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DEVELOPMENT POLICIES, RESOURCE CONSTRAINTS, AND AGRICULTURAL EXPANSION ON THE PHILIPPINE LAND FRONTIER

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Abstract

This paper examines ways in which agricultural policies interact and influence incentives for agricultural expansion in frontier areas. A model of household response to economic and technical stimuli, conditional on agronomic and household characteristics, is developed. Three years of survey data, gathered from low-income corn and vegetable farms near a national park in the southern Philippines are used to evaluate the model empirically. Within farms, land allocation is responsive to relative crop prices and yields. However, different crops elicit different responses. In particular, some crop expansion takes place primarily through land substitution and intensified input use, while changes in prices or yields of other crops induce an expansion of total farm area. Land and family labor constraints bind at different points for different crops. These results suggest that because multiple agricultural development policies interact, environmental policies must have multiple strands in order to replace incentives to further land expansion.

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Introduction

In developing agrarian economies, the growth of land-dependent populations in "frontier" agricultural areas poses a challenge to the carrying capacities of natural systems. On-site impacts of agricultural development on sloping lands, often characterized by relatively fragile soils, include fertility loss, salinization, and water logging. Off-site damages include siltation and sedimentation of irrigated farming systems, reductions in performance and life expectancy of hydroelectric facilities, and degradation of coastal environments (Anderson and Thampapillai 1990; Munasinghe 1992; Naiman 1995; UNESCO 1982; OECD 1993). While population growth relative to land is the *direct* source of many environmental problems, it is widely recognized that the persistent dependence of growing populations on land for income is itself an outcome of wider trends, including economic and development policies that promote agricultural expansion and intensification (e.g. Munasinghe and Cruz 1995) without penalizing actions that deplete soils and otherwise degrade the natural resource base.

The Philippines exemplifies both the environmental problems of unchecked agricultural expansion in uplands, and the policy settings that encourage it. Even after decades of reasonably robust growth in the aggregate economy, agricultural expansion continues to be a fundamental characteristic of economic activity, with severe environmental consequences. The area devoted to upland agriculture in the Philippines increased sixfold between 1960 and 1987, and coincided with a rapid decline in forest cover (Cruz et al. 1992; Bee 1987).

Throughout the developing world, government policies influence incentives for both expansion and intensification in marginal agricultural lands (Askari and Cummings, 1976; Heath and Binswanger, 1996; OECD 1996; Lipton, 1987; Schneider 1995). In the Philippines these policies find expression both in the prices faced by farmers and in the set of technologies developed and made available to them. Moreover, price and technology policies clearly interact. Price supports, for example, increase the profitability of affected crops; this promotes the demand for R&D investments aimed at increasing the supply of technical innovations for those crops. When agricultural R&D budget constraints are inflexible, research on less protected crops suffers as a consequence. In this way, price policies can significantly alter both the constituencies for and the perceived returns to agricultural research (Alston, Edwards, and Freebairn, 1988; Coxhead 1997). Price and technology biases can thus promote frontier land expansion, usually at the expense of forest or other permanent ground cover, as well as land reallocation among crops having differing propensities for environmental damage.

In this chain of reasoning, the extent to which farmers actually alter land use in response to relative price and technology shifts is an important empirical question. Upland farmers in developing countries exist "at the margin" in more than a merely geographic sense; they are typically very poor, with few non-farm income sources, and may have only tenuous long-term control over the land they farm. These factors influence their resource allocation choices in ways that reinforce or counteract the effects of policy- or market-induced price shifts. At the extreme, market opportunities may be circumscribed entirely by subsistence needs, in which case the search for agricultural price policy answers to frontier environmental problems will be futile.

In this paper we use Philippine data to conduct an econometric evaluation of the factors affecting farmers' land use decisions in a frontier region. Specific features of Philippine economic policy and of the site from which data are drawn influence our choices in modeling farmer behavior, so we begin with a brief review of these features. Subsequently we present a model of land expansion and allocation by risk-averse farmers and derive a reduced form suitable for econometric estimation. This allows us to test a number of hypotheses relating to the

What factors have precipitated these changes? Infrastructural improvements and a relative abundance of labor in relation to arable land have clearly been important, as documented below. However, we hypothesize that the relative trend and variability of major crop prices has also helped determine land use. By implication, agricultural price policies affecting both prices and price variation have been influential in shaping environmental change in the uplands.

Since the late 1970s, improved roads, bridges, ports and telecommunications have strengthened links between the provincial and national economies. Increasing national demand for corn and temperate-climate vegetables have reinforced the trend towards commercial agriculture. Corn production has flourished, and is now primarily a commercial crop where formerly it was seldom traded outside the area. Vegetable cultivation has also continued to increase in area and economic importance. Infrastructure improvements have caused marketing risks to diminish and this has reduced trade margins, with some benefits presumably returning to farmers in the form of higher and more stable prices.

An abundance of low-skilled labor has also precipitated agricultural expansion. After five decades of modern economic growth with rapidly increasing population, Philippine agriculture remains the largest employment sector, and until recently at least, most industrial production was highly capital-intensive. Within agriculture, labor-abundance has favored relatively labor-intensive annual crops. Furthermore, the land frontier served for a long time as the employer of last resort for underemployed, unskilled labor. Over time, land shortages associated with rising rural populations have promoted intensification. Intensification has increased labor demand and has raised returns to land used for intensive production; however, impact of this change on the labor market has been modest. Only very recently has the rate of growth in non-agricultural employment overtaken total labor force growth. Although a significant slow-down in the net growth of upland population thus seems possible, Lantapan, after decades of rapid population growth, is barely beginning to show signs of labor shortage.

Prices appear also to have been central to land allocation decisions. In brief, relative crop prices have changed over time in ways that favor land expansion. Furthermore, since the major crops grown in Lantapan differ widely in their factor-intensities of production, changes in input prices also have been influential. We highlight the role of specific government policies in fostering these price changes in the next section.

Agricultural development policies and links to land use

Over time, the profitability of corn and vegetable cultivation in Lantapan has been directly and indirectly affected by a number of policies. These consist mainly of market interventions directed at supporting and stabilizing some crop prices; trade interventions aimed at reducing dependence on imports and defending farmer livelihoods; and technology interventions in the form of public support for research aimed at raising yields and reducing vulnerability to pests and diseases.

Corn and temperate-climate vegetables are import substitutes in the Philippines, and their producers—mainly upland farmers—have received considerable encouragement in the form of import restrictions and domestic price supports (Coxhead 1997, 2000). Quantitative restrictions on corn, cabbage and potato imports (recently converted to tariffs at the maximum allowable rate under the WTO) have raised their domestic prices relative to border (world) prices. For these crops, nominal protection has been so high as to more than offset the prevailing bias against agriculture introduced through industrial promotion and exchange rate policies (Intal and Power 1990). In the more recent era of trade liberalization, protection of vegetable crops has remained stable while that of corn has risen: the implicit tariff on corn rose from near zero in the early

1970s to close to 100% by the early 1990s (Intal and Power 1990; Pagulayan 1998). Conversely, direct and indirect export taxes on coffee, formerly an important commercial crop in Lantapan, and one in which Mindanao enjoys comparative advantage (ADB 1993), have discouraged its cultivation. The stock of coffee trees has deteriorated in both quantity and quality, and processing and marketing infrastructure, extension support and other assistance to the industry have all but disappeared.

