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Poverty, Agricultural Development, and the Environment: Evidence from a Frontier Region of the Philippines

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Abstract

We measure impacts of agricultural intensification on environmental outcomes in the Philippines. We develop models of labor demand outside a forest zone and labor allocation and asset accumulation inside a forest zone to study household response to technical change. Using household data from 1995-2000 we estimate a series of dynamic econometric models to trace the impacts of irrigation development to changes in incomes and activities at the forest margin.

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1. Introduction

In this paper we study the linkages between poverty and environment in frontier areas, the degree to which the poor might be agents of degradation, and the extent to which technological changes that increase agricultural productivity might reduce pressure on adjacent forests. In many situations, poor farmers have few options beyond degrading natural resources in their struggle to survive (Brundtland Commission, 1987; Durning, 1989, Mink, 1993; Pagiola, 1995; Reardon and Vosti, 1997). Increasing agricultural production is often seen as a solution to the need to increase food production while preserving remaining natural habitats (Paarlberg, 1994; Pagiola *et al*., 1997). But despite considerable interest, empirical research on this topic remains scarce. We seek to help fill this empirical gap and thereby contribute to the larger literature on the impacts of agricultural intensification and expansion (see, for example, Lee and Barrett, 2001).

In this paper we illustrate how, over time, agricultural intensification outside a forested zone affects patterns of labor allocation and forest use inside an adjacent forested zone. Our analysis has two parts. We study changes in lowland labor demand that have resulted from irrigation development in a lowland rice growing area of the Philippines. We then examine the impacts of changes in labor demand on employment and incomes among households living near the irrigation area, but not in it, as well as the impacts of these employment changes on activities undertaken along the forest margin. In tracing out this causal chain we ascertain whether, over time, the irrigation systems have had spillover effects on adjacent upland communities, and whether and to what extent these effects have alleviated pressures on nearby forests.

2. Study site and data

Our data come from a series of three farm surveys covering the years 1995, 1997, and 1999 in southern Palawan, in the Philippines. Palawan's population has been growing at a rate of 4.6% annually, primarily due to immigration from other areas of the Philippines (Western, 1988). This has led to the expansion of agriculture into upland areas, resulting in deforestation and resource degradation, with adverse consequences both on-site and off-site (Sandalo, 1996). In upland areas of Palawan agriculture is primarily subsistence oriented (Shively, 1998). Considerable efforts have been made in recent years to develop irrigation in suitable lowland areas of Palawan. The National Irrigation Administration targeted nearly 6,000 hectares for irrigation development during the 1990s. By 1999, 16 of 20 proposed irrigation projects had been completed.

Our study sites are two of these areas of irrigation development: Tamlang (Municipality of Brooke's Point) and Marangas (Municipality of Bataraza). Garcia (1995) and Martinez and Shively (1998) describe the sites in detail. Both locations have large and growing upland populations, and have experienced extensive degradation of forest cover and forest resources in the local watersheds (see Shively, 1997). At both sites the lowland irrigation projects are in close geographical proximity to upland and coastal communities. In 1995, at the time of our first survey, all lowland farming took place under rainfed conditions. By the time our second survey was completed in 1997 lowland farming had begun a transition to irrigation: 48% of farms in the sample were irrigated in 1997. By the conclusion of our third survey (covering the 1999 growing season), 93% of lowland farms had gone from rainfed to irrigated production.

Table 1 summarizes the lowland and upland samples. A comparison of the situation before and after irrigation reveals some striking short-term effects of the technical change. Using data from 1995 and 1997 only, Martinez and Shively (1998) and Shively and Martinez (2001) documented an increase in labor use following irrigation, a corresponding increase in lowland employment for upland residents, a rise in lowland wages and lowland and upland incomes, and a modest but statistically significant reduction in forest-degrading activities. These findings suggested the lowland irrigation projects had an early and immediate affect on upland households by increasing opportunities for working off farm. This led to a reallocation of time away from forest clearing and farming in the uplands, thereby reducing rates of deforestation.

However, follow-up work by Shively (2001) raised concerns about whether these initial gains in welfare and environmental conditions could be sustained, especially in the face of economic incentives to reduce labor use (see also Zelek and Shively, 2001). Adding data from the 1999 production year casts light on this issue. Between 1995 and 1997 the proportion of sample farms reporting off-farm work rose from 62% to 80%, the total days of off-farm labor rose from 17 to 38, and the average off-farm wage received rose from 19 pesos to 52 pesos per man-day. But extending the sample to 1999, we find some reversal in these gains. Although the average wage received continued to rise (to 54 pesos per man-day in 1999), the proportion of households reporting off-farm work declined (to 64%) and the average number of days of employment fell also (to 23 per household). Restricting ourselves to the panel of households that appear in the 1999 and earlier surveys, we find a pattern broadly consistent with that described above. This suggests that—aside from growth in nominal wages—initial labor market gains have not been sustained in full.

