Measuring the Environmental Impacts of Technical Progress in Low-income Agriculture: Empirical Evidence on Irrigation Development and Forest Pressure in Palawan, the Philippines

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ABSTRACT. Data from the Philippines are used to measure impacts of technical progress in lowland agriculture on upland forests. Irrigation development, labor demand, and employment are studied. Total annual labor use increased following irrigation. Employment of household members living along forest margins increased also. Time allocation data from the uplands show that increases in employment among households living along the forest margin were accompanied by reductions in forest clearing and forest-degrading activities. Empirical findings show irrigation-induced increases in agricultural employment can reduce pressure on tropical forests. Implications for policies and trends in use of labor saving methods that could undermine the observed changes are discussed.

Keywords: Philippines, irrigation, rice production, labor markets, environment

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1. Introduction

Inadequate labor absorption is an important economic and environmental policy problem in many developing countries. An important outcome of rapid population growth in many frontier areas has been the expansion of agriculture into marginal and environmentally sensitive areas (Cruz, et al., 1992). Rates of deforestation and resource degradation in many upland areas are particularly high, and are driven, in part, by the efforts of low-income farmers to secure subsistence. Finding ways to increase agricultural capacity and rural incomes without jeopardizing remaining forest resources is an important policy goal in many countries. Intensification of agriculture in lowland areas—for example, through irrigation development—is one obvious pathway through which pressure on forest resources possibly might be reduced. From a theoretical perspective, however, the overall impact of agricultural intensification on rural employment is ambiguous. For example, in some settings, irrigation could increase labor demand by facilitating multiple cropping and thereby increasing the annual effective area under cultivation. But irrigation could also reduce overall labor demand if it precipitated a shift toward labor saving production practices. For example, a number of researchers have observed that while irrigation may not have a "built-in" bias against labor, farmers who have access to irrigation also tend to adopt labor-saving methods such as mechanization or chemical-based weed control (e.g. Lingard, 1994; Boyce, 1993; Coxhead and Jayasuriya, 1986; Castillo, Gascon and Jayasuriya, 1983; Kikuchi and Hayami, 1983).

This paper provides an empirical test of the hypothesis that technical progress in lowland agriculture – in the form of irrigation development – reduces upland deforestation rates. To do this, observed patterns of employment on irrigated and non-irrigated farms are connected to changes in activities undertaken by upland households as a result of irrigation. Production decisions and agricultural outcomes are compared for two lowland rice-farming communities in the Philippines—one newly irrigated and the other rainfed. The hiring patterns observed at these sites underscore the importance of the rural labor market as a mechanism influencing environmental outcomes in remote and environmentally sensitive areas. Results suggest that irrigation has increased overall labor demand (vis-à-vis rainfed conditions). Although labor demand per hectare was found to be lower on irrigated farms than rainfed farms, higher cropping intensity on irrigated farms was sufficient to compensate. Agricultural employment in the irrigated area was higher, the number of upland workers hired to work on lowland farms increased as a result of irrigation and – as a result – upland households that experienced an increase in employment reduced rates of forest clearing by small but statistically significant amounts.

2. A simple model of upland activity and lowland labor demand

Consider the labor allocation decision of a representative upland household. For simplicity, it is assumed that (i) labor is the only resource allocated by upland household, (ii) the pool of labor available in the household is homogenous, and (iii) labor is allocated to maximize economic returns.

The upland household can engage in three income-generating activities: upland agricultural production (identified by subscript *A*); forest use (identified by subscript *F*); and work on a lowland farm (identified by subscript *L*). Returns to upland activities are determined by the price of output associated with the activity, the level of labor effort devoted to the activity, and the technology of production. The upland production functions are $A(L_A, \theta_A)$ for upland agriculture and $F(L_F, \theta_F)$ for forest activity, where θ_A and θ_F represent technologies available for production in each sector . Both functions are assumed to exhibit decreasing returns to use of labor. When working on a lowland farm, an upland worker receives a wage *w*, which is determined by returns to the factor. This lowland wage is set in a competitive market and depends on the technology of lowland production, which is represented by θ_L.

