies, crop area declines and competition between crops and hedgerows for light, nutrients, and water may become severe (Nair, 1990; Rosecrance et al., 1992; Nair, 1993; Garrity et al., 1995). Thus while more intensive use of hedgerows reduces soil loss, more intensive use does not guarantee better yield performance, and unambiguously increases the opportunity cost of adoption. For example, on fields of moderate slope (e.g. 0–10%) hedgerows are typically spaced at 6–8 m intervals. This results in a loss of cultivated area of 11–15%. For more steeply sloping land, recommended spacing may be as narrow as 2–3 m, resulting in a loss in cultivated area of 25–33%. From a farmer's perspective, an important question is whether crop yield on remaining area can eventually compensate for area occupied by hedgerows.

Several authors — among them Nelson et al. (1998), Partap and Watson (1994) and Shively (1995) provide estimates of costs and returns for hedgerows. Conclusions in these studies tend to hinge on the values assumed for the opportunity cost of labor and land, the assumed planning horizon, and the rate of discount used in calculating net present values. Nevertheless, a consistent pattern is that the cost of establishing hedgerows exceeds returns in early years (due to labor costs and forgone production). In later years, hedgerows appear to provide yield benefits vis-a-vis conventional practices. Eventual yield increases of 10–100% have been reported in the literature, although the combination of high discount rates and short planning horizons can produce negative net present values for adoption. Partap and Watson (1994) examine corn production with and without hedgerows on experimental plots in the Philippines and report results that imply NPV gains (compared with conventional practices) of 1519 and 5753 pesos per hectare (US$61 and $230) for discount rates of 10 and 5%, respectively. These results, which are based on a 6-year horizon, indicate the NPV of hedgerow production exceeds that of conventional tillage for all the discount rates below 17%. In another study from the Philippines, Nelson et al. (1998) conclude that at a discount rate of 12% the NPV impact of hedgerows in corn production is positive (vis-a-vis the conventional method) for planning horizons longer than 7 years. However, the same study concludes that at a discount rate of 40% (which, the authors argue, better represents the opportunity cost of capital for Philippine smallholders), the NPV is negative for all planning horizons less than 25 years. Shively (1995) accounts for the impact of spacing on hedgerow productivity and finds that at a discount rate of 10% the implied optimal hedgerow spacing translates into 2% of cultivable area, considerably less than the 11–14% associated with recommended spacing. In brief, these studies conclude that hedgerows provide a small but potentially favorable rate of return for hedgerow investments, and suggest that adoption would likely be optimal, especially in light of the limited set of investment opportunities available to most smallholders.

Below, yields and NPVs are compared using data collected on farmers' fields between November 1994 and March 1995. Data include 89 plots drawn from a sample of 115 upland farms in Barangay Bansalan, in the Philippine province of Davao del Sur. Garcia et al. (1995) describe the survey site and farming practices in the area[4]. Although the sample is small, it is broadly representative of upland corn farming throughout the

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[4]Sample soils consisted of slightly acid (pH 5.0–5.5) sandy clay loams of volcanic origin. More than 80 per cent of land area in the sample was above 18° slope, at elevations ranging from 500 to 1200 m above sea level.

Table 1
Sample means for selected production variables in Bansalan

	Average per hectare				Average per effective hectare			
	All plantings	Second planting	Non-hedgerow	Hedgerow plots	All plantings	Second planting	Non-hedgerow	Hedgerow plots
Yield (kg/ha)	1335	1068	1266	1437	1409	1130	1266	1619
Labor (days/ha)	326	334	267	412	352	366	267	477
Fertilizer (kg/ha)	136	141	130	145	146	151	130	170
Time used (months)	83	85	90	117	83	85	90	117
Slope (°)	26	26	25	27	26	26	25	27
Soil depth (mm)	850	847	838	867	850	847	838	867
% of plots with hedgerows	0.39	0.40	–	1.0	0.39	0.40	–	1.0
% of land with hedgerows	0.05	0.06	–	0.12	0.05	0.06	–	0.12
Hedgerow age (years)	1.48	1.60	–	3.80	1.48	1.60	–	3.80
n	89	50	53	36	89	50	53	36

Philippines and benefits from plot-level measurements of areas, yields, and input levels. At the time of the survey, corn production was characterized by two harvests per year, fallow periods of 0–2 years, use of animal traction for field preparation, and application of modest amounts of commercial fertilizer (135 kg/ha, on average). Hedgerows were typically constructed using double-rows of *Desmodium rensonii* and *Flemengia macrophylla*. The oldest hedgerows had been in place for 7 years. Among the hedgerow sample, plots were stratified by hedgerow age.

Sample means of relevant production variables are reported in Table 1. To summarize, 40% of sample plots had hedgerows; these were 4-years-old on average. Hedgerows, on plots that had them, occupied 12% of parcel area, on average. Average estimated soil depth in the sample was 850 mm. Per hectare yields ranged from 0 to just over 3000 kg. Average yield on hedgerow plots (1437 kg/ha) was higher than average yield on conventional plots (1266 kg/ha), and for both systems average yield during the second cropping period (dry season) was significantly lower than average yield during the first cropping period (wet season). It is worth noting that the only plots that experienced harvests below 300 kg/ha were conventional plots, a pattern that suggests hedgerows may afford some protection against catastrophic erosion events.