Nevertheless, nearly half of the upland households reported in the 1999 survey that they had benefited from lowland irrigation. Evidence supports the conjecture that most wages were directed toward short-run improvements in well-being: 69% of upland households used some or all of their 1999 wage income for food purchases, 52% devoted their wages to the purchase of household goods, and 46% purchased medicines. More direct evidence, in the form of reported rates and extent of forest clearing also provide statistically significant support for the view that both economic and environmental improvements have occurred over time. Between 1995 and 1999 the proportion of sample farmers reporting forest clearing fell from 0.57 to 0.23 (F=28.2), and the average area cleared fell from 0.38 hectares per household in 1995 to 0.19 hectares per household in 1999 (F=6.0). Nevertheless, descriptive data reveal a tangled and statistically weak set of connections between wage earning and forest pressure: 1999 saw an up-tick in forest clearing compared with 1997, and while the proportion of wage earners reporting forest clearing was slightly lower than the proportion of non wage earners (0.33 vs. 0.36), those who earned wages cleared slightly more land on average than those who did not (0.27 ha vs. 0.21 ha per year). To the extent higher wages lead to higher upland incomes, enhanced consumption also may be accompanied by investments in liquid or non-liquid assets. Over time, the accumulation of these assets alters the production possibilities space for upland households.

Two factors determine how upland, forest-degrading activities respond to a technological shift in the lowlands. The first is the extent to which the technological change precipitates an increase in the wage. The second is the degree to which a change in the opportunity cost of upland labor—as reflected in the lowland wage rate—precipitates a reallocation of effort and resources away from forest degrading activities. In section 3 we examine the development of demand for upland labor in the irrigated areas. In section 5 we study the resulting changes in behavior in upland areas.

3. Lowland farms

3.1 An analytical model of technical change and lowland agricultural production

Our analysis of lowland farms builds on a standard static model of household production, which integrates producer, consumer, and worker decisions (e.g. Singh, Squire, and Strauss 1986). For convenience, we assume production and consumption decisions are separable. For the current study this approach is justified by empirical facts: the lowland households we are studying face exogenously determined prices; they utilize credit and have access to markets for all inputs and products; and they are, at least in years without aberrant rainfall patterns, net sellers of food.

The lowland household's problem is to maximize utility subject to a full income constraint and a time constraint. The problem is defined as:

$$\underset{c_a, c_f, c_l}{Max}\, u(c_a, c_f, c_l; Z) \qquad [L.1]$$

subject to:

$$\pi^* + w\bar{l} = p_a c_a + p_f c_f + wc_l + \mathbf{p_x x} \qquad [L.2]$$

$$c_l + l^s = \bar{l} \qquad [L.3]$$

where π^* denotes maximum agricultural profit, l^s represents the lowland household's supply of labor to agricultural production, $\bar{l}$ represents the household's labor endowment, and c_a, c_f and c_l are consumption of an agricultural commodity, a composite forest product, and leisure. Prices of these goods are p_a, p_f, and w, where the latter reflects the opportunity cost of leisure time. We define $\mathbf{x}$ as a k x 1 vector of agricultural inputs that includes fertilizer, pesticide, and application of owned or rented machinery and livestock; $\mathbf{p_x}$ is a corresponding vector of factor prices. We use Z to represent features of the household, such as size and composition. The household first solves the production problem, namely maximization of profit $\pi = p_a q_a - \mathbf{p_x x} - wl$ subject to the technology of production $\Gamma(q_a, \mathbf{x}, l; \theta) = 0$, where q_a represents agricultural output, θ represents the technology of production, and l represents the combination of household and hired labor. We note that the productivity of hired labor may differ from that of family labor due to work capacity, managerial capacity, or supervision requirements.

Via standard analytical techniques one can assess household response to price and technology changes. Defining full income as:

$$y = p_a q_a - \mathbf{p_x x} - wl + w\bar{l} \qquad \text{[L.4]}$$

the reduced form of the household problem includes one equation for agricultural supply:

$$q_a = q_a(p_a, \mathbf{p_x}, w; \theta) \qquad \text{[L.5]}$$

k + 1 equations for factor demands:

$$x_i = x_i(p_a, \mathbf{p_x}, w; \theta), \quad i = 1 \text{ to } k \qquad \text{[L.6]}$$

$$l = l(p_a, \mathbf{p_x}, w; \theta) \qquad \text{[L.7]}$$

and three equations for commodity demands:

$$c_j = c_j(p_a, p_f, w, y), \quad j = a, f, l. \qquad \text{[L.8]}$$

We assume that technical change is exogenous. The impact of changes in technology on household income is found via equation [L.4]. This impact is:

$$\frac{\partial y}{\partial \theta} = p_a \frac{\partial q_a}{\partial \theta} - \sum_i p_{x_i} \frac{\partial x_i}{\partial \theta} - w \frac{\partial l}{\partial \theta}, \qquad \text{[L.9]}$$

which is positive if technical change is factor augmenting and inputs are normal.

Two interacting forces influence how lowland technical change affects patterns of lowland labor demand, the agricultural wage, and demand for upland labor: (i) the extent to which technical change increases or decreases demand for labor on lowland farms, i.e. $\partial l/\partial \theta$, and (ii) the extent to which technical change increases demand for consumption of leisure by lowland household members, i.e. $\partial c_l/\partial \theta$. Note that the first force may include both direct and indirect effects. For example, one might observe a direct rise in the use of labor due to the requirements of irrigation and a simultaneous release of labor due to indirect effects. This could happen, for example, if irrigation precipitates an increase in the use of tractors or herbicides and therefore a reduction in use of hand plowing or hand weeding. A rising wage tends to reduce incomes on farms that purchase labor, and therefore discourages consumption of leisure. However, if technical progress raises returns to land owned by a household, this increase in income may outweigh the reduction in income associated with a higher wage bill and lead to greater consumption of leisure and a shift toward hired labor.