Technology policies have likewise promoted corn and vegetable production. Bukidnon province was designated as a 'key production area (KPA)' for corn in the Philippine government's Grain Production Enhancement Program (GPEP). KPA farmers are eligible for a range of subsidies and supports directed at increasing corn production, and are the first beneficiaries of research and development directed at increasing corn yields (Department of Agriculture 1994). As a result, the area planted to corn has risen steadily in Bukidnon even as it has declined nationally.[1]

Vegetable producers have also been the beneficiaries of disproportionate research funding allocations (Coxhead 1997) and research effort (Librero and Rola 1995). Potato, a cool-climate crop that is widely grown in Lantapan in some years, was recently identified by the Philippine Department of Agriculture as a "high-valued crop," thus placing it in a special category receiving priority allocations of research and extension resources. Foreign assistance further supplements domestic potato research. Potato production is threatened by disease and insect pests, and as a result, pesticide use is high. Much research concentrates on development and dissemination of new planting materials such as True Potato Seed (TPS) which, under suitable management regimes, greatly reduce the risk of crop losses through disease. Studies of the Philippine potato industry indicate that were TPS or equivalent improvements to become widely available, potato production costs would fall, yields would increase, and the variability of yields would decline (Brons 1996). A similar story applies to cabbage and other vegetable crops, for which pests and disease pose the greatest threats to yields, and the maintenance of crop health is a large component of production costs.

Technological breakthroughs in vegetable production, if they are realized, will be at least as important for dampening the volatility of vegetable yields as for increasing mean yields. The implication of this is that technical progress could have a substantial impact on the land use decisions of risk-averse farmers. Other things equal, as risks diminish, vegetable farmers will increase production, and farmers not presently growing vegetables may reallocate land or expand planted area in order to initiate vegetable production. However, the magnitude of the land area response will depend on other factors, in particular product prices and their volatility, and the availability of inputs that are complementary with land in production. For farmers, both the credit for inputs, and the managerial skills necessary for technologically advanced vegetable production, are likely to constrain vegetable area expansion.

A dynamic model of land allocation decisions under risk

With the preceding observations in mind, we now develop an *ex ante* model to study the effects of price changes and technological improvements on land use patterns, while taking account of potentially binding household resource constraints that would dampen responsiveness to shifts in yield and price distributions. Our objective is to identify farmer's land use responses to economic and technological stimuli, conditional on relevant agronomic and household characteristics. We assume that farmers choose land use strategies consistent with utility maximization over time, based on per-period net farm income. We characterize a representative farmer's economic choices in stylized form and derive an estimable econometric model.

To begin, we suppose that farms are endowed with family labor, a quantity of land, and land quality. They use these to produce a combination of crops, either using all the land at their disposal, or leaving some fallow. For convenience, we work with a two-crop portfolio. The farm purchases inputs (including labor), and sells output at a market-determined price. Given family labor availability and initial land quality, the major decisions each farmer faces at the beginning of a season are (1) the total area to plant, and (2) the fraction of planted area to allocate to each crop.

Since prices and yields are stochastic, we assume that farmers seek to maximize the net present value of a stream of expected utility. That is, they have the objective function

$$Max \int_0^T e^{-rt} EU(t)dt, \tag{1}$$

which they maximize subject to conditions outlined below. In equation (1), r is a discount rate and the planning horizon is defined by the interval $[0,T]$. We suppress time subscripts, except where required for sake of clarity. Following Sandmo (1971) and Anderson *et al.* (1976), we construct a per-period expected utility function EU in terms of expected profit and its variance:

$$EU = U(\mathrm{E}(\pi), \mathrm{Var}(\pi)) \tag{2}$$

We adopt the conventional assumptions that $\partial U/\partial E(\pi) > 0$ and $\partial U/\partial(\mathrm{Var}(\pi)) \leq 0$. Uncertainty has two sources, prices and production. Crop prices at harvest time are unknown when land use decisions are made (input prices are observed at planting time). Production risk arises both from the characteristics of the land and family labor endowments, and from external events such as weather, disease, and pest infestations. Assuming no joint production, the production function for each crop is

$$Y_i = f_i(N_i,\ F_i,\ \mathbf{X}_i, \varepsilon_i, q) \tag{3}$$

where N_i is area planted to the i'th crop, F_i is family labor, $\mathbf{X}_i$ is a vector of variable inputs (fertilizer, chemicals, and hired labor), ε_i is a random variable representing production risk, and q is an index of soil quality. Using a standard multiplicative representation of production uncertainty, the random production function can be written:

$$Y_i = \varepsilon_i f_i(N_i,\ F_i, \mathbf{X}_i, q) \qquad \text{i = c, v} \tag{4}$$

$$\text{E}(\varepsilon_i) = \mu_i\text{; Var}(\varepsilon_i) = \sigma^2_i, \qquad \text{i = c, v;}$$

$$\partial f_i/\partial N_i > 0,\ \partial f_i/\partial L_i > 0,\ \partial f_i/\partial X_{ik} > 0,\ \ \forall \text{ variable inputs } k.$$

For convenience we assume that σ^2_i captures production risk from all sources.

It is worth noting that, from our survey, we observe three basic farmer responses to external shocks and perceived changes in land quality. At the extensive margin, farmers increase and decrease total cultivated area by bringing new plots into production, or by leaving plots fallow. At the intensive margin, they adjust labor and input use by crop, using more or less of each to attain a desired production target. And between the intensive and extensive margins, farmers adjust land allocation among different crops. Accordingly, the land constraint is:

$$\sum_{i=c,v} N_i \le A_{-1} + \Delta A, \tag{5}$$

where A_{-1} is total area cultivated in the previous crop season, and ΔA is the change in area between seasons, i.e. the addition of new land or the movement of previously cropped land into fallow. A cost is associated with bringing new land into cultivation. We write this as $M(\Delta A)$, with $M' > 0$. As highlighted below, availability of a bundle of complementary factors, such as family labor, may influence ΔA.

Family labor and hired labor are not perfect substitutes, because family labor embodies supervisory capacity as well as farm-specific land and crop management skills. It is reasonable to assume that, in the short run, family labor is fixed in supply. We assume that each unit of land cultivated requires s units of family labor for management and supervision, in addition to labor used in usual farming tasks. It follows that we can write the constraint for family labor as:

$$\sum_{i=c,v} F_i + s(A_{-1} + \Delta A) \leq F, \tag{6}$$

where F is the number of adult family members.

Dynamics of the model are defined by a constraint equation that specifies the evolution in soil quality, which we define as:

$$\dot{q} = h(\mathbf{N}, \mathbf{X}, \Delta A), \tag{7}$$

where $\dot{q}$ represents the per-period change in an index of soil quality on the plot. Equation (7) expresses the fact that changes in soil quality reflect choices regarding crop mix, levels of input use, and changes in land area. Signs of these relationships are indeterminate.