Yield comparisons in this sample are complicated somewhat by the fact that hedgerow intensity varied across adopters. A question that arises, therefore, is whether one should compare yields on a per hectare or per effective-area (i.e. net of hedgerow) basis. The former is likely to be an important measure when farmers are land constrained — as they are in many areas — and when land displaced by hedgerows has a correspondingly high opportunity cost. However, to accurately measure the impact of hedgerows — net of the influence of other inputs — on crop performance, it is necessary to compare yields on an effective-area basis, and to study the extent to which a per hectare yield gap persists over time. This approach is facilitated by an examination of the sample yield data presented in Table 2. The table disaggregates and reports average yields on both a per hectare basis (i.e. including hedgerow area) and an effective basis (i.e. based on corn area only). Experimental plot yields (MBRLC, undated) are presented for comparison. These data suggest hedgerow plots outperformed conventional plots on both an effective and per hectare basis. However, yield differences partly reflect higher average labor and fertilizer use on hedgerow plots. Yield differences observed in Table 2 are also clouded by differences in hedgerow age: as subsequent analysis will show, yields under contour hedgerows tend to increase over time. The importance of these factors in explaining yield differences is assessed in Section 4.

2.2. Yield variability and tests of stochastic dominance

In addition to affecting average yields and expected returns from farming, hedgerows have the

Table 2
Observed corn yields for hedgerow plots and non-hedgerow plots

	Experimental plots		Farmers' plots	
	Observed yield	Effective yield	Observed yield	Effective yield
First planting	n.a.	n.a.	1670	1770
Second planting	n.a.	n.a.	1070	1130
Conventional plots	1910	1910	1270	1270
Hedgerow plots	1480	2880	1440	1620
All plots	1700	2400	1340	1410

Source: Experimental plots, MBRLC; (undated) Farmers' plots, Bansalan survey (figures are rounded).

potential to mitigate yield variability in at least two ways. First, hedgerows can improve moisture retention during low-rainfall periods, and thereby reduce, moisture stress and enhance plant growth. Second, hedgerows tend to reduce overland water flow, and can thereby reduce associated crop damage — especially to young plants — during high rainfall periods. As a result of these two features, one might conjecture that hedgerows stabilize the overall yield distribution and also trim the left-hand tail of the yield distribution by reducing downside deviations in yield. Both of these risk-reducing properties could potentially recommend hedgerow use among risk-averse farmers, even in the face of modest losses in NPV terms. However, a comparison of coefficients of variation (CV) for yields fails to support a conjecture of variance reduction for hedgerows: a CV of 51% is observed for conventional plots in the sample and a CV of 61% is observed for hedgerow plots.

To gain greater empirical insight into the merits of these competing systems stochastic efficiency analysis is used. The basic methods of stochastic efficiency analysis — which include first- and second-degree stochastic dominance as well as stochastic dominance with respect to a function — are discussed by Meyer (1977) and Anderson et al. (1977). In brief, the approach relies on direct comparisons and rankings of distributions of outcomes for risky alternatives. Conclusions regarding dominance of any particular approach depend upon the restrictions one places on the utility function that underlies the analysis.

Fig. 1 portrays smoothed cumulative density functions (CDF) for yields obtained on conventional and hedgerow plots in the sample. The CDFs in Fig. 1 are based on 14 equi-probability fractiles for yields per effective area. As the graph illustrates, the yield distributions cross twice. This feature immediately eliminates any potential for first-degree stochastic
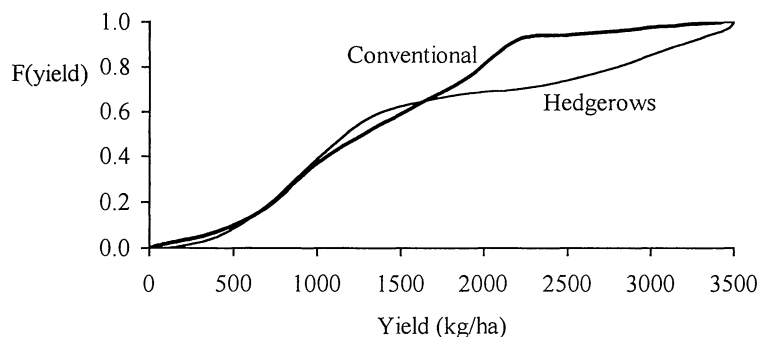

Fig. 1. Cumulative density function for effective yields in Bansalan, 1994.