To further motivate our empirical investigation, consider an initial equilibrium in which a lowland farm produces rice, using rain fed techniques. Suppose an innovation takes place in the lowland agricultural sector, for example development of an irrigation system to provide water storage and delivery. If this innovation raises the value of labor used in production, it will tend to boost labor use. Furthermore, if irrigation facilitates multiple cropping during a calendar year, annual labor demand might rise. This could occur because more labor is used during a single cropping season, because labor is used during times of the year that it was formerly not used, or both. In other words, the technical change may increase *effective labor demand*, i.e. the total amount of labor used on a hectare of land in a calendar year. If lowland farmers have imperfect information regarding upland worker abilities, considerable friction may exist in the hiring decision. And to the extent hired labor is only an imperfect substitute for family labor, incentives to replace family labor with hired labor may be weak (see Coxhead, Shively, and Shuai, 2002). To account for the underlying characteristics and information upon which labor hiring decisions are based, we posit a modified reduced form for the lowland labor demand equation [L.7] in which decisions are conditioned on knowledge:

$$l_t = l\left(w_t, \theta; Z \mid \Omega_t\right) \qquad \text{[L.7´]}$$

where Ω_t represents the decision maker's information set at time *t*. In specifying this dynamic labor demand equation, we assume that the lowland farmer's knowledge of land productivity and worker ability, based on accumulating experience, is embodied in Ω_t.

3.2 Empirical results for lowland farms

Data from the panel of lowland farms suggest that annual lowland labor use was approximately 50% higher in 1999 (post irrigation) than in 1995 (pre-irrigation). During the same period, the average agricultural wage rose approximately 18% (from 89 pesos/man-day in 1995 to 105 pesos/man-day in 1999), the nominal farm-gate price of rice remained virtually constant (at 7.5 pesos/kg), and the nominal retail price of rice rose about 8% (from 17 pesos/kg to 18.5 pesos/kg).[1] Thus while the average daily wage purchased roughly 5.2 kilograms of rice in 1995, the daily wage purchased approximately 5.7 kilograms of rice in 1999. Combined with the overall expansion of employment opportunities, this suggests irrigation had a beneficial economic impact on wage earners in the area, of whom a disproportionate number are poor.

In most cases, the lowland farms in our sample used a combination family, shared, and hired labor to produce rice. To some extent, the labor market story that emerges from the data is one of substitution across labor categories over time. For example, while family labor constituted 57% of all lowland labor used in 1995, it accounted for only 23% in 1999. The emergence of labor sharing between lowland households accounts for part of the shift (shared labor increased from 2% of labor in 1995 to 4% in 1999), but the rapid growth in wage labor accounts for most of the shift. Hired workers provided 37% of all labor used on lowland farms in 1995, but 70% of labor in 1999. Furthermore, upland workers maintained a fairly constant share of hired labor over

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[1] The nominal price of fertilizer in the sample rose 17% between 1995 and 1999.

this period, resulting in 2066 more days of work for upland households in the sample in 1999 than in 1995.

To further explore the determinants of labor demand on lowland farms in the sample, we turn now to results from a series of two reduced-form regressions for lowland labor demand. Given our focus on the lowland-upland nexus, we confine ourselves to an assessment of demand for upland labor. Regression results are reported in Table 2.

Model 1 explores lowland use of upland labor using the pooled sample and a two-step regression strategy. The model uses farm-level observations, representing an unbalanced panel of 149 farm households. Our aim in Model 1 is to identify factors correlated with the upland labor hiring decision on lowland farms. Because one of our primary concerns is the extent to which, over time, the shift toward mechanization may be influencing the labor hiring decision on lowland farms, we begin with a regression designed to produce an instrumented version of the (contemporaneously determined) binary variable for tractor use. Having derived an instrumented version of this variable we then incorporate it into a two-stage sample selection model for hired labor use. For the selection model we jointly estimate a probit regression for the upland labor hiring decision and a lower-truncated Tobit regression for days of upland labor used. Results for Model 1 are presented in the first two columns of Table 1. We estimate the probit model for tractor use controlling for farm-level random effects. In choosing regressors, we restrict ourselves to a small set of variables that are unmistakably exogenous to the tractor use decision.[2] As indicated in the table, the coefficients for the 1997 and 1999 dummy variables clearly reflect the strong and statistically significant rise in tractor use that followed irrigation. We fail to uncover age- or education-dependent effects, and also note no site-specific effects. Farm size, however, emerges as a statistically significant variable in the regression: other things equal, the probability of tractor use rises with farm size. In elasticity terms, a 1% increase in farm size is matched by a 1.1% increase in the probability of tractor use. The model predicts a probability of tractor use of approximately 21%, which is just slightly lower than the sample mean of 24%. The model correctly predicts 77% of the observed values. We retain the instrumented version of the tractor variable for use in the second stage of Model 1.