Defining a vector $\mathbf{W}_i$ of the prices of variable inputs used in crop i, the current period profit function is:

$$\pi = \sum_{i=c,v} \left[P_i \varepsilon_i f_i(\cdot) - \mathbf{X}_i \cdot \mathbf{W}_i \right] - \delta M(\Delta A) \tag{8}$$

$$\text{where } \delta = \begin{cases} 1 & \text{when } \Delta \mathrm{A} > 0 \\ 0 & \text{otherwise} \end{cases}$$

For simplicity, we assume price risk and yield risk are independent. If we define expected prices as $\mathrm{E}(P_i) = \theta_i$ and the variances of prices as $\mathrm{var}(P_i) = \phi_i^2$ then we can write expected profit as:

$$E(\pi) = \sum_{i=c,v} \left[\theta_i \mu_i f_i(\cdot) - \mathbf{X}_i \cdot \mathbf{W}_i\right] - \delta M(\Delta A), \tag{9}$$

and the expected variance rate for profit as:

$$var(\pi) = \sum_{i=c,v} f_i^2(\cdot)\left(\phi_i^2\sigma_i^2 + \phi_i^2\mu_i^2 + \theta_i^2\sigma_i^2\right). \tag{10}$$

To minimize notation, it is convenient to define $V_i = \phi_i^2\sigma_i^2 + \phi_i^2\mu_i^2 + \theta_i^2\sigma_i^2$. The present value Hamiltonian for this problem can be written:

$$H = e^{-rt} EUdt + \lambda_q h(\mathbf{N}, \mathbf{X}, \Delta A), \tag{11}$$

subject to the definitions provided above, constraints (5)-(7), and an initial condition for the land quality, $q(0) = q_0$. In this expression the multiplier λ_q is the shadow price of land quality.

Maximizing the Hamiltonian with respect to **N**, **F**, **X**, and ΔA, and subject to the per-period and dynamic constraints yields the following system of first-order conditions:

$$\frac{\partial H}{\partial N_i} = \frac{\partial EU}{\partial N_i} + \lambda_q \frac{\partial h}{\partial N_i} = 0 \qquad \forall\, i \tag{13}$$

$$\frac{\partial H}{\partial F_i} = \frac{\partial EU}{\partial F_i} + \lambda_q \frac{\partial h}{\partial F_i} = 0 \qquad \forall\, i \tag{14}$$

$$\frac{\partial H}{\partial X_{ki}} = \frac{\partial EU}{\partial X_{ki}} + \lambda_q \frac{\partial h}{\partial X_{ki}} = 0 \qquad \forall\, i, k \tag{15}$$

$$\frac{\partial H}{\partial \Delta A} = \frac{\partial EU}{\partial \Delta A} + \lambda_q \frac{\partial h}{\partial \Delta A} = 0 \tag{16}$$

$$\dot{q} = \frac{\partial H}{\partial \lambda_q} = h(\mathbf{N}, \mathbf{X}, \Delta A) \tag{17}$$

$$\dot{\lambda}_q = -\frac{\partial H}{\partial q} = -e^{-rt}\frac{\partial EU}{\partial q} - \lambda_q \frac{\partial h}{\partial q} = 0, \tag{18}$$

along with the initial condition $q(0) = q_0$ and transversality condition $lim_{T\to\infty} \lambda_q(T) q(T) = 0$.

Equations defining the paths of the choice variables can be written in expanded form as:

$$N_i\!: \quad \frac{\partial U(\cdot)}{\partial E(\pi)}[\theta_i \mu_{ic}]\frac{\partial f_i}{\partial N_i} + \frac{\partial U(\cdot)}{\partial Var(\pi)}V_i 2 f_i(\cdot)\frac{\partial f_i}{\partial N_i} + \lambda_q \frac{\partial h}{\partial N_i} = \lambda_N \qquad \forall\ i \tag{13$'$}$$

$$F_i\!: \quad \frac{\partial U(\cdot)}{\partial E(\pi)}[\theta_i \mu_{ic}]\frac{\partial f_i}{\partial F_i} + \frac{\partial U(\cdot)}{\partial Var(\pi)}V_i 2 f_i(\cdot)\frac{\partial f_i}{\partial F_i} + \lambda_q \frac{\partial h}{\partial F_i} = \lambda_F \qquad \forall\ i \tag{14$'$}$$

$$X_{ki}\!: \quad \frac{\partial U(\cdot)}{\partial E(\pi)}[\theta_i \mu_i]\frac{\partial f_i}{\partial X_{ki}} + \frac{\partial U(\cdot)}{\partial Var(\pi)}V_i 2 f_i(\cdot)\frac{\partial f_i}{\partial X_{ki}} + \lambda_q \frac{\partial h}{\partial X_{ki}} = W_k \qquad \forall\ i, k \tag{15$'$}$$

$$\Delta A\!: \quad \frac{\partial U(\cdot)}{\partial E(\pi)}M'(\Delta A) + \lambda_q \frac{\partial h}{\partial \Delta A} + s\lambda_F = \lambda_N \tag{16$'$}$$

where we now explicitly incorporate the inequality constraints in (5) and (6). The multipliers associated with the inequality constraints, λ_N and λ_F, can be interpreted as the shadow prices of land and family labor.[2]

Equations (13′)-(16′) require that along the optimal path the implicit value of soil quality must be equal to the marginal cost of enhancing soil quality, either through additions of land or through application of inputs in excess of crop uptake. For well-behaved utility and production functions, the constraints specified by (5) and (6) are binding at all points along the path, and the system of equations yields optimal path values for $\mathbf{T}^*$, $\mathbf{F}^*$, $\mathbf{X}^*$, q^*, ΔA^* and λ_i^*, $i = (N, F, q)$. At each point along the planning horizon the problem comprises $(2k + 9)$ equations with the same number of endogenous variables. Given observed data, we can construct a set of reduced form equations that provides a solution for $\mathbf{T}^*$, $\mathbf{F}^*$, $\mathbf{X}^*$, and ΔA^*. Since each endogenous variable depends only on the set of exogenous variables, we can estimate each equation independently.

The presence of a fixed cost associated with the introduction of new land means that even if the solution of ΔA^* is positive, it does not necessarily follow that farmers will cultivate new land. In theory, a threshold for ΔA^* exists, below which farmers make no change in the total area of the farm. As long as the indirect profit function $\pi^*(\Delta A^*)$ and the land quality equation $h^*\left(\mathbf{N}^*, \mathbf{X}^*, \Delta A^*\right)$ are increasing in ΔA^*, we can define $U(\pi^*, q^*)$ as the instantaneous indirect expected utility function. In theory, a farmer will bring new land into cultivation if the expected discounted return along the continuation path warrants doing so; that is, if the following condition holds:

$$\int_s^T e^{-rs} U\left[\pi^*\left(\Delta A^*, q^*\right)dt - M\left(\Delta A^*\right)\right] > \int_s^T e^{-rs} U\left[\pi^*(0, q)dt\right] \tag{19}$$

where the interval $[s, T]$ represents the time remaining in the planning horizon. Equation (19) defines the minimum amount of land to be brought into cultivation. The new land may be part of the farm that was previously uncultivated, or it may be newly acquired; we do not distinguish these cases. An increase (reduction) in the fixed cost of land clearing will move the threshold up (down) monotonically. Because of the managerial input required to cultivate crops, the empirical analysis below explicitly accounts for the fact that household labor endowments may constrain the amount of new land cultivated in any period.