dominance (FSD)[5]. Further analysis based on the criterion of second-degree stochastic dominance (SSD) also fails to identify a dominant strategy. As Fig. 1 indicates, hedgerows clearly afford some modest protection against very low yields. That is, for fractiles below approximately 0.12 (corresponding to yields in the range 0–600 kg/ha) the hedgerow CDF lies to the right of the conventional CDF. At fractiles above 0.65 (corresponding to yields above 1600 kg/ha) the hedgerow CDF also lies to the right of conventional CDF. However, in a large intermediate range of yields (600–1600 kg/ha), the conventional CDF lies to the right of the hedgerow CDF. One implication of this pattern is that a dominant strategy cannot be identified solely on the basis of risk aversion. However, by assuming constant absolute risk aversion and introducing bounds on the risk-aversion coefficient, stronger discriminatory power can be brought to bear on the comparison. For this analysis, McCarl's RISKROOT program was used to conduct comparisons. RISKROOT searches for values of the coefficient of (constant) absolute risk aversion such that on either side of the coefficient one activity dominates. In other words, if one defines *UD* as the utility difference between two activities, RISKROOT finds the risk aversion coefficient *r* that satisfies the equality:

$$UD = \sum_{i=1}^{N} \rho_i \left[-\delta e^{-rX_{iI}} - \left(-\delta e^{-rX_{iII}} \right) \right] = 0, \quad (1)$$

where ρ_i is the probability of occurrence of the ith observation, X_i is the *i*th observation for the activity under consideration (I or II) and δ is a switching variable equal to 1 if $r > 0$ and equal to -1 if $r < 0$. McCarl (1988) discusses the characteristics of this function and the algorithm for finding break-even risk aversion coefficients. Using RISKROOT, the pairwise

comparison of outcomes for conventional and hedgerow systems reveals the following pattern for a risk-averse decision-maker. First, below an absolute risk-aversion coefficient of 0.0023 the conventional technology dominates hedgerows. Second, for coefficients of absolute risk-aversion between 0.0023 and 0.0041 hedgerows dominate conventional tillage. Third, for risk-aversion coefficients above 0.0041, the conventional technology dominates hedgerows. In terms of relative risk aversion (based on mean income), results imply hedgerows might be preferred by a risk-averse decision-maker with a coefficient of relative risk aversion in the (relatively high) range of 3–5.5.

The switching pattern exhibited here is typical of comparisons involving multiple CDF crossings and fails to clearly distinguish a dominant cropping strategy for a risk-averse decision-maker. It is important to reiterate, however, that the stochastic dominance approach assumes any observed differences between CDFs correspond to characteristics of choices being compared. In experimental settings, where other factors are held constant, such an assumption may hold. However, in non-experimental settings other factors such as differences in input levels, plot characteristics, or farming practices may explain observed differences in yield distributions. To control for these factors when assessing risks and returns from hedgerows, the next section uses an econometric approach to measure differences in yields and yield variability. The cost of approaching the problem in this way is that distributional assumptions are required. For this reason, the econometric analysis should be viewed as complementary to the stochastic dominance analysis, which imposes no restrictions on the distributions under consideration.

3. A model of soil conservation, yields, and yield risk

3.1. Regression model

To further investigate the hypothesis that hedgerows increase yields and mitigate yield variability consider a model of agricultural production that relates agricultural inputs to yield, accounting for the fact that yield variance may also depend on technology, levels of input use, or other features of production. As

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[5]The test for FSD rests only on the assumption that the decision-maker has positive marginal utility. Given two actions I and II, with probabilities of outcome Y_I and Y_{II}, Action I is said to dominate Action II in the first-degree sense if $F(Y_I) \leq F(Y_{II})$ with at least one strict inequality. The test for SSD adds the assumption that the decision-maker is risk averse over the range of all possible outcomes. In general, the test for SSD requires a comparison of areas under CDFs. Stochastic dominance with respect to a function (SDRF) provides greater discriminatory power than either FSD or SSD, and can be used to identify bounds on the absolute risk-aversion coefficient corresponding to the second-degree stochastic dominance test.

discussed above, the advantage of approaching the analysis in this way is that it provides a method for controlling input use that is not easily incorporated into stochastic efficiency analysis. The approach used here follows Just and Pope (1979) recommendations for a functional form that imposes as little structure on the risk properties of the arguments as possible. The production function is:

$$y = g(x, \theta, z) + h(x, \theta, z)\varepsilon \qquad (2)$$

where x, θ, and z represent inputs, a hedgerow indicator, and plot characteristics, respectively, and ε represents a production shock. This additive specification permits increasing, decreasing, or constant marginal risk[6]. Theoretical concerns favor a flexible form for the production function. Unfortunately, identification of parameters of a translog production function proved difficult with these data. A log-linear Cobb–Douglas model was chosen for the analysis on the basis of overall performance and results from specification tests[7].

To proceed, let $u = y - g, (x, \theta, z)$ and let $\hat{u}$ denote the residual from a regression of observed yield on factors of production. With $u^2 = [y - g(x, \theta, z)]^2$ define $v = \hat{u}^2/s^2$ (where s^2 is the sample yield variance). Below, regressions are used to examine the relationships between v and factors hypothesized to influence yield variance. Note that $\hat{u}$ will include measurement error, as well as covariate and idiosyncratic shocks. The latter may include environmental

differences among farms, and factors that might be conditioned on farmer behavior. For the moment, these limitations in $\hat{u}$ as an indicator of pure yield variability are accepted. An attempt to control for farmer-specific factors in determination of yields and yield risk is undertaken in Model 3 below (also see Shively, 1998b). In general, correct specification of the stochastic component in Eq. (2) is necessary for obtaining consistent and efficient estimates of the deterministic component of the equation.