We find interest in studying both the probability and extent of upland labor hiring. Unfortunately, exact identification of demand for upland labor in the pooled sample is problematic. For the time being we follow an exploratory approach. Below, we use a refined method of identification using a restricted set of farms. We assume that the probability of upland hiring is guided by three main forces: the potential increase in labor needs that accompanies irrigation (indicated by the year dummy variables and a measure of the extent of irrigation on the farm), the household's needs and capacity (indicated by the overall size of the farm, the size of the household labor pool, and our instrumental variable for tractor use), and the extent to which the members of the lowland farm remain residual claimants to farm profits (indicated by the degree of farm ownership). Accordingly, we use a probit model. Taking the binary decision as an indicator of endogenous selection into the sample of farms that hire upland labor (following Barnow et al. 1981), we then estimate overall demand for upland labor (in total days hired) using a lower-truncated Tobit regression, using as our regressors a measure of cultivated area, the household size, and our instrumented variable for the use of a tractor—a potentially labor-saving input. Note that in terms of the instruments used in the tractor use regression, only three appear in the probit regression (the year dummies and farm size), and none appears in the Tobit

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[2] Given that irrigation adoption cannot be ruled strictly exogenous, especially during 1997, we do not account for irrigation directly in the regression for tractor use; we instead rely on the year dummy

regression. As stated above, the models are estimated jointly, and as in the tractor regression we again control for farm-level random effects.

We obtain mixed results in terms of statistical significance. The probit regression reveals a statistically significant reduction in the probability of upland hires over time (in keeping with the observed decline in labor use). However, this decline over time is offset by a positive correlation between irrigation status and hiring. As one would expect, the probability of hiring upland workers is positively correlated with farm size in the sample, but negatively correlated with household size. Owners tended to be more likely to hire than renters, although the correlation is statistically weak. A conjecture that hand tractors substitute for upland workers cannot be accepted at standard test levels, although the sign on the estimated coefficient suggests possible substitution between capital and labor.

In the Tobit regression for days of upland labor hired we find that, after controlling endogenous self-selection, two strong and statistically significant correlations remain in the model: days of upland hired labor is positively correlated with cultivated area and negatively correlated with household size. Regarding mechanization we find that, in contrast to the results of the probit regression, results from the Tobit regression point to a positive correlation between tractor use and days of labor hired. A test for selectivity bias clearly supports the perspective that endogenous self-selection characterizes those lowland farms that hired upland labor ($\sigma = 62.0$, $t = 34.0$). We explore the factors that might account for this bias via Model 2 below.

In Model 2 we aim for a more complete assessment of the reduced form labor demand equation. Although we observe some degree of heterogeneity in wages both within and across years, wage variability is typically insufficient for econometric identification of the standard

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variables. These are highly correlated with the spread of irrigation in the sample.

reduced form labor demand equation. For this reason we take a somewhat different approach, and explicitly account for the fact that the relevant wage to be considered when making labor-hiring decisions is the shadow value of labor used in production. Thus we follow a modified form of the technique used by Jacoby (1993) and Abdulai and Regmi (2000) to incorporate shadow wages in the labor demand equation. We estimate [L.7′] in a two-step process, using only the sub-sample of 88 farms for which we observe outcomes in both 1997 and 1999. First, using production data from these farms for 1997 we estimate a plot-level per-hectare Cobb-Douglas production function of the form $\ln g = \alpha + \sum_{j=1}^{3} \beta_j \ln x_j$, where g = grain yield (in kilograms per hectare) and j indexes the inputs labor (in man-days per hectare), fertilizer (in kilograms per hectare), and pesticides (in pesos per hectare). For each household we retain the fitted value of output ($\hat{g}_i$) and the observed level of labor input ($\mathbf{x}_{labor}$). We combine these with the estimated parameter for labor ($\hat{\beta}_{labor}$) to generate a shadow value for labor input on the plot in 1997, namely $\hat{w}_i = \frac{\hat{\beta}_L \hat{g}_i}{l_i}$.[3] From the perspective of 1997, this measure of labor productivity is jointly determined with actual hiring decisions, since upland labor appears in the denominator of $\hat{w}_i$. But from the perspective of 1999 hiring decisions, $\hat{w}_i$ is clearly observed *prior* to the time a hiring decision is made, and is thus an exogenous variable. We can therefore include the 1997 farm-specific shadow wage as a regressor in a reduced form labor demand equation for 1999. We expect that, other things equal, a lowland farm that experienced a value of $\hat{w}_i$ that was higher than the sample average in 1997 would have had greater incentives to use labor in subsequent years, and—by extension—greater incentives to use hired labor, including upland labor. As in

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[3] For farms with more than one plot $\hat{w}_i$ represents an area-weighted average value for the farm.

Model 1 we control for potentially latent characteristics associated with the hiring decision, as well as the fact that we observe non-zero days of hiring on only 60% of our sample farms, by employing joint estimation of the probit regression (for the binary hiring decision) and the lower-truncated Tobit regression (for actual man-days of upland labor hired).