Equation (16′) is the condition that governs farmers' decisions to change the total area of land. In this equation, λ_N is the marginal benefit of adding a unit of land, $M'(\Delta A)[\partial U/\partial \mathrm{E}(\pi)]$ is the marginal loss in utility associated with the cost of bringing new land into production, $s\lambda_F$ is the family labor cost of cultivating crops grown on new land, and $\lambda_q[\partial h/\partial(\Delta A)]$ is the amount by which the new land will contribute to greater overall land quality along the continuation path. Other things equal, an exogenous shock that raises the marginal productivity of land increases the value of λ_N. Condition (16′) then requires that farmers respond by allocating family labor to preparing and cultivating any new land. This adjustment increases total farm area and reduces the quantity of family labor available for crop cultivation. Condition (16′) holds so long as the production function is concave and the land brought into cultivation is of greater average quality than land currently under cultivation. It thus provides insights into why policy makers emphasize policies to improve land quality—or reduce the rate of its decline. Other things equal, policies that reduce the rate at which land quality degrades (such as promotion of soil conservation, mulching or agroforestry) also reduce incentives for land expansion. However, it is important to note that decisions regarding land expansion are conditioned by access to complementary inputs.

How do land allocations respond to exogenous shocks such as changes in expected prices and yields, price or yield volatility, and farm-level endowments of land and family labor? On the basis of the model just developed, we can make the following observations.

First, the area planted to each crop is an increasing function of expected price and yield. For cross price responses, since N_c and N_v are clearly substitutes by (5), we expect $\partial N_i^* / \partial \theta_j < 0$ for $i \neq j$. Similarly, an increase in the expected yield of one crop should reduce area planted to the other. Under risk neutrality, and without constraints on land and labor resources or access to credit, price shocks and yield shocks (representing factor-neutral technical progress) should dominate the explanations of land allocation to crops and of total land planted.

Risk-aversion will bring new variables into play and will also alter the above predictions. Under risk-neutrality we expect land allocation by crop to be invariant to own price and yield variability. Under risk aversion, the signs associated with own variance will be unambiguously negative.[3] For a positive corn price or yield shock, risk-neutral farmers will expand corn area by more than risk-averse farmers, since an increase in corn production also implies an increase in the variance associated with income from corn. In general, risk-averse responses to price or yield shocks should be less strong than risk-neutral responses. Since corn prices and yields are rather stable, however, $\partial N_c^* / \partial \theta_c > 0$ should continue to hold under risk aversion.

The same reasoning holds for vegetables, although empirically, vegetable prices and production are both more volatile than corn, so we expect that small increases in expected price or expected yield may elicit very small (or even zero) responses among risk-averse farmers. Exogenous changes in variances may have more measurable effects.

An interesting feature of our empirical sample is that some farmers grow no vegetables, only corn. Though the model presented above does not fully explain such specialization, it can provide insights into why some farmers might be reluctant to change to vegetables. A corner solution (growing only one crop) implies discontinuity in the response function; only a sizable jump in the expected vegetable price relative to corn (or equivalent shifts in relative yields) will provide sufficient incentives to diversify. Once again, if variances are the subject of exogenous shocks through price policy or technological innovation, then risk-averse farmers might find it advantageous to make non-marginal changes in their crop portfolios.

Finally, we note the role of land and labor constraints. The model permits new land to be added to the farm at the beginning of each period. This land can only be acquired at some cost, however. This might be the cost of preparing fallow land for cultivation, or of establishing a claim to the land— whether through colonization of forest or fallow land, negotiation of a tenancy contract, or some other means. The nature of these costs directly implies that family labor availability is likely to be a binding constraint on the acquisition of new land, and a reduction in family labor availability may cause the size of the operated farm to contract.

Family labor and total land constraints should also operate differently between crops. Vegetable crops are considerably more management-intensive than corn, so whereas corn production can be expanded by hiring more labor (given land), the same may not be true of vegetables. Conversely, relaxing the land constraint (given family labor) should expand corn area, but may have no leave vegetable production unchanged if the household cannot provide matching managerial resources. The presence of land and labor constraints indicates a short-run model. Empirically, if these constraints are found to bind, then we can draw inferences about the incentives for farmers to take steps to relax them, following a shock of a given kind.

Data and econometric method

Our model implies the following equations for econometric estimation:[4]

$$N_c^* = N_c\left(\theta_i, \phi_i^2, \mu_i, \sigma_i^2, \mathbf{W}, A_{-1}, F, \mathbf{Z}^N\right) \qquad \text{i =c, v} \tag{20}$$

$$N_v^* = N_v\left(\theta_i, \phi_i^2, \mu_i, \sigma_i^2, \mathbf{W}, A_{-1}, F, \mathbf{Z}^N\right) \qquad \text{i =c, v} \tag{21}$$

$$\Delta A_v^* = \Delta A_v\left(\theta_i, \phi_i^2, \mu_i, \sigma_i^2, \mathbf{W}, A_{-1}, F, \mathbf{Z}^A\right) \qquad \text{i =c, v} \tag{22}$$

where N_c is land allocated to corn, N_v is land allocated to vegetables, and ΔA is the year-on-year change in total land area. To the set of exogenous variables in each equation we add a vector $\mathbf{Z}^i$ of farm-specific variables that might serve as additional constraints on land use behavior. For all equations, we include a variable representing security of tenure; this takes several values ranging from low (most secure) to high (least secure). We also include a binary "credit constraint" variable. This takes a value of 1 if the farmer reported either not planting a crop, or altering total land area, because he was unable to obtain credit (or if he reported being constrained in other ways readily capable of the same interpretation). For the total land change equation, we also include dummy variables for other reported reasons for area changes, notably contractual reasons such as the expiry of a lease. A dummy variable for 1995 was added to each regression equation to capture fixed effects associated with year-on-year variation in growing conditions.

Data are drawn from three annual surveys (1994-96) of production, household, plot and farm characteristics of a sample of 85 farmers in the corn-vegetable zone of Lantapan. Tables 3 and 4 provide brief summaries. The data provide direct observations of land use, technology, input use, production, and plot/farm/household characteristics. Variables representing expected prices and their variances were constructed from a separate survey of local traders and markets.[5] Variables representing expected yields and their variances were constructed from the predicted values and residuals of production functions fitted to the data (see Appendix for details).

The system (20)–(22) is a reduced form in which individual equations explain the allocation of land between crops and year-on-year change in total land area in terms of the exogenous variables of the model presented earlier. Because the equations contain lagged values we use only data from the second and third years (1995-96) in estimation. We construct farm-level crop area, labor use, and land characteristics variables by aggregation from plot-level data using area weights. In estimation, a practical problem arises due to lack of variation in wages; this requires that we exclude wages from the set of explanatory variables used in estimation. For chemicals, the difficulty of imputing a price per unit of active ingredient, and of aggregating these across different chemicals, precludes their inclusion in the estimation.