Analysis is conducted at the plot level. Yield per hectare is measured in kilograms of grain and is assumed to depend on the per-hectare rates of application of fertilizer and labor, as well as on the choice of technology. In order to compare yields adjusted for input use, variables are divided by area actually occupied by corn (i.e. net of area occupied by hedgerows, if any). As discussed above, this adjustment favors hedgerows: to the extent farm size is a binding constraint, results may misrepresent the short-run opportunity costs from adopting hedgerows. However, from an agronomic perspective it is necessary to measure yield and input use in terms of cropped area. An adjustment to account for the per hectare impact of hedgerows in net value terms is undertaken below.

To account for the impact of soil conservation measures on yields and yield variability, a binary indicator of hedgerows and a continuous measure of the share of land in hedgerows are included in the model. The latter variable measures the intensity of hedgerow use on a parcel - that is, the percentage of the plot area devoted to hedgerows. It is included under the assumption that an increase in hedgerow intensity may influence yield either via crop competition or via improved soil and moisture retention. Introducing this variable in conjunction with a binary indicator of hedgerow presence allows both the overall impact of hedgerows on yield and the marginal impact of additional hedgerow intensity on yield to be examined. In addition, because the ability of hedgerows to maintain or enhance fertility may improve over time, the reported models include a variable measuring the age of hedgerows (in years) at planting time.

Several other conditioning variables are included in the regressions. First, because harvest data span a calendar year the impact of timing on yields must be considered. For example, seasonal variations in rainfall may introduce seasonal variations in yield that

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[6]Distributional assumptions maintained in the analysis include the following:

$$E(\varepsilon) = 0; V(\varepsilon) = \sigma; E(y) = g(x, \theta, z); V(y) = h^2(x, \theta, z)\sigma;$$

$$\text{and } \frac{\partial E(y)}{\partial x_i} = g(x_i); \frac{\partial^2 E(y)}{\partial x_i} = g_{ii}(x_i); \frac{\partial V(y)}{\partial X_i} = 2hh_i\sigma.$$

[7]The specification test used here follows MacKinnon et al. (1983). The test specifically assesses the significance of the estimate of the coefficient a in the model:

$$g = x'b + a[\ln g - \ln(x'b)] + e,$$

where g represents yield, x is a vector of independent variables, b is a coefficients vector, and ε is a vector of regression residuals. Patterns of coefficient significance were similar in linear and log-linear regressions, but based on the specification test the linear model was rejected in favor of the log-linear model at a 95% confidence level. Signs and estimated magnitudes of regression coefficients in a translog model were broadly similar to those of these parsimonious models.

Table 3
Tests of heteroskedasticity in corn yield regression

Independent variables	Test		
	Breusch–Pagan	Glejser	critical value
Labor, fertilizer, second cropping dummy	4.32	9.22	7.82
Labor, fertilizer, soil depth, second cropping dummy, hedgerow dummy, hedgerow share	6.52	18.21	12.59

Note: Test statistics are distributed χ^2 with degrees of freedom equal to the number of independent variables. Residual regressions contained a constant term in all cases.

are systematic in the sample. To account for this, the data are partitioned into two groups, corresponding to first and second planting periods. These groups are distinguished via a binary indicator, identified as second cropping in the regressions. Harvests that occurred between April and October (*wet* season) are labeled first cropping; those that occurred between November and March (*dry* season) are labeled second cropping. In addition, an attempt is made to control for plot-specific differences in soil stocks, in recognition that available soil fertility or quality may differ across the sample. Here it is assumed that soil depth provides indirect evidence of soil fertility. The regressions, therefore, include an imputed value of soil depth for each plot. This regressor measures soil depth at planting time (in mm), and reflects the length of time the parcel had been in use, the length of fallow periods (if any), and the history of hedgerow adoption on the plot[8].

3.2. Testing for heteroskedasticty

The presence of heteroskedasticity in yields was confirmed by diagnostic tests for conditional variance in the yield regression. Diagnostic tests outlined by Breusch and Pagan (1979) and Glesjer (1969) were used to examine the null hypothesis of homoskedasticity in the yield function against an alternative hypothesis of heteroskedasticity. The tests require that

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[8]Cumulative soil loss was imputed for each plot based as a function of the age of the plot and the historical pattern of fallow periods and hedgerow adoption. Plot-specific soil losses were combined with village-specific estimates of initial soil depths drawn from a 1991 soil survey of the area (Latada et al., 1994). Rates of soil loss were derived from experimental data for hedgerows as reported in MBRLC. Details regarding the procedures used to impute soil losses are reported in Shively (1997).

one regress transformed residuals from a base regression on independent variables of the mean regression. Residuals used in the tests were obtained from a regression of the equation $g = x'b + e$, where g represents yield, x is a vector of independent variables, b is a coefficient vector and e is a vector of regression residuals. The Breusch-Pagan test is a Lagrange multiplier test using squared residuals. The Glejser test uses the absolute value of the residual. Both tests were applied to the data using two subsets of the independent variables. The first set consisted of labor, fertilizer, and a dummy variable for second cropping. The second included these variables as well as soil depth and hedgerow indicators. Test results are reported in Table 3. To summarize, the Breusch–Pagan test suggests accepting the null hypothesis of homoskedasticity in both instances. The Glejser test recommends rejecting the null. The Glesjer test tends to have greater power than the Breusch–Pagan test within the specific context of the chosen regression model (Greene, 1990). Therefore, the null hypothesis of homoskedasticity is rejected in this sample.