Defined in this way, the upland household's income-generation problem is to maximize:

$$\pi = P_A Y(L_A, \theta_A) + P_F F(L_F, \theta_F) + w(\theta_L) L_L \tag{1}$$

subject to:

$$\bar{L} = L_A + L_F + L_L . \tag{2}$$

The problem described by equations (1) and (2) assumes production and consumption decisions are separable. This assumption, of course, may be unrealistic for many poor households. Nevertheless, the presentation subsumes a wide range of possibilities and is general enough to serve a range of interests. Here, the focus is on the relationship between technical progress in lowland agriculture (i.e. irrigation) and the amount of labor devoted to the forest-degrading activity; that is, the sign and magnitude of $\partial L_F / \partial \theta_L$.

If a household engages in all activities, then a household maximum occurs where the value of the marginal product of labor is equal for each activity:[1]

$$P_A \frac{\partial Y(L_A, \theta_A)}{\partial L_A} = P_F \frac{\partial F(L_F, \theta_F)}{\partial L_F} = w(\theta_L). \qquad (3)$$

Despite obvious limitations, the logic behind equation (3) provides a useful framework for investigation. For example, a household that reports no off-farm employment (i.e. $L_L = 0$) may be interpreted as revealing that the available wage (w) is less than the expected return to labor ($\partial A/\partial L_A$) allocated on the farm. Similarly, a household that clears forest to establish new agricultural areas ($L_F > 0$) may be responding to a low rate of return to farming an existing parcel of land. A striking feature of low-income agriculture in many remote areas is the large number of household activities undertaken in response to different rates of return and seasonal patterns of returns and resource constraints. Equation (3) is meant to capture the basic economic logic behind these patterns.

To proceed, consider an initial equilibrium characterized by existing technology in all sectors and a representative upland household that engages in each activity. Suppose technological innovation occurs in the lowland agricultural sector. We represent this by a shift in the lowland technology parameter from θ_L^0 to θ_L^1. Technical progress that raises labor demand will increase the wage rate. This results in a temporary disequilibrium in the upland household's optimal labor allocation pattern since $P_A \frac{\partial Y(L_A, \theta_A)}{\partial L_A} = P_F \frac{\partial F(L_F, \theta_F)}{\partial L_F} < w(\theta_L^1)$. An increase in the wage will lead the household to re-equate marginal returns to labor. If (as is assumed) the production functions $A(L_A, \theta_A)$ and $F(L_F, \theta_F)$ are concave, a new equilibrium can be obtained by reducing levels of L_A and L_F (so that $\partial Y/\partial L_A$ and $\partial F/\partial L_F$ rise). In theory, labor use in all alternative activities will fall in response to an increase in the lowland wage. Which allocation falls by more depends on the curvature of the respective production functions. In general, the

[1] Not all households engage in all activities, of course. If a household specializes (either by choice or due to resource constraints), an appropriate modification of equation (3) may be required to account for inequalities. The deviation of shadow prices from market prices will depend, in general, on transaction costs, risk aversion, and the covariance of risks across activities (for a discussion, see Sadoulet and de Janvry, 1995). A household's apparent failure to equate marginal returns may actually reflect attempts to equate shadow values. This will especially be the case if production and consumption decisions are made jointly.

extent to which upland forest-degrading activities decline in response to a technological shift in the lowlands depends on two factors: first, the extent to which the technological change precipitates an increase in the wage (i.e. $\partial w/\partial \theta_L$); and second, the degree to which a change in the opportunity cost of upland labor – as reflected in the wage rate – precipitates a reallocation of effort away from the forest margin, i.e. $\partial L_F/\partial w$. The impact of lowland technical progress on rates of upland deforestation will therefore depend on the effects of technical progress on factor intensities and factor payments, as well as the income elasticity of demand for products of the upland sector. Specifically, if one thinks of the uplands as a mini-Hecksher-Ohlin economy, the impact of technical progress in the lowland economy on upland activity will depend on both the direct impacts arising in the labor market and the indirect impacts arising in commodity markets. Growth in lowland production (as a result of irrigation) tends to pull labor out of upland production (a Rybczynski cost effect), but—to the extent it increases incomes in the rest of the economy—could increase demand for upland products (such as temperate-zone vegetables, fuelwood, or timber for building materials). As Jayasuriya (1999) argues, as long as the upland sector does not produce a highly income elastic product, the labor-pull effect is likely to dominate, and faster growth in the lowland economy will tend to reduce deforestation by pulling labor resources out of the uplands. The remainder of the paper approaches this conjecture empirically, using data from lowland and upland farms.