Despite the loss in sample size that results in this approach, utilizing a dataset based on 1999 observations for which we observe 1997 outcomes provides significant scope for identifying structural dynamics in the hiring decision. Model 2 relies on a set of regressors analogous to those used in Model 1, with the addition of variables conveying information from the 1997 sample period. We also incorporate an appropriately instrumented value of the binary tractor use variable.[4] In terms of signs and magnitudes, the results in Model 2 closely parallel those of Model 1. However, the addition of independent variables from 1997, combined with reduced sample size, diminishes considerably the significance of point estimates in the regression. In the probit regression we find strong statistical support for the conjecture that greater labor use (overall) in 1997 leads to a greater probability of upland hiring in 1999. The probit regression further indicates that higher labor productivity in 1997 (as indicated by the shadow wage rate) was correlated with a higher probability of upland labor use in 1999. The fact that the probability a farm hired upland workers in 1999 is positively correlated with the amount of overall labor used in 1997 provides further evidence of the process of labor substitution highlighted above and suggests a dynamic process of adjustment in labor demand whereby lowland farms increase their reliance on hired upland labor over time. Area planted, land ownership, and tractor use are neither strongly nor significantly correlated with the decision to hire upland labor in Model 2.

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[4] Instrumental variables include age and education of household head (in years), farm size (in hectares), and 1997 household income from all sources (in pesos).

The Tobit regression provides additional insights into the factors associated with upland labor demand. The shadow value of labor is again positively and significantly correlated with days of upland labor hired, as is the total amount of labor hired in 1997. Neither area cultivated nor tractor use is correlated with upland labor use at standard test levels. Controlling for self-selection and other factors, labor abundance and days of upland labor hired are positively correlated, although the result is statistically weak.

In addition to the direct changes in labor use and composition highlighted above, we have observed three other changes in lowland activity that can be correlated with the shift from rainfed to irrigated farming. One, we observe a significant reduction in farm size and a slight (but not significant) shift away from ownership toward rental and share tenancy in the lowlands. The average farm size in the sample declined from 4.6 ha in 1995 to 2.5 ha in 1999, and the share of owner-occupied farms declined from 95% of the sample to 84%. Two, we see a modest but perceptible increase in investments in durable capital on lowland farms. This includes investments in tools (especially backpack sprayers for chemical application) and investments in machinery (primarily motorized hand tractors). While no lowland households reported use of tractors in 1995, 29% reported use of hand tractors in 1999. Three, we find a shift toward increased use of pesticides, including molluskacides, insecticides, and—to a lesser extent—herbicides. Pesticide use rose five-fold in value terms between 1995 and 1999. Moreover, the contemporaneous correlations between days of hired labor and use of pesticides and machinery are both negative: further shifts may reduce labor hiring over time.

4. Upland farms

4.1 A dynamic model of upland labor allocation and asset accumulation

We now turn to the upland household. We seek to identify upland farmers' responses to economic and technological stimuli, conditional on relevant agronomic and household characteristics. We focus on labor allocation decisions and patterns of asset accumulation as they relate to forest use over time. We adopt an intertemporal perspective and assume farmers choose resource allocation 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 an upland farm is endowed with a quantity of land *M*, a quantity of labor $\overline{L}$, and soil quality *s*. The household chooses a level of labor L^A to allocate to agricultural production and combines this with a vector of purchased inputs **x** (e.g. fertilizer, seeds, chemicals) to produce a single consumable crop using a strictly concave production function. The household may also allocate labor to other activities. These activities include extraction of minor forest products L^F, land clearing L^M, and off farm employment L^O. We assume the farmer seeks to maximize the net present value of a stream of utility. Defining *c* as consumption, ℓ as leisure, and Z as a vector of household-specific attributes the farmer's objective function is:

$$Max\int_{t=0}^{t=T} e^{-rt}U(c,\ell;Z)dt\,. \qquad \text{[U.1]}$$

The farmer seeks to maximize [U.1] subject to conditions outlined below. In equation [U.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. Assuming no joint production, production functions for the crop and the bundle of minor forest products are:

$$G = g\left(A, L^A, M, s, x\right) \qquad \text{[U.2]}$$

and

$$F = f\left(A, L^F\right), \qquad [U.3]$$

where A is a stock of productive assets.

Coxhead, Shively, and Shuai (2002) note that upland farmers typically respond to external shocks and perceived changes in land quality in one of three ways. At the extensive margin, farmers increase total cultivated area by bringing new plots into production, or decrease it 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. Here we ignore portfolio allocations but posit a flexible land constraint:

$$M_t = M_{t-1} + \Delta M \ , \qquad [U.4]$$

where M_{t-1} is total area cultivated in the previous crop season, and ΔM is the change in area between seasons. We assume that a fixed cost in terms of labor is incurred when bringing new land under cultivation. Building on Pagiola and Holden (2001), we assume the efficiency of labor used in land clearing depends on a stock of physical capital (e.g. hand tools, chainsaws, draught animals), so that the unit cost of clearing new land is $\alpha(A, L^M)\Delta M$. We write the constraint for family labor as:

$$\overline{L} = L^A + L^F + L^M + L^O + \ell \ , \qquad [U.5]$$

where ℓ represents the consumption of leisure.