4. Regression results

Results from three jointly estimated mean and variance regressions are reported as models 1–3 in Table 4. Regressions were estimated by maximum likelihood techniques under the assumption of Gaussian errors. Dependent variables in the variance regressions are the squared residuals from mean regressions. For all the models, coefficient estimates in mean regressions are similar in sign and magnitude to those estimated using OLS under an assumption of homoskedasticity. In most cases, individual coefficient estimates are individually significant at the 95% confidence level.

Table 4
Heteroskedastic corn production functions Mean Equation: dependent variable is natural log of corn yield per hectare

Independent variables	1	2	3
Mean Equation			
Constant	3.7797 (0.6091)	4.2480 (0.3933)	3.7277 (0.4123)
Log of labor (man days per ha)	0.3669 (0.0549)	0.2558 (0.0334)	0.3434 (0.0423)
Log of fertilizer (kgs/ha)	0.0624 (0.0208)	0.0187 (0.0122)	0.0533 (0.0087)
Log of soil depth (mm)	0.1012 (0.0626)	0.1702 (0.0529)	0.1002 (0.0519)
Second cropping {0.1}	−0.5757 (0.0939)	−0.5637 (0.0546)	−0.4840 (0.0544)
Hedgerows {0.1}	0.2387 (0.1771)	0.2686 (0.1934)	0.4767 (0.1003)
Hedgerow share (0.1)	−1.6343 (0.6727)	−1.5881 (0.8805)	−2.7360 (0.9451)
Hedgerow age (years)	0.0448 (0.0364)	0.0485 (0.0370)	0.0211 (0.0129)
Inverse Mill's ratio from adoption probit (0.1)			−0.1227 (0.0643)
Variance Equation			
Constant	−0.0982 (0.2821)	0.2099 (0.1613)	−0.3327 (0.1316)
Log of labor (man days per hectare)	−0.0826 (0.0313)	−0.1021 (0.0216)	−0.0310 (0.0136)
Log of fertilizer (kgs per hectare)	−0.0206 (0.0124)	−0.0088 (0.0032)	0.0048 (0.0035)
Log of soil depth (mm)	0.1250 (0.0278)	0.0574 (0.0195)	0.0650 (0.0250)
Second cropping {0,1}	−0.0189 (0.0399)	0.0645 (0.0151)	0.0284 (0.0157)
Log of slope (degrees)	0.1123 (0.0313)	0.1372 (0.0263)	0.1212 (0.0236)
Hedgerows {0,1}	−0.1203 (0.0477)		−0.2624 (0.0577)
Hedgerow share (0,1)		1.9790 (0.7171)	2.9212 (0.8308)
Inverse Mill's ratio from adoption probit (0,1)			0.1198 (0.0237)
Log-likelihood	−83.90	−72.88	−63.06
n	89	89	89

Note: Asymptotic errors are in parentheses.

Results from the mean equations for all models indicate labor and fertilizer contributed positively to output. Hypotheses of constant returns to labor or fertilizer are rejected in favor of the one-sided alternative of decreasing returns to input use: labor and fertilizer each contributed positively to output, but at a decreasing rate. Similarly, decreasing returns to scale are indicated for combined inputs. In elasticity terms, a 1% increase in available labor is associated with a 0.3% increase in corn yield at the mean. For fertilizer, results indicate a 1% increase in available fertilizer is associated with a 0.06% increase in corn yield. The marginal impact of an additional kilogram of fertilizer is approximately 0.5 kg of corn per hectare at mean application levels. Given prevailing prices of fertilizer and corn in 1994 (7 pesos ($0.28) and 5 pesos ($0.20) per kg, respectively), the regressions indicate the economic benefit of additional fertilizer application was positive at levels of fertilizer application below 50 kg/ha, but potentially negative above that level. In part, this pattern reflects relatively high reliance in the sample on native varieties of seed, which exhibit poor nitrogen response. All regressions clearly indicate that, controlling for input use and other factors, yields during the second cropping period were statistically lower than yields during the first cropping period. Results also reveal positive correlation between soil depth and corn yield. Based on results from Model 1, a 1% reduction in soil depth was associated with a 0.12% reduction in corn yield. This translates into approximately 2 kg/ha at the mean. Higher order terms for soil depth failed to indicate either increasing or decreasing rates of yield decline associated with changes in soil depth[9].

All the models include a set of three regressors in the mean equation to measure the impact of hedgerows on corn yield. These variables are jointly significant at the 95% confidence level in all regressions. Results show that as the share of land in hedgerows rises, effective yield falls. However, based on the coefficient for the binary hedgerow indicator the pre-