3. Data

Data used for the analysis were collected on lowland and upland farms in two communities of southern Palawan in 1996 and 1997.[2] The lowland sample includes data from 53 irrigated and 45 rainfed farms, representing approximately 35% of the underlying lowland population. The upland sample consists of data from 104 upland rice and corn farms adjacent to the lowland study area, representing approximately 30% of the underlying upland population. All upland households lived on or near the forest margin. Previous studies from the area reveal strong links between poverty and natural resource degradation in the uplands (Shively, 1997). The site and

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[2] The study area has a Type III climate, characterized by a distinct dry season between January and March. Rainfall typically exceeds 1600mm/yr but the area is typhoon free. Soils are slightly acidic clay loam with pH of 5 to 6. Slopes on most upland farms exceed 18%.

upland farming systems are described by Garcia et al. (1995). Data used in this study are described in detail in Martinez and Shively (1999).

Although the lowland communities are similar in terms of demographic features and incomes, average farm size differs significantly at the two locations: average farm size was 2.6 ha at the irrigated site and 5.1 ha at the rainfed site (the largest farm in the sample was 12 ha). Irrigation is the primary factor explaining differences in farm size and agricultural practices between the lowland study sites. Columns 1 and 2 of Table 1 illustrate some of the differences observed between irrigated and rainfed lowland farms. With the exception of hired labor, all means for irrigated farms reported in Table 1 were significantly different from means for rainfed farms (at a 90% confidence level). As one might expect, average yield per hectare on irrigated farms (3,639 kgs/ha) was higher than on rainfed farms (3,200 kgs/ha). Furthermore, due to uncertain water availability during the dry season, rainfed farms tended to produce only one crop per year while irrigated farms produced two crops per year, on average. Irrigated farms spent 80% more on pesticides per hectare than rainfed fields (P1656 vs. P917). However, they used less labor per hectare overall, and less family labor per hectare than rainfed farms (38 and 13 man-days per hectare compared with 43 and 20 man-days, respectively). The latter pattern suggests the adoption of irrigation was accompanied by a release of family labor and a reduction in overall labor use per hectare.

The final columns of Table 1 contain data from the sample of upland farms. As the table indicates, 83 households (80% of the sample) reported some earnings from off-farm work. Although off-farm employment was not limited to work on lowland irrigated farms, upland households in the irrigated area were far more likely to have one or more household member working off farm than households in the rainfed area. Households engaging in off-farm work had slightly smaller farms, on average, than those not engaging in off-farm work (2.0 ha vs. 2.5 ha). They also had lower incomes (13,566 P/yr vs. 18,255 P/yr). These patterns suggest off-farm employment helped to augment income for households with limited agricultural capacity. However, as Shively and Martinez (1999) point out, off-farm earnings were not sufficient to close the income gap between those with and without off-farm employment. As a result of low agricultural capacity, upland households with off-farm workers were more likely to report activities with relatively low rates of return. This included a greater likelihood of forest clearing, as well as higher probabilities of charcoal making, fuelwood collection, and minor forest product extraction. Upland households with off-farm employment reported that they cleared larger areas of forest than did those without off-farm work (0.18 ha/hh/yr vs. 0.10 ha/hh/yr). Based on deforestation rates reported by respondents and the estimated 30% sample frame, it appears that newly cleared area represented about 7% of all cropped area in the uplands.[3]

4. Results

Patterns of labor use on lowland farms

Overall patterns of labor use on irrigated and rainfed lowland farms display some parallels. For example, per-hectare labor use (especially of family and shared labor) is greatest on small farms, and decreases as farm size increases, regardless of farm type. This pattern is in part reflective of modest increases in use of tractors and chemicals (especially pesticides) as farm size increases. However, Martinez and Shively (1999) show that when employment is decomposed by source and farm size, patterns of labor use differ across irrigated and rainfed conditions. For example, for all farm sizes, levels of family and shared labor tend to be lower on irrigated farms than on rainfed farms. In contrast, use of hired upland labor tends to be higher on irrigated farms than on rainfed farms, regardless of farm size. This suggests that during the shift from rainfed to irrigated operation family labor is released from rice production, and *upland* workers are hired to substitute. A second pattern is illustrated by data in the first two rows of Table 2. Specifically, the amount of labor used on irrigated farms is lower than on rainfed farms (37 vs. 43 man-days per hectare, per cropping). That is, the transition from rainfed to irrigated production has been accompanied by a decrease in labor demand per hectare. However, after accounting for the change in cropping intensity that accompanied irrigation (from 1.2 on rainfed farms to 1.9 on irrigated farms), it can be seen that total annual labor demand in the sample was approximately 36% higher under irrigated conditions than under rainfed conditions. These figures translate into total annual labor use of 70 days/ha on irrigated farms and 55 days/ha on rainfed farms.