Defining a vector $\mathbf{p_x}$ of the prices of variable inputs used in production, and defining p^A and p^F as the prices of the agricultural good and the bundle of forest products, the current period profit function is:

$$\pi = p^A G + p^F F + w(\theta)L^O - \mathrm{p_x x} - \alpha \Delta M \ , \qquad [U.6]$$

where we make explicit use of the fact that the available wage depends on the technology of lowland production. Dynamics of the model are defined by two state variables: soil quality and a stock of physical assets. First, we posit an equation specifying the evolution in soil quality, which we define as:

$$\dot{s} = h(M, \Delta M, \mathbf{x}), \qquad \text{[U.7]}$$

where $\dot{s}$ represents the per-period change in an index of soil quality on the farm. Equation [U.7] expresses the fact that changes in soil quality reflect choices regarding intensity of cultivation, levels of input use, and changes in land area. We define the accumulation of assets by:

$$\dot{A} = \pi - c - \delta A, \qquad \text{[U.8]}$$

where $\dot{A}$ represents the per-period change in the stock of physical capital on the farm. Equation [U.8] says the farm can accumulate assets when current net income exceeds current consumption or smooth consumption in years of shortfall by liquidating assets. We assume the existing stock of capital depreciates at the constant rate δ. The stock of capital is here defined in a rather non-specific way so as to simplify the statement of the problem. In the empirical section below we investigate the extent to which investments flow toward assets that support either land-intensive or land-extensive paths of agricultural development.

To proceed, the present value Hamiltonian for the upland problem can be written:

$$H = e^{-rt}U(c, \ell; Z) + \lambda_s h(M, x, \Delta M) + \lambda_A[\pi - c - \delta A] \qquad \text{[U.9]}$$

subject to the definitions provided above and initial conditions for land quality and the stock of assets, which we write $s(0) = s_0$ and $A(0) = A_0$. In equation [U.9] λ_s is the shadow price of land quality and λ_A is the shadow price of the capital stock.

Maximizing the Hamiltonian with respect to c, $\mathbf{L}$, $\mathbf{x}$, and ΔM, and subject to the per-period and dynamic constraints leads to the following first-order conditions:

$$\frac{\partial H}{\partial c} = e^{-rt}\frac{\partial u(\cdot)}{\partial c} - \lambda_A = 0 \tag{U.10}$$

$$\frac{\partial H}{\partial L_j} = -e^{-rt}\frac{\partial u(\cdot)}{\partial \ell} + \lambda_A \frac{\partial \pi}{\partial L_j} = 0 \qquad \forall j \tag{U.11}$$

$$\frac{\partial H}{\partial x_k} = \lambda_s \frac{\partial h(\cdot)}{\partial x_k} + \lambda_A \frac{\partial \pi}{\partial x_k} = 0 \qquad \forall k \tag{U.12}$$

$$\frac{\partial H}{\partial \Delta M} = \lambda_s \frac{\partial h(\cdot)}{\partial \Delta M} + \lambda_A \frac{\partial \pi}{\partial \Delta M} = 0 \tag{U.13}$$

$$\dot{s} = \frac{\partial H}{\partial \lambda_s} = h\left(M, x, L^A, \Delta M\right) \tag{U.14}$$

$$\dot{A} = \frac{\partial H}{\partial \lambda_A} = \pi - c - \delta A \tag{U.15}$$

$$\dot{\lambda}_s = -\frac{\partial H}{\partial h(\cdot)} = -\lambda_s \tag{U.16}$$

$$\dot{\lambda}_A = -\frac{\partial H}{\partial A} = -\lambda_A + \left[\frac{\partial \pi(\cdot)}{\partial A} - \delta\right] \tag{U.17}$$

along with the initial conditions $s(0) = s_0$, $A(0) = A_0$ and the transversality conditions $\lim_{T\to\infty} \lambda_s(T)s(T) = 0$ and $\lim_{T\to\infty} \lambda_A(T)A(T) = 0$.

Equations [U.10]-[U.15] constitute an optimal control problem with two state variables, *s* and *A*—with equations [U.16] and [U.17] as their equations of motion—and two control variables, *c* and Δ*M*. The model contains four differential equations, and so the system cannot be easily analyzed with a phase diagram. For well-behaved utility and production functions the system of equations yields optimal path values for c(t), **L**(t), **x**(t), *s*(t), Δ*A*(t), and Δ*M*(t). Written in the form $U'(c) = \lambda_A e^{rt}$, equation [U.10] states that the marginal utility of consumption at all points along the optimal path should equal the amplified shadow value of an additional unit of capital. Similarly, equation [U.11] implies that, at all points in time, the shadow value of labor should be equated across all *j* activities.[5]

4.2 Empirical results for upland farms

We focus on three reduced form equations for the upland sample: off-farm labor supply (L^{O}); land clearing (ΔM); and purchase of fertilizer ($\mathbf{x}^{\mathrm{F}}$). Reduced form equations are:

$$L^O = L(\hat{w}; z) \qquad \text{[U.18]}$$

$$\Delta M = L(\hat{w}, A, M, q; z) \qquad \text{[U.19]}$$

$$X^F = X\left(A^I, M, q, \hat{p}^{\mathrm{F}}; z\right) \qquad \text{[U.20]}$$

where we represent shadow values of labor and fertilizer by $\hat{w}$ and $\hat{p}^F$.