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[9]Based on results from an unreported model including a fertilizer-soil depth interaction term, the hypothesis that fertilizer serves as a substitute for soil depth could not be rejected for the range of outcomes observed in this sample.
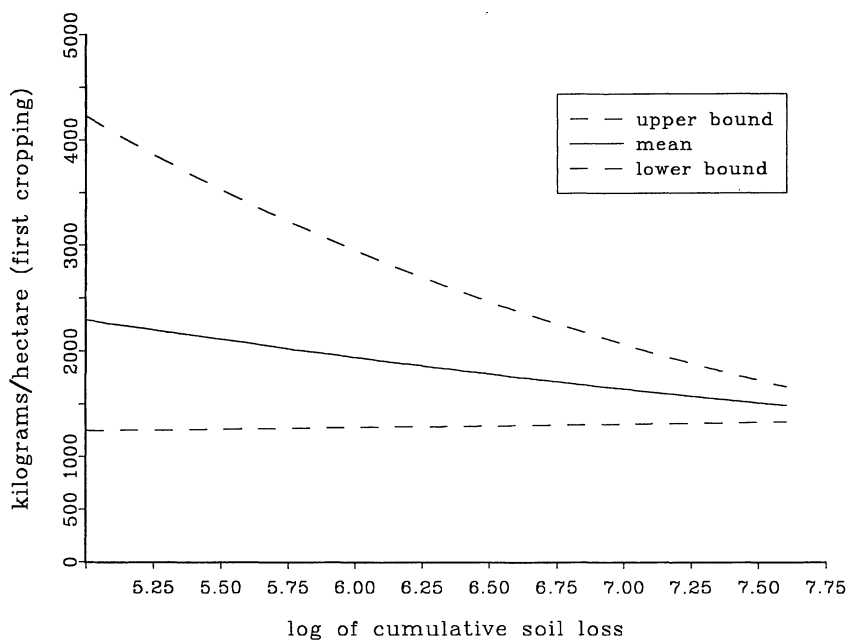
Fig. 2. Yield and conditional yield variance with hedgerows.

sence of hedgerows is positively correlated with yield. Results further indicate this benefit increases over time. At sample means (12% of area and 4-year-old hedgerows), the yield gain from hedgerows (roughly 350 kg/ha) compensates for the reduction in yield due to loss of cultivated area (approximately 300 kg). However, more intensive hedgerow use is associated with a net reduction in yield, particularly during early years of adoption. Because hedgerow pruning is generally erratic among farmers in the sample, and because the hedgerow technology itself is somewhat unfamiliar, this result may indicate crop competition. Unfortunately, agronomic issues can not be examined fully using these data. In fact, if pruning and mulching were performed regularly then shading would be reduced and soil moisture content might be increased. This could potentially raise yields in the alleys. This underscores the importance of both the farmer practices and the chosen technology in generating outcomes.

Turning to the variance regressions the models indicate labor is a risk reducing input. Models 1 and 2 also reveal fertilizer to be a risk-reducing input on upland farms. This finding differs from findings in lowland agricultural studies in which fertilizer use and

production risk are positively correlated (e.g Roumasset, 1976)[10]. In general, the nitrogen response of corn observed in this study is somewhat greater and more wide-ranging during the wet season than the dry season. Lower conditional yield variance during the dry season is a natural byproduct of this relationship. Models 2 and 3 provide evidence that yields during the second cropping period were more variable than during the first cropping period. All the models indicate yields were more variable on more steeply sloping fields, a finding that is robust to inclusion of soil depth and parcel age in the variance equation. Results from all models indicate prior soil loss reduces yield variability. Fig. 2 graphs the predicted relationship between soil loss and yield variance, based on results from Model 1. The figure includes upper and lower bounds on yield (defined as mean yield ± one standard devia-

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[10]For example, Roumasset 1976, reports a consistent increase in average yields of lowland rice as nitrogen application rises, but either an increase or decrease in yield variance depending on setting. In particular, when nitrogen was applied during the dry season, Roumasset reports that it significantly reduced yield variance. Since upland corn is grown under rainfed conditions, a variance pattern similar to that reported for lowland rice may be appearing in these data.

tion). Patterns indicate soil losses tend to compress the yield distribution.

To measure the impact of hedgerows on yield variability, Model 1 includes a binary hedgerow indicator in the variance regression. The estimated coefficient indicates the overall impact of hedgerows is a reduction in yield variance (at the mean) of approximately 5%. Model 2 replaces the binary indicatory in the variance regression with a measure of hedgerow intensity. In contrast to Model 1, results from Model 2 reveal a pattern in which yield variance rises with hedgerow intensity. In order to reconcile the ambiguity exhibited in the variance equations of models 1 and 2, Model 3 includes both the binary indicator and the measure of hedgerow intensity. Results indicate the overall presence of hedgerows on a parcel serves to reduce yield variance (as in Model 1), but that an increase in hedgerow intensity raises yield variance at the margin (as in Model 2). For example, using sample mean values, coefficients from Model 3 suggest that when the hedgerow share is below 0.08, the net impact is a reduction in yield variance of up to 8%. In contrast, at a hedgerow share of 0.12 (the observed average for adopters) the net impact of hedgerows is an increase in yield variance of 3%.

The mean and variance equations of Model 3 also include a measure of latent farmer characteristics to explore the hypothesis that unobserved farmer characteristics may be correlated with production outcomes[11]. In order to test this hypothesis, a probit model is used to predict the probability of hedgerow adoption on a plot using a range of household and plot characteristics. Based on results from the probit model, a measure of self-selection into the sample is then generated for each household and included as an explanatory variable in the production function.

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[11]As is well known, estimation of production functions without regard to stochastic features in the maximization process can produce simultaneous equation bias in parameter estimates. Correction for this potential bias depends on the nature and sources of stochasticity. If disturbances are unknown at the time inputs are chosen, then these disturbances cannot enter into the maximization process (or the first-order conditions), and hence estimation of the production function independent of the factor demand equations appears reasonable (e.g. Zellner et al., 1966; de Janvry, 1972). In contrast, if one asserts that decision-makers understand the sources of risk, then a potential solution is to estimate jointly the production function and the factor demand equations. Here, a two-step procedue based on Heckman (1979) is used.