Results

Estimated OLS coefficients of (20)-(22) are reported in Table 5; Table 6 summarizes these in elasticity form.[6] Most coefficients exhibit the expected signs but, overall, the efficiency of the estimates is low. This may be due to genuinely weak economic relationships or to the fact that data are measured with error, as is typical in studies of this kind. Moreover, we find a high degree of correlation between the expected yield variables ($r = 0.96$), and between expected yields and the dummy variable for 1995 (average $r = -0.95$).[7]

In the regressions in which planted-area serves as dependent variable, estimated responses to own prices are positive and estimated responses to cross-prices are negative. Input prices also exhibit the expected signs: corn area declines when the nitrogen price rises, and a rise in the price of manure, which is used most intensively on vegetable plots, reduces vegetable area. However, none of the crop prices, and only the two input prices just mentioned, have statistically significant relationships with the dependent variables.

More explanatory power resides with the variables indicating risk aversion. Area changes are negatively correlated with increases in own-price variances, and are positively correlated with increases in cross-price variances. Area changes are also negatively correlated with increases in the variability of own yields, and are positively correlated with increases in cross-yield variability. These results, which are statistically robust, are consistent with a hypothesis of risk-aversion on the part of sample farmers. The elasticity measures in Table 4 show that changes in the riskiness of corn are more important than changes in the riskiness of vegetables—both for corn and vegetable area decisions.

Land and labor constraints are clearly important overall, and the pattern of statistical significance of coefficient estimates reveals the expected differences between crops. Consistent with our expectations, the land area constraint (lagged farm area) binds for corn, but not for vegetables. If new land were to be added to the farm, it would go mainly into corn production. Conversely, the number of adults in the household limits the area planted to vegetables, but not that planted to corn. These findings accord with our hypothesis that vegetable production is more intensive in use of the managerial and supervisory skills best provided by family members. Finally, lack of credit significantly constrains the area of both crops.

The third equation captures change in total farm area. As in the crop equations, prices have no measurable effect on the year-on-year farm area change. Nor is farm area significantly affected by price and yield variability, although we note that increases in the variability of corn yield and price and positive associated with growth of the farmed area, while instability of vegetable incomes has an opposed sign. Farmers clearly reduce risk through their crop portfolios rather than by planting larger areas. The fact that expected prices, yields, and input prices have low explanatory power is perhaps not surprising, given that we are estimating a short-run model.

As expected, increases in family labor and greater access to credit are both correlated with the addition of new land to the farm. The empirical link between credit availability and farm area expansion accords with predictions from a formal intertemporal model of a credit-constrained farm household presented by Barbier and López (1999). These authors have argued that while the effects of credit constraints on incentives for indebted households to invest in natural resources are ambiguous, it may be rational for severely indebted households to degrade resources at a greater rate when liquidity is increased.

Implications for policy and environmental outcomes

Our results provide some basis for speculation as to the effects of economic policy changes on incentives for agricultural intensification and extensification. Our goal in this section is to assess the influence of policy-driven exogenous changes in prices, yields, and variances on land use and land expansion in Lantapan and similar sites—bearing in mind that the degree of statistical confidence of some of our results is rather low. Given the rather limited number of empirical studies from frontier areas, we see value in linking our econometric evidence to the policy atmosphere in which the fate of natural resources, including tropical forests, is decided.

From a policy perspective, the pronounced pattern of risk averting behavior observed among the sample farmers is of great importance. In the short run, it appears that farmers alter their crop shares more or less predictably, in line with changes in expected prices and yields. But more significantly, we find that farmers will switch land among crops so as to avoid the uncertainty associated with income volatility, especially as driven by yield variability. This focus on yield risk, more than price risk, appears to be the main expression of risk aversion in the sample. Furthermore, our estimates of changes in total farm area indicate a safety-first motive among farmers: increases in the volatility of corn yields induce farmers to expand farm size, while higher vegetable yield volatility, if it has any effect at all, reduces incentives to expand farm area. These results accord with findings from other frontier areas of the Philippines where farmers appear to take into account risk considerations both when choosing between annual and perennial crops (e.g. Shively 1998) and when undertaking investments in soil conservation (e.g. Shively 1997). Taken together, the main policy message behind these findings is that policies that reduce economic risks are likely to be environmentally favorable: resource "overuse" is, in part, insurance against loss.

We now return to our earlier discussion of price and technology, in light of these results. Recall that the most important policies, from the perspective of upland or frontier farming areas, are those that protect or encourage production of staple grains and those that seek solutions to pest- and disease-induced yield variability in commercial vegetables such as cabbage and potato. For corn, our results suggest that policies to support and stabilize prices (e.g. through import restrictions) have little short-run effect on land use. Technical progress aimed at reducing the variability in corn yields, in contrast, will raise the share of area planted with corn, but may actually reduce total area planted. In other words, improving the stability of corn income may be sufficient to discourage area expansion, even if expected incomes do not rise.

For vegetables, price supports and price stabilization will also increase allocation of existing land to these crops. Technical progress that reduces the volatility of vegetable yields will result in a marked land use substitution towards vegetables, but again we would expect little impact at the extensive margin. This is because in the short run expansion of total farm area remains constrained by access to credit and by the availability of the special skills and attention brought to land and crop care by family members, as opposed to hired labor.

These latter findings draw attention to some potentially relevant interactions among economic and technology policies as they affect upland land use. First, much Philippine investment in corn and vegetable productivity is driven by the perception that these crops generate potentially high incomes for farmers. We have seen, however, that much of this perception is due to the presence of price supports, particularly those reflecting trade policy interventions. For potatoes, which are classified as a "high-value crop" and thus targeted for additional research and development expenditures by the Philippine government, current domestic production might be non-existent, if not for past barriers to imports (Coxhead 1997). However, having been brought into existence by economic policies, the vegetable industry could be rendered viable even at free trade prices by sufficiently large shifts in the production function (including reductions in yield volatility). Similarly, the widespread replacement of coffee by corn in Lantapan—a pronounced shift from permanent to annual crops—can be attributed both to policy distortions and to the effects of yield-increasing research and development investments in corn, but not in coffee.[8]

Finally, in the broader policy context of Philippine economic development, continuing pressure of population at the agricultural frontier can largely be explained by reference to past policies that failed to set the country on a path of stable aggregate growth and labor-intensive industrialization. Policy reforms in the 1990s have addressed these failings through sweeping reforms in the areas of trade, finance and banking, and macroeconomic management. These changes have raised the growth rate of GNP; over time, the reorientation of the Philippine economy can be expected to raise the opportunity cost of farm labor. This will diminish incentives to expand agricultural area in spite of technical progress in agriculture. Of course growth outside agriculture, especially growth in the manufacturing sector, is likely to generate other sets of environmental concerns. Nevertheless, it seems clear that a realignment of economic incentives could reduce demand for innovations in upland farming, and might in turn reduce the number of households seeking livelihood at the forest margin, with the long-run result that upland agricultural area ceases to expand.

References

ADB (Asian Development Bank), 1993. *Industrial Crops in Asia.* Manila: ADB.

Alston, J. M., G. W. Edwards and J. W. Freebairn, 1988. Market distortions and benefits from research. *Amer. J. Agric. Econ.*. 70(2):281-288.

Anderson, J.R., J.L Dillon and J.B. Hardaker. *Agricultural Decision Analysis*. Iowa State University Press, 1976.

Anderson, J. R. and J. Thampapillai. 1990. "Soil Conservation in Developing Countries: Project and Policy Intervention." Washington, DC: The World Bank.