Estimates of optimal labor use under irrigated conditions.

Table 2 also reports two estimates of potential labor demand on irrigated farms. These predictions are derived from a production function estimated using plot-level yield data, results

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[4] Not all area cleared constitutes destruction of primary forest. Data from the site suggests that about 30% of newly planted area in 1996 had been virgin forest in the preceding year, 46% had been degraded forest and shrubland, and 24% had been grassland.

of which are reported in Table 3. All parameter estimates in the regression have the expected signs and – with the exception of the parameter estimate for pesticide use – are statistically significant at the 95% confidence level. Labor, fertilizer and pesticide all contribute positively to yields. The wet season is associated with higher yields and the negative sign on farm size suggests smaller irrigated farms in the sample were either more efficient in their production or occupied more productive land. Owner-occupied farms reported significantly higher yields than rented farms. The regression exhibits strongly diminishing returns to input use.

Regression results reported in Table 3 were used to derive profit-maximizing input levels conditional on input and output prices, in order to determine input levels that would constitute profit-maximizing optima for a representative irrigated farm. Comparisons between observed and optimal levels of labor demand can be used to infer how labor demand might change in the long run as a result of irrigation. Results reported in the final rows of Table 2 are based on the predicted labor demands. Results suggest observed labor use exceeded optimal labor use on irrigated farms. In other words, irrigated farms appear to be operating below profit maximizing levels.[4]

In attempting to explain how labor use might change in the long run in response to irrigation, it is helpful to imagine a stylized two-stage progression. In stage one, rainfed farms become irrigated and employ sub-optimal input levels. In stage two, these farms move to profit maximizing factor proportions and levels. For this sample, the first stage resulted in a 13% reduction in labor demand per hectare and the second stage is predicted to produce an additional 11% reduction in labor demand. Nevertheless, effective annual demand rises unambiguously from the rainfed base. Full utilization of irrigation in the dry season would also tend to offset these per hectare declines (see the final row of Table 2). Implications of these patterns are discussed below.

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[4] Simulations reported in Martinez and Shively (1999) show that sub-optimizing behavior in the dry season could lead to an overall reduction in labor use of up to two percent compared with rainfed levels. Thus while the short-run impact of irrigation on forests may be beneficial, the long-run impact will depend on whether irrigated farms seek and achieve profit-maximizing factor intensities and, if so, whether irrigation in the delivery area is fully utilized during the dry season.

5. Implications for patterns of activity on upland farms

Data in Table 4 highlight reported activities and outcomes on upland farms before and after irrigation. Changes in rates of forest clearing, average area cleared, and wages all differ in the pre- and post-irrigation samples by statistically significant amounts.

Regarding deforestation, data point toward a small but significant reduction in the proportion of households reporting forest clearing before and after irrigation. The proportion of households reporting they cleared forest fell from 18% before irrigation to 12% after irrigation. Also significant is the change in reported area cleared. In the pre-irrigation sample the average area reported cleared (by those reporting land clearing) was 2.5 ha. In the post-irrigation sample the corresponding figure was 1.9 ha. Taken together, these statistics suggest a 48% decline in annual forest area cleared in the pre-irrigation and post-irrigation periods.

Modest changes in agricultural practices were also observed. Although the reported area planted to rice (the staple upland crop) did not change, the average area planted to corn (a cash crop), fell slightly – from 1.2 ha to 1.1 ha. This pattern suggests wages from off-farm employment more likely serve as a substitute for cash income from corn production, than as a substitute for the staple.[5]

Overall welfare changes for upland households cannot be completely assessed with these data. However, data on days of employment and average off-farm wage payments do support a hypothesis that lowland irrigation development resulted in welfare gains for some upland households. Average days of employment rose considerably, and the average reported daily wage was two-thirds higher after irrigation. These patterns corroborate anecdotal evidence that a small "boom" took place in the local labor market following irrigation: data suggest wage income rose nearly 3-fold following irrigation in upland households that had off-farm work.