This inverse of the 'Mill's ratio' is a monotone decreasing function of the probability an observation falls into the sample (Heckman, 1979). Here it measures the extent to which yields may be influenced by the same set of unobserved factors that determine hedgerow adoption[12].

Results from the probit model are presented in Table 5. The regression reveals a positive correlation between the probability of hedgerow adoption and farm size, available labor, and tenure security. In contrast, the probability of hedgerow adoption is negatively correlated with plot size, soil depth, plot age, and the opportunity cost of adoption. Production function results presented above are invariant in sign and magnitude to the inclusion of the inverse Mill's ratio in the mean and variance equations. Controlling for plot-specific factors, farmers exhibiting characteristics associated with hedgerow adoption tend to have lower corn yields and higher yield variance, on average, than those who do not exhibit these characteristics. That is, the hypothesis hedgerow farmers perform no worse than non-hedgerow farmers is rejected for this sample. Inclusion of the inverse Mill's ratio in the variance regression strengthens the negative correlation between hedgerows and yield variance.

5. Discussion

Tests of stochastic efficiency produce unclear outcomes regarding the dominance of hedgerows over conventional practices. In the case of hedgerows, less density in the yield distribution occurs below 600 kg/ha, and more occurs above 1600 kg/ha. Nevertheless, hedgerows cannot be considered unambiguously preferred for a risk-averse decision-maker, except when bounds are placed on the coefficient of absolute risk-aversion. The advantage of the stochastic efficiency approach is that it is free from distributional assumptions. One drawback with this method is that it rules out explanations for differences in yields other than the choice of technique. Regression analysis, in con-

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[12]Normality assumptions underlie the Heckman procedure. In practice, violation of these assumptions can undermine model identification and accurate estimation of model parameters. For a discussion of these points and some alternative estimation procedures, see Deaton (1997).

Table 5
Probit model of soil conservation adoption

Independent variable	Coefficient estimate (standard error)
Constant	1.1722 (1.9255)
Farm size (hectares)	0.1666 (0.0821)
Available household labor per hectare (man days per hectare)	0.0021 (0.0011)
Proportion of cultivated area with secure tenure (0,1)	1.2737 (0.6700)
Plot size(hectares)	−0.9187 (0.5200)
Soil depth of plot (mm)	−0.0028 (0.0014)
Period of continuous cropping on plot (months)	−0.0162 (0.0084)
Ratio of initial cost of adoption on plot to total household corn availability	−0.4498 (0.1663)
Value of log-likelihood function	−48.71
Percentage correct predictions	0.65
n	89

Note: Asymptotic standard errors are presented in parentheses. Likelihood ratio test for regression with constant only is −60.1.

trast, provides a method for comparing yields and yield variability while controlling for factors other than choice of technology. Regression results show that soil conservation measures have the potential to increase yields and can reduce yield variance slightly. However, changes in yield variance associated with hedgerow adoption are modest, and sensitive in both sign and magnitude to the intensity with which hedgerows are used.

Regression results presented in Section 4 can be used as the basis for computing representative yield trajectories with and without hedgerows. These results indicate a break-even point for contour hedgerows (in terms of yield per hectare, undiscounted) at approximately year 7. Combined with data on costs of establishing hedgerows, expected yield trajectories provide the information needed to compute net returns for hedgerows. Assuming a 10-year planning horizon, these computations show that, compared with conventional practices, an investment in hedgerows would generate additional net present values of 853 and 2305 pesos per hectare (US $34 and $92) at discount rates of 10% and 5%, respectively[13]. Taken together, results

[13]Net present values reported in the text were derived using an average corn price of five pesos per kilogram, an average cost of labor of 40 pesos per man-day, and an average labor requirement to establish hedgerows of 60 man-days per hectare. A loss in cultivated area corresponding to a hedgerow intensity of 10 per cent was assumed. The model used to compute expected yield trajectories also relies on non-linear rates of soil loss derived from experimental data reported in (MBRLC, undated). Soil losses over time are assumed to depend on time and hedgerow use. A description of the model and procedures used to compute rates of soil loss, yield trajectories, and NPVs are available from the author upon request.

from the stochastic efficiency analysis, the regressions, and these NPV calculations suggest hedgerows could be an attractive technology for very risk-averse decision-makers, provided planning horizons were sufficiently long and rates of impatience were low. However, evidence clearly indicates that hedgerows initially reduce effective yields, and substantially reduce observed yields. This argues against their use over short planning horizons or when discount rates are high. For example, at a 20% rate of discount, the NPV of hedgerows is negative for all planning horizons shorter than 15 years.