Askari, H. and T. J. Cummings 1976. *Agricultural Supply Response: A Survey of Econometric Evidence*. New York: Praeger.

Barbier E. B. and R. López. 1999. Debt, Poverty and Resource Management in a Rural Smallholder Economy. Paper prepared for Royal Economic Society Conference, University of Nottingham, 29 March-1 April 1999.

Barrett, C. B. 1999. Stochastic food prices and slash-and-burn agriculture. *Envir. Devel. Econ.*. 4(2):161-176.

Bee, O. J. 1987. *Depletion of Forest Reserves in the Philippines. Field Report Series No. 18.* Singapore: Institute of Southeast Asian Studies.

Brons, J. 1996. True potato stories: costs and benefits of planting materials. CIP/UPWARD, Los Banos (manuscript).

Coxhead, I. 1997. Induced innovation and land degradation in developing countries, *Aust. J. Agr. Res. Econ.* 41(3):305-32.

Coxhead, I. 2000. The consequences of Philippine food self-sufficiency policies for economic welfare and agricultural land degradation. *World Devel.,* 28(1), January, in press.

Coxhead, I. and G.E. Shively. 1998. Some economic and environmental implications of technical progress in Philippine corn agriculture: an economy-wide perspective. *J. Agric. Econ. and Devel.* XXVI (1/2), pp. 60-90.

Coxhead, I. and A.C. Rola. 1998. Economic development, agricultural growth and environmental management: what are the linkages in Lantapan?. Paper presented at a conference on Economic Growth and Sustainable Natural Resource Management, Malaybalay, Bukidnon, Philippines, May 18-21 1998.

Cruz, M. C., Meyer, C. A., Repetto, R., & Woodward, R. 1992. *Population Growth, Poverty, and Environmental Stress: Frontier Migration in the Philippines and Costa Rica.* Washington, DC: World Resources Institute.

Department of Agriculture. 1994. *Grain Production Enhancement Program.* Quezon City: Philippine Department of Agriculture.

Heath, J. and H. Binswanger 1996. Natural resource degradation effects of poverty and population growth are largely policy-induced: the case of Colombia, *Envir. Devel. Econ.*, 1(1):65-83.

Intal, P. and J. Power. 1990. *Trade, Exchange Rate and Agricultural Pricing Policies in the Philippines* (Washington, D.C.: World Bank).

Lantapan, Municipality of. 1994. Municipal agricultural and demographic data base.

Li Bin. 1994. Impact assessment of land use changes in a watershed area using remote sensing and GIS: a case study of Manupali watershed, the Philippines. M.S. thesis: Asian Institute of Technology, Bangkok.

Librero, A. R. and A.C. Rola. 1994. Vegetable economics in the Philippines. Paper presented at an AVRDC/GTZ Workshop on Agricultural Economics Research on Vegetable Production Systems and Consumption Patterns in Asia, Bangkok, Thailand, Oct. 11-13, 1994.

Lipton, M. 1987. Limits of Price Policy of Agriculture: Which Way for the World Bank? *Devel. Policy Rev.* 5(2):197-215.

Munasinghe, M. 1992. *Water Supply and Environmental Management*. Boulder: Westview Press.

Munasinghe, M. and W. Cruz. 1995. *Economywide Policies and the Environment: Lessons from Experience*. Environment Paper No. 10. Washington, DC: The World Bank.

Naiman, R. J. 1995. *Watershed Management: Balancing Sustainability and Environmental Change*. New York: Springer-Verlag.

National Statistics Office. 1990. *Bukidnon Provincial Profile* (Manila: NSO).

Organisation for Economic Co-Operation and Development (OECD) 1993. *Coastal Zone Management:Integrated Policies*. Paris: OECD.

Organisation for Economic Co-Operation and Development (OECD) 1996. *Saving Biological Diversity: Economic Incentives*. Paris: OECD.

Pagulayan, A.C. Jr. (1998) Philippines, in *Agricultural Price Policy in Asia and the Pacific*, ed. Asian Productivity Organization, pp. 265-278. Asian Productivity Organization, Tokyo.

Sandmo, A. 1971. On the Theory of the Competitive Firm under Price Uncertainty. *Amer. Econ. Rev.* 61:65-73.

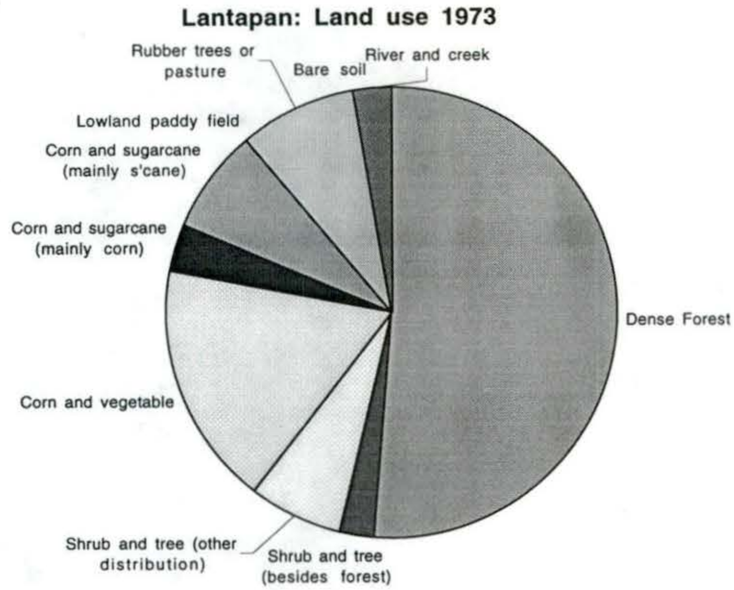
Schneider, R. R. 1995. *Government and the Economy on the Amazon Frontier*. Environment Paper No. 11. Washington, DC: The World Bank.

Shively, G. E. 1997. Consumption Risk, Farm Characteristics, and Soil Conservation Adoption Among Low-Income Farmers in the Philippines." *Agric. Econ.* **17**(2):165-177.

Shively, G. E. 1998. "Economic Policies and the Environment: the Case of Tree Planting on Low-income Farms in the Philippines." *Envir. and Devel. Econ.*, **3**(1):15-27.

Shively, G. E. 1999. "Risks and Returns from Soil Conservation: Evidence from Low-income Farms in the Philippines." *Agric. Econ.* 21(1), pp.53-67.

UNESCO. 1982. *Sedimentation Problems in River Basins.* Paris: UNESCO.