6. Conclusions

Activities that degrade forests in low-income areas result from lack of economic opportunity and low economic returns from existing agricultural options. This study examined whether observed technical progress in lowland agriculture led to an increase in agricultural productivity and

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[5] Data reported by Shively (1998) show an inverse relationship between agricultural capacity and rates of perennial crop adoption in the area. These results suggest poverty alleviation might not only reduce the rate of deforestation in an upland community, but can also encourage a transition to more sustainable perennial-based cropping patterns on upland farms.

wages, and whether these, in turn, increased employment opportunities for low-income households near the forest margin. The analysis shows that, in the short run, technical progress in lowland agriculture – in the form of irrigation – led to an increase in employment opportunities for upland residents. This change was simultaneous with a reallocation of time away from forest clearing and hillside farming in the uplands. This finding is important because it confirms that lowland agricultural intensification is a potentially useful vehicle for improving environmental outcomes in marginal upland areas.

Despite the upbeat conclusion, these findings must be qualified in three ways. First, the upland area studied was physically adjacent to the lowland area. If larger distances separated lowland and upland areas, the opportunity cost of travel for upland households could discourage reallocation of labor from upland to lowland activities. Second, while the irrigated farms in the sample exhibit fairly intensive use of fertilizers and pesticides, additional reductions in labor use could occur over time as a result of increased use of mechanization or adoption of direct seeding of rice. Third, because factor substitution is driven in part by factor costs, government policies that reduce costs for pesticides or machinery without taking account of the favorable environmental impacts of more labor-intensive production could also undermine employment gains reported here.

Table 1 Characteristics farms in the sample

	Lowland		Upland	
	Irrigated	Rainfed	With off-farm work	Without off-farm work
Farm size (hectares)	2.5	4.2	2.0	2.5
Household size (members)	5.8	4.8	4.9	4.8
Total income (pesos, 1996)	104,128	108,867	13,566	18,255
Income per capita (pesos/person)	22,604	25,364	3,224	4,586
Tenure security (% w/title)	48%	78%	42%	43%
Rice yield (kgs/ha)	3,639	3,200	1,733	1,833
Effective cropping (crops/yr)	1.9	1.2	1.0	1.0
Fertilizer use (kgs/ha or %)	157	180	29%	33%
Pesticide use (pesos/ha or %)	1,656	917	14%	10%
Total labor use (days/ha)	38	43	--	--
Family & shared labor (days/ha)	13	20	--	--
Hired labor (days/ha)	25	23	--	--
Number of farms	53	45	83	21

Source: survey data. Note: at the time of the survey $1 US = 25 pesos.

Table 2 Labor use, cropping intensity, and changes in effective labor demand

	Labor (days/ha)	Effective area (ha/yr)	Effective demand (days/ha/yr)	% change from rainfed
Rainfed	42.7	1.29	55.1	--
Irrigated (observed)	37.1	1.89	70.1	+27.2
Irrigated (predicted)	33.0	1.89	62.4	+13.2
Irrigated (full utilization)	33.0	2.00	66.0	+19.8

Table 3 Production Function Results

	Coefficient	Standard error
Constant	6.9375	0.3585
Log of labor (man-day per hectare)	0.1273	0.0571
Log of Fertilizer (kgs per hectare)	0.0696	0.0394
Log of Pesticide (Pesos per hectare)	0.0397	0.0228
Season {0 = dry,1 = wet}	0.2614	0.0494
Farm size (hectares)	-0.0168	0.0089
Tenure {0 = rented,1=owned}	0.1121	0.0458
R^2	0.35	
Number of observations	105	

Note: Regressions corrected for heteroskedasticity related to input levels and farm size.

Table 4 Forest conversion indicators before and after irrigation

	Before irrigation	After irrigation
% of households reporting forest clearing	18%	12%*
Average forest area cleared (ha/yr)	2.5	1.9*
Area in rice (ha)	0.95	0.94
Area in corn (ha)	1.20	1.05
Lowland employment (days/hh/year)	18	44*
Average lowland wage (Pesos/man-day)	45	75*
Wage income (Pesos/hh/yr)	1,150	3,226

Note: * indicates means are significantly different at a 95% confidence level.

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