To illustrate the empirical findings from the regression analysis, Fig. 3 illustrates a 10-year trajectory for effective yield and an approximate lower bound on
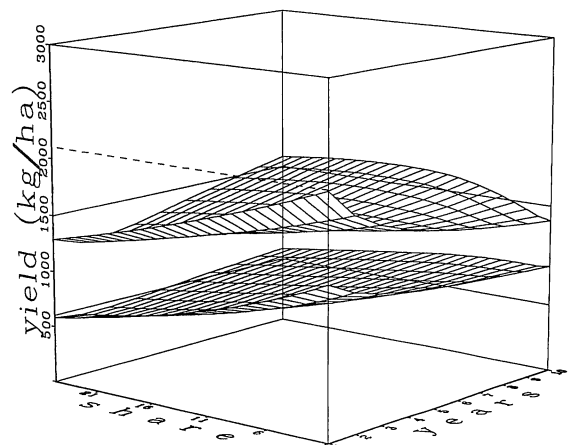

Fig. 3. Yield surface for corn planted with hedgerows.

yield (one standard deviation below the mean). The *x*-axis in Fig. 3 corresponds to time; the *y*-axis corresponds to the share of land occupied by hedgerows. The figure illustrates several important empirical features of hedgerows. First, the underlying tendency is for yields to fall as parcels age. Hedgerows can dampen or reverse this decline, but they initially reduce effective and observed yields. This recommends against their use over short or greatly discounted planning horizons, and helps explain why many low-income farmers are reluctant to adopt hedgerows.

Second, as the age of hedgerows increases, soil-conserving and yield-enhancing properties improve. The increase in yield depends on hedgerow intensity: more intensive use of hedgerows increases effective yields. The maximum effective yield after 10 years (exclusive of hedgerow area) is estimated as 1650 kg/ha. This yield would be achieved with a 15% hedgerow share (corresponding to hedgerow spacing of approximately 5.5 m). By comparison, the maximum per-hectare yield (inclusive of hedgerow area) is 1450 kg/ha, based on an eight per cent hedgerow share (corresponding to spacing of 10 m).

Third, hedgerows appear to provide a modest reduction in yield variance (as much as 4%), but their overall impact in this regard is ambiguous. Variance around the yield trajectory decreases over time when hedgerows are in place, and plots of CDFs (Fig. 1) indicate the yield distribution for hedgerows has less mass in the lower tail than the yield distribution for conventional tillage. This suggests hedgerows might provide protection against downside deviations in yields, especially the risk of yields falling below 600 kg/ha. However, as the intensity of hedgerow use rises, overall yield variability increases. These results are robust to inclusion of parcel slope in the regressions, and suggest that yields may become more variable due to crop-hedgerow competition or difficulty with hedgerow management.

In summary, from a 'mean perspective' the optimal hedgerow intensity falls into the range 5–10% of area. This provides positive NPVs for moderate discount rates and planning horizons of 10 years or more. From a 'variance perspective' the optimal hedgerow intensity is likely to be lower - in the range 0–5%. As a result, it is possible that for many low-income farmers the eventual increase in expected yield associated with

using hedgerows could be outweighed by the potential increase in yield variance associated with this strategy.

6. Conclusions

This paper examined the impact of soil conservation on yield and yield risk using data from corn production on hillside farms in the Philippines. The approach used in the paper combined stochastic dominance with heteroskedastic regression analysis. These techniques were used to test the hypothesis that contour hedgerows mitigate yield risk. Tests based on stochastic dominance with respect to a function suggest hedgerows would be appealing to risk-averse decision-makers with coefficients of relative risk aversion in the range 3–5.5. The main feature of hedgerows leading to this result is their tendency to add positive skewness to the yield distribution. Regression results show that hedgerows can dampen or reverse the rate of yield reduction on farmers' fields. The analysis also suggests modest use of hedgerows may reduce yield variance.

Results from a probit model suggest the quantity of labor available on a farm is positively correlated with the probability of hedgerow adoption. Similarly, farmers reported 54% greater labor use per hectare on hedgerow plots than conventional plots. These patterns are consistent with previous studies highlighting the critical role of available labor in conditioning soil conservation adoption (e.g. Harper and El-Swaify, 1988; Fujisaka, 1993; Clay and Reardon, 1994) and offer one possible explanation for low rates of soil conservation adoption. However, regression results show that as hedgerow intensity rises above approximately 5% of area, both the opportunity cost of adoption (in terms of occupied area) and the variance impacts of hedgerows recommend against their use. These findings suggest that typical hedgerow intensities, for example those recommended to control erosion, are unlikely to provide economically efficient spacing in terms of NPV and variance impacts. This unfavorable risk-return relationship provides an additional explanation for the reluctance exhibited by many low-income farmers toward adopting soil conservation measures (e.g Shively, 1998a). These findings should be of particular value to those who are interested in the practical application of soil conserva-

tion strategies in low-income settings, as well as to those who wish to consider broader welfare issues related to promoting resource conservation by low-income farmers. However, additional investigations are needed to clarify whether these patterns hold in other settings including experimental settings and whether the risk properties of other soil conservation measures follow patterns similar to those identified here.

From the perspective of low-income farmers, access to income-enhancing activities that simultaneously reduce risks is important. Results reported here suggest nitrogen application on farms with currently low rates of use could both boost yields, and within the range of experiences examined here reduce yield variability. Similarly, access to improved crop varieties that combine nitrogen responsiveness with heat or drought tolerance would satisfy the twin goals of productivity maintenance and risk reduction. Development of economically valuable hedgerow species and diversified cropping strategies within the context of contour hedgerow systems should also receive high priority.

Acknowledgements

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