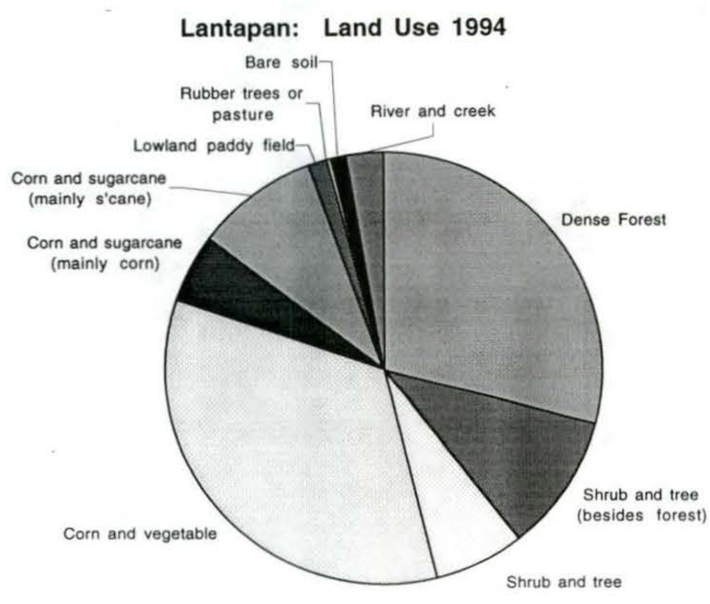


Figure 1: Land Use Changes, Municipality of Lantapan, 1973-94

Source: Li Bin 1994, Tables 5.9 and 6.12

Table 1: Land use by slope (10% and greater), 1973 and 1994

Land use class	10-20%		20-40%		40-90%	
	1973	1994	1973	1994	1973	1994
Dense Forest	69.5	38.9	88.3	59.9	91.7	57.3
Shrub and tree (besides forest)	3.0	11.1	6.2	22.7	3.9	32.5
Shrub and tree (other distribution)	4.0	5.2	1.2	1.7	1.4	0.9
Agriculture	17.6	41.8	3.4	13.1	1.9	7.0
Grass	4.1	..	0.17	..	0.85	..
Bare soil	0.1	1.3	0.2	2.0	0.1	2.3
River and creek	1.7	1.7	0.5	0.5	0.1	0.1

Source: Li Bin 1994, Tables 5.5 and 5.11. .. indicates data not available.

Table 2: Summary of farm-level data

Variable	Units	Mean	Std. Dev.
No. adults resident in HH		3.416	2.055
Total farm area	ha.	2.769	2.772
No. plots per farm		1.682	0.822
Av. area added/year	ha.	0.064	0.326
Av. Area reduced/year	ha.	0.458	2.359
Corn:			
Exp. price	pesos/kg	6.336	0.814
Variance of price		0.637	0.156
Exp. yield	kg/ha	362.93	557.48
Yield variability		2.8225	0.6983
Vegetables:			
Exp. price	pesos/kg	8.936	1.686
Variance of price		4.499	2.825
Exp. yield	kg/ha	2787.6	3278.6
Yield variability		7.267	4.171

Table 3: Estimated crop area and land area response functions

Variable	Area planted: Corn (T_c)	Area planted: Vegetable (T_v)	Net area added (ΔA)
Expected corn price	0.0613	-0.064	0.0006
	(0.428)	(-0.479)	(0.006)
Expect vegetable price	-0.0761	0.0581	0.0049
	(-1.575)	(1.329)	(0.161)
Expected corn yield	-0.1425	0.1601	0.2688
	(-0.452)	(0.5434)	(1.312)
Expected vegetable yield	0.2391	0.1500	-0.3347
	(0.516)	(0.3524)	(-1.171)
Variance of corn price	-2.1229	0.7136	-0.8154
	(-1.406)	(0.500)	(-0.812)
Variance of vegetable price	0.1599	-0.0877	0.0439
	(1.936)[c]	(-1.126)	(0.803)
Corn yield variability	-1.5352	1.3821	0.4382
	(-2.736)[a]	(2.664)[a]	(1.183)
Veg. yield variability	0.5484	-0.3060	-0.0259
	(3.475)[a]	(-2.09)[b]	(-0.248)
Price of nitrogen from fert.	-0.0752	-0.0060	0.0167
	(-3.407)[a]	(-0.350)	(1.371)
Price of manure	0.0473	-0.1856	-0.4894
	(1.127)	(-4.923)[a]	(-1.774)[c]
Lagged farm area	0.3233	-0.1572	-0.1392
	(11.661)[a]	(-0.560)	(-5.166)[a]
Adults in household	-0.0003	0.1088	0.1500
	(0.007)	(2.649)[a]	(5.090)[a]
Tenure	-0.0110	-0.0353	-0.0754
	(-0.314)	(-1.101)	(-3.261)[a]
Credit constraint	-1.2401	-1.0684	-2.9051
	(-2.997)[a]	(-2.736)[a]	(-10.12)[a]
Contractual constraint			-1.9076
			(-6.516)[a]
Other constraint			0.3740
			(0.788)
Year 1995 = 1	0.3162	1.2537	0.3112
	(0.413)	(1.756)[c]	(0.5699)
Constant	0.6514	-1.2614	1.3975
	(0.202)	(-0.421)	(0.659)
R^2 Adj.	0.612	0.304	0.645
Obs.	158	162	170

T-statistics in parentheses. Superscripts a, b, and c indicate significance at 1%, 5% and 10% respectively.

Table 4: Estimated elasticities of crop and farm area response functions

Variables	Corn Area	Vegetable Area	Area Change
Expected corn price(peso/kg)	0.3769	-0.7607	0.0089
Expected vegetable price(peso/kg)	-0.6600	0.9789	0.1124
Expected corn yield	-0.1382	0.3016	0.6817
Expected vegetable yield	0.2320	0.2826	-0.8489
Variance of corn price	-1.3120	0.8564	-1.3173
Variance of vegetable price	0.6983[c]	-0.7432	0.5005
Corn yield variability	-1.4896[a]	2.6042[a]	1.1114
Vegetable yield variability	0.5321[a]	-0.5766[b]	-0.0657
Price of nitrogen (peso/kg)	-0.9027[a]	-0.1407	0.5240
Price of manure (peso/kg)	0.4898	-3.7306[a]	-1.3240[c]
Total farm area last year(ha)	0.9921[a]	-0.0937	-1.1171[a]
Number of adults in the household	0.0010	0.7002[a]	1.2998[a]
Average tenure of the farm	-0.0370	-0.2297	-0.6616[a]
Credit constraint	-0.5564[a]	-0.0931[a]	-0.3407[a]
Contractual reason for dropping plot	--	--	-0.1678[a]
Other reason for dropping plot	--	--	0.1096

Appendix: data and the construction of variables

Most data used in this study were reported directly by farmer interviews between 1994 and 1996. Some variables, however, were either missing from farm data sets or required external information. These include expected prices and price variances and crop yield variances. Other variables, such as expected crop yields, were inferred from the data by methods described below.

Expected Prices Expected crop prices are constructed from a 3-year weekly price series collected at several marketing points in the watershed. We use these series to predict harvest-time prices of each crop for the month in which the harvest was reported to have taken place. We assume that corn and vegetable prices follow an AR(1) process,

$$P_{t+1} = \lambda P_t + D + e, \text{ where D is a seasonal dummy.} \tag{A1}$$

We further assume that farmers base their crop area decision on expected prices. For example, the average crop season is four months for corn and two months for vegetables. If the farmer makes the decision of how much land to grow corn or vegetable in April, he or she forecasts the price of corn in August and that of the vegetables in June, based on the prices of each crop in April. Thus, the forecast function for corn and vegetable prices can be written:

$$E\left(P_{t+4}^{C}\right) = \eta^{C} P_t^{C} + D^{C} \tag{A2}$$

$$E\left(P_{t+2}^{V}\right) = \eta^{V} P_t^{V} + D^{V} \tag{A3}$$

Combining (A1) with (A2) and (A3), the forecast function for corn and vegetable prices is:

$$E\left(P_{t+4}^{C}\right) = \left(\lambda^{C}\right)^{4} P_t^{C} + \left[1 + \lambda^{C} + \left(\lambda^{C}\right)^{2} + \left(\lambda^{C}\right)^{3}\right] D^{C} \tag{A4}$$

$$E\left(P_{t+2}^{V}\right) = \left(\lambda^{V}\right)^{4} P_t^{V} + \left[1 + \lambda^{V}\right] D^{V} \tag{A5}$$

We first estimate (A3) for corn and vegetables to get λ^{C} and λ^{V} and seasonal dummies. Then we use (A4) and (A5) with the current-month price to construct the expected price series.