Given that decisions regarding labor supply, land clearing, and fertilizer purchase are made jointly, we estimate equations [U.18] – [U.20] as a set of seemingly unrelated regression (SUR). Regression results are presented in Table 3. Model 1 is based on a set of pooled data. Model 2 is estimated using only data from 1999 for which 1995 or 1997 data were observed. In the case of Model 2 we follow the procedure outlined above and estimate equations [U.18] – [U.20] in a two-step process. We first estimate production functions for upland farms, retaining necessary data and computing shadow values for both labor and fertilizer. We then use these estimates in the reduced form equations for off farm labor supply and fertilizer use.[6] It is important to note that, in this case, high values of labor productivity imply *reduced* incentives for

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[5] Integration of equation [U.16] implies an exponential decline in the shadow value of soil quality along the path $\lambda_s(t) = s_0 e^{-t}$, where at each point in time the shadow value of maintaining soil quality must equal the shadow cost of maintaining soil quality through the addition of new land or application of quality-maintaining variable inputs.

off-farm work, as well as reduced incentives for land clearing. We also include in Model 2B a lagged measure of total household income (including the value of retained agricultural production) so as to capture the possible impacts of income on the supply of labor and the decision to clear forest, as well as the capacity to purchase fertilizer.

For all three regressions, the results of Model 2A indicate changes over time. Controlling for other factors, labor supply (L^O) was higher in both 1997 and 1999 than in 1995. Land clearing (ΔM) showed a sharp decline in 1997, followed by a further decline in 1999. Upland fertilizer use (x^F) also spiked in 1997 and remained above the 1995 level in 1999. Consistent with expectations, the number of workers in the upland household was positively correlated with both the supply of off-farm labor and the amount of forest cleared, the latter at statistically significant levels. This indicates that population pressure exerts strong influence over the process of land expansion. Existing farm size is negatively correlated with forest clearing, suggesting that the operators of smaller farms are more likely to increase planted area through land expansion. Surprisingly, farm size is positively correlated with the supply of off-farm labor. Younger farmers were more likely to both supply off-farm labor and clear forest. Education was found to be only weakly associated with labor supply and forest clearing. Ownership of a carabao, an unambiguous indicator of prior investments in agriculture, was strongly associated with expenditures on fertilizer. In short, Model 2A suggests a pattern of rising labor supply over time, accompanied by intensification of existing cultivated area. Intensification (both in terms of reduced area expansion and purchases of fertilizer) appears to be more likely on slightly larger farms, and where education, tenure security, and investment in complementary inputs are higher.

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[6] Note that unlike the lowland regressions, in which only data from 1997 were used in deriving estimates of shadow values, for the upland regressions we rely on shadow values of labor and fertilizer derived from regressions estimated with pooled 1995, 1997, and 1999 production data.

In Model 2B we extend the analysis further by restricting ourselves to a sub-sample of the upland farms for which previous-period information has been observed. The cost of this approach is that we must work with a rather small dataset ($n = 45$) and therefore restrict our analysis to a set of short regression models. We again adopt the SUR approach to obtaining efficient estimates, by controlling for cross-equation correlation in errors. Our choice of regressors is guided by the insights provided by Model 2A, as well as our theoretical model. Given the small sample size, statistical precision of our estimates is low.

We specify labor supply (L^O) as dependent upon available workers, the shadow value of labor used in prior-period upland production, and previous-period income. Estimated coefficients are statistically weak but consistent with our expectations: farms with a larger number of workers supply more off-farm labor; poorer households supply more off-farm labor; and on farms for which labor is more productive locally, less labor is supplied off-farm. In the case of our measure of forest area cleared (ΔM), we find a positive and statistically significant relationship between the number of workers and the extent of forest clearing. Moreover, results suggest high observed levels of labor productivity translate into less forest clearing pressure: in elasticity terms, a 1% increase in the marginal value product of labor in upland production is exactly matched by a 1% reduction in forest area cleared. Results from the fertilizer demand regression (x^F) suggest that, not unexpectedly, the quantity of fertilizer used rises with farm size. Correlation between fertilizer use and the previously observed on-site value of fertilizer is positive. Similarly, households with higher incomes, tend to purchase and use fertilizer at higher rates in subsequent periods. Taken together, the results from Models 2A and 2B suggest that the rise in off-farm opportunities provided by lowland irrigation were more likely to accrue to larger and poorer households. These income gains were likely to precipitate fertilizer purchases. Increases in labor productivity likely undermined incentives to clear forest in subsequent periods.

5. Conclusions

In this paper we measure the impacts of agricultural intensification on environmental outcomes in the Philippines. Our analysis is based on panel data collected between 1995 and 2000 from lowland and upland households in southern Palawan. We estimate a series of two-stage, dynamic econometric models to trace lowland technological change to changes in employment, incomes, and activities at the forest margin.

Data from the lowland panel suggest irrigation led to rising employment and wages in the lowlands. Annual labor use rose approximately 50% following irrigation; this was primarily due to increases in cropping intensity. Regression patterns suggest an ongoing dynamic process of labor substitution on lowland farms, whereby upland workers replace family labor. Results also demonstrate that the shadow value of labor used on a lowland farm is positively and significantly correlated with days of upland labor hired. We find no strong statistical support for a conjecture that the use of hand tractors reduces either the probability or extent of labor hiring.

Upland farms exhibit a pattern of rising labor supply over time, accompanied by intensification of existing upland agricultural area. Upland intensification (both in terms of reduced area expansion and purchases of fertilizer) appears to be more likely on larger farms, and on those farms where education and tenure security are higher. Results demonstrate that higher observed levels of labor productivity on upland farms translate into less forest clearing. This suggests that intensification both inside and outside forested zones can provide pathways for reducing forest pressure.