Price Variances We hypothesize that farmers are risk averse, and therefore expect that the perceived variance of prices may have an impact on land allocation decisions. Variance forecasts for prices are constructed in the following way. Suppose that farmer makes the decision of how much land to grow corn or vegetables in time *t*. We assume the farmer's information set includes the price history to time *t*, and use this price history to calculate the farmers' perceived price variance at time *t* using the regression residual from the expected price regression.

Expected Yields We estimate expected yields from production functions (Table A-2) fitted to the plot-level data production and input data (Table A-1). We then aggregate these plot-level data to the farm level. Farms reporting no production of a crop are assigned expected yields constructed by fitting available predicted yields on a set of plot characteristics.

Yield Variances Many farm-specific, idiosyncratic and covariate factors contribute to yield variability. Unfortunately, we have little information from which to construct *ex ante* predictions of yield variability. We use the absolute value of the residual of the production function as a measure of variability. We assert that plot-level yield variability is positively related to slope, and negatively related to the adoption of soil conservation practices such as hedgerows or contour plowing, since these greatly diminish the risk of crop loss during monsoonal storms (for some evidence, see Shively 1999). We thus constructed plot-level yield variances as the absolute value of the predictions from the regression:

$$\sigma = \beta_0 + \beta_1 * \text{SLOPE} + \beta_2 * (\text{SLOPE} * \text{CONS}) + \beta_3 * \text{AREA} + \beta_4 * \text{CORNHIS}$$
$$+ \beta_5 * \text{VEGHIS} + \beta_6 * \text{YR95} + \beta_7 * \text{YR96}, \qquad \text{(A6)}$$

where SLOPE takes values of 0 for flat land, 0.15 for medium-slope, and 0.35 for steep land, and CONS is a dummy with a value of 1 when farmers report any conservation practices on the plot.

Table A-1: Summary of plot-level data

Variable	Units	Mean	Std. Dev.
Area	ha.	1.488	1.650
Area planted	ha.	0.845	1.251
Corn area	ha.	0.524	0.847
Veg. area	ha.	0.134	0.414
Slope (flat=0, med=15%,steep=35%)	%	15.120	11.596
Distance from national rd.	km.	2.623	3.571
Tenure	see note	3.665	2.202
Farmers' soil descriptions:			
Acidity (1=acid, 0=otherwise)		0.189	0.393
Fertility (2=fertile, 0=infertile)		0.942	0.818
Color (2=black, 0=yellow/red)		0.926	0.604
Plot-specific cultivation history:			
Corn		0.905	0.798
Vegetable		0.345	0.371

Notes: *Tenure*: 1 = most secure (title or equivalent), 7 = least secure (share rental or equivalent). *Cultivation history*: Five-year index of cultivation intensity, by crop. Constructed by adding (1, 0.8, 0.6, 0.4, 0.2) to the index for crop *i* if the crop was planted in year (t-1, t-2, t-3, t-4, t-5). Thus $0 \leq \text{index}(i) \leq 3$.

Table A-2: Double-log production function estimates

	Corn production		Vegetable production	
	Coeff.	t	Coeff.	t
Area planted	0.61	8.77[a]	0.28	1.90[c]
Area*variety	-0.41	-2.32[a]		
Labor	0.21	3.06[a]	0.03	0.15
Labor*variety	0.27	1.85[c]		
Nitrogen	0.15	3.69[a]	0.11	0.41
N*variety	0.17	2.06[b]		
Phosphorus	-0.03	-0.56	-0.63	-1.96[c]
P*variety	-0.19	-1.76		
Potassium	0.01	0.22	0.84	3.25[a]
K*variety	-0.00	0.25		
Manure	0.003	0.11	0.08	1.13
M*variety	0.04	0.26		
Chemicals	0.05	0.94	0.04	0.49
Chem*variety	0.07	0.42		
Slope (L=0, H=2)	0.004	0.55	0.18	1.06
Variety (M=1, T=0)	-1.04	-1.84[c]		
Year 1994 = 1	0.09	0.73	-0.32	-0.76
Year 1995 = 1	0.02	0.15	-0.81	-1.72[c]
Constant	5.74	19.60[a]	5.92	5.76[a]
$\overline{R}^2$	0.55		0.39	
No. of observations	276		72	

Note: values of all continuous variables are in logs. Superscript letters a, b, and c indicate significance at 1%, 5% and 10% respectively. Variety dummy variable applies to corn only (M = Modern (improved), T = traditional).

Notes

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[1] Experiments with an economy-wide model of the Philippines indicate that at constant prices, technical progress in corn production, which has the same effect on farm profitability as a price rise, would increase area planted to corn by a substantial margin (Coxhead and Shively 1998).

[2] Control problems with inequality constraints on the control variables generally require that rank conditions hold, i.e. that the number of active constraints not be greater than the number of control variables. While this condition is clearly satisfied for our problem, in addition, the resource constraints defined by (5) and (6) result in a pair of complementary slackness conditions for labor and land that define the optimal control paths. Numerical and qualitative solutions that take account of potentially binding control conditions along the optimal path are available (see Léonard and van Long (1992)). Our aim here is to motivate the empirical example provided below; hence we bypass the qualitative solutions, except to note that in general, patterns of land allocation and land clearing will in principle be strongly influenced by the extent to which constraints on labor—especially family labor—bind.

[3] As Barrett (1999) argues, it may be the case that net buyers could suffer from an increase in the mean or variance in a staple price and respond by allocating more labor to land clearing.

[4] As noted, the reduced form equations are independent. We estimate only the three land use equations shown because data constraints prevent construction of labor variables. Specifically, our data do not permit us to identify labor use by crop, only for the whole farm.

[5] Coxhead and Rola (1998) provide results of Granger causality tests demonstrating that commodity prices are exogenous to producers in Lantapan, i.e. that an expansion of production in the watershed will not affect market prices of crops.

[6] Although there are a number of observations clustered at zero in the vegetable area regression, use of a Tobit estimator produces no significant difference in the estimates or overall efficiency.

[7] This multicollinearity arises because we cannot directly observe expected yields, and therefore must impute them, based on a sample-wide mean adjusted by plot-level characteristics and other variables. As a result of this procedure, many observations have similar values.

[8] Coffee is indicative. Policy distortions have affected other perennials in similar ways. However, evidence from other areas of the Philippines suggests that appropriate price incentives can result in substantial planting of commercially valuable trees by smallholders. See Shively (1998).