Table 1—Characteristics of lowland and upland farms in the sample

	Lowland farms[a]			Upland farms[b]		
	1995	1997	1999	1995	1997	1999
Farm size (hectares)	4.6	3.7	2.5	2.7	2.1	2.0
Household size (members)	6.0	5.3	4.9	4.8	4.8	4.7
Income per capita[b] (pesos/person, 1996)	10,496	18,301	11,999	3098	3934	3225
Tenure security (% w/title)	95%	68%	84%	73%	44%	58%
Carabao (number or %)	1.6	1.4	1.3	0.3	0.4	0.5
Cropping intensity (crops/yr)	1.04	1.61	1.85	—	—	—
Fertilizer use (kgs/ha)	237	160	170	30	54	19
Pesticide use (litres/ha)	0.91	4.2	4.4	0.07	0.10	0.12
Total labor use (days/ha)	17.6	41.2	40.7	—	—	—
Hired labor (days/ha)	5.6	28.2	31.9	—	—	—
Upland labor (days/ha)	3.0	6.3	8.2	—	—	—
Tractor use (%)	3%	28%	28%	—	—	—
Forest clearing (% of households)	—	—	—	57%	16%	23%
Area of forest cleared (ha/yr, average)	—	—	—	0.38	0.16	0.19
Number of farms	37	111	103	121	104	99

Notes:

[a] Contains observations for rice production only.

[b] For upland households, data in this table are pooled across years and do not distinguish between pre-irrigation and post-irrigation periods.

Table 2—Results from lowland labor demand regressions

	Model 1	Model 2
Probit regression: dependent variable is upland labor hired (0=no, 1=yes)		
Constant	-0.9279	-6.9137
	(0.4154)	(4.6277)
Indicator for 1997	-0.2341	—
(1 = 1997, 0 otherwise)	(0.2056)	
Indicator for 1999	-0.7417	—
(1 = 1999, 0 otherwise)	(0.3228)	
Farm size	0.1658	-0.0142
(hectares)	(0.0432)	(0.2684)
Household size	-0.0015	0.0749
(number of members)	(0.0411)	(0.1060)
Land ownership	0.0499	-0.0302
(percent of area cultivated)	(0.1941)	(1.2654)
Irrigation	1.0828	0.3208
(percent of area cultivated)	(0.2602)	(4.2708)
Use of tractor	-0.9627	-0.5463
(1 = yes, 0 = no)	(1.0186)	(1.9680)
Total labor used in 1997	—	0.0043
(man-days)		(0.0025)
Shadow value of labor in 1997	—	0.3494
(pesos/man-day)		(0.1051)
Tobit regression: dependent variable is total upland labor hired (man-days/year)		
Constant	19.7846	-145.4859
	(11.7451)	(52.6546)
Planted area	4.8856	-0.0710
(hectares)	(1.0037)	(4.2589)
Household size	-9.6493	3.5083
(number of members)	(1.8941)	(3.1132)
Use of tractor	24.9812	0.1880
(1 = yes, 0 = no)	(18.0211)	(22.0683)
Total hired labor used in 1997	—	0.1709
(man-days)		(0.0470)
Shadow value of labor in 1997	—	6.6121
(pesos/man-day)		(3.1404)
n	251	88
Log-likelihood	-775.22	

Notes: All models were estimated at the farm level using pooled unbalanced panel data, controlling for farm-level random effects; probit and Tobit regressions were jointly estimated using maximum likelihood. Space limitations preclude us from reporting regression results for the production functions used to derive $\hat{w}_{97}$ and those used to derive our instrumented values for tractor use. These are available upon request.

Table 3—Results from upland labor supply and asset accumulation regressions

	Model 1			Model 2		
	L^{O}	ΔM	x^{F}	L^{O}	ΔM	x^{F}
Constant	9.6143 (11.0347)	0.4249 (0.1505)	-19.3700 (14.8086)	22.8458 (16.3718)	-0.1852 (0.3037)	-32.2645 (30.5350)
D97 (0/1)	23.5851 (5.0892)	-0.1813 (0.0693)	33.5336 (14.2196)	—	—	—
D99 (0/1)	8.6021 (5.1024)	-0.1985 (0.0695)	7.3256 (14.2762)	—	—	—
Workers (number)	2.0365 (2.0973)	0.1482 (0.0286)		4.1438 (5.8548)	0.3292 (0.1085)	—
Farm size (hectares)	3.5820 (1.0934)	-0.0168 (0.0149)	4.0357 (2.9801)	—	—	23.4185 (10.4654)
Age of household head (years)	-0.2364 (0.1759)	-0.0046 (0.0024)	—	—	—	—
Education of household head (years)	-0.0295 (0.9992)	-0.0158 (0.0136)	3.1523 (2.9916)	—	—	—
Ethnicity (1=Pala'wan)	2.5027 (8.1402)	-0.1310 (0.1110)		—	—	—
Carabao (0/1)	—	—	63.7036 (13.3234)	—	—	—
Tenure security (1=CSC)	—	—	13.0527 (12.1693)	—	—	—
Farm income (lagged, pesos)	—	—	—	-0.6937 (0.4096)	0.1266 (0.7607)	0.2134 (0.7514)
$\hat{w}$ (lagged)	—	—	—	-0.2919 (0.2368)	-0.7270 (0.4392)	—
$\hat{p}^{F}$ (lagged)	—	—	—	—	—	0.7279 (0.1360)
n	324	324	324	41	41	41

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