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Agricultural Efficiency and Labor Supply to Common Property Resource Collection: Lessons from Rural Mexico

Dale T. Manning and J. Edward Taylor

Most common property resource (CPR) collection in developing countries occurs in imperfect market environments, in which endogenous prices link the economic returns in non-resource activities (i.e., agriculture) with effort supplied to CPR collection. A model of an imperfectly integrated rural household demonstrates the theoretically ambiguous connection between agricultural productivity and resource collection. Using unique panel data from rural Mexico, we find evidence that households with higher agricultural efficiency supply less labor to CPR collection. Interventions that raise agricultural productivity thus may complement resource conservation efforts.

Key words: common property resources, economic linkages, household producer, stochastic frontier

Introduction

Many traditional models of natural-resource use assume that resource collection effort is determined by output prices and an exogenous opportunity cost (e.g., Gordon, 1954; Scott, 1957; Smith, 1968). More recent resource models (Homans and Wilen, 1997; Robinson, Albers, and Williams, 2008; Wilen, 2013) and experiments related to regulation of the commons (Walker, Gardner, and Ostrom, 1990; Velez, Stranlund, and Murphy, 2009; Fehr and Leibbrandt, 2011) also assume exogenous reward functions. Yet in developing countries, resource collection often takes place in a context of imperfect market integration. For example, almost two-thirds of households in rural Mexico collect natural resources, but only 3% of those households sell the output (table 1). Collection effort is almost entirely undertaken by family labor; only 4% of households hire labor for resource collection.

Different incentives guide households' labor allocation decisions in the context of imperfect market integration than with well-functioning markets. This has important implications for natural-resource conservation policies. If reward functions are endogenous, then policies that focus on other sectors (e.g., agricultural production) could complement resource-conservation efforts by raising the opportunity cost of extraction.

In this paper, we test whether households in rural Mexico respond to nonmarket time valuation signals. We find evidence that the market wage does not adequately reflect the opportunity cost

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Table 1. Market Participation in Rural Mexico, 2007 (N = 1,480)

	Count	Proportion
Households that Collect Resources	906	0.61
of which:		
Hire Labor	32	0.04
Sell Output	26	0.03
Households that Farm	629	0.43
of which:		
Hire Labor	242	0.38
Sell Output[a]	131	0.27
Households that Earn a Wage	445	0.30

Notes: [a]Out of 483 agricultural households that indicated market participation status.
Source: ENHRUM.

of resource collection for rural Mexican households. This means that resource policies assuming well-developed labor markets may not be appropriate in this setting.

To bring nonmarket resource activity into our analysis, we develop a model of an imperfectly integrated household and use it to explore the relationship between agricultural productivity and labor supplied to common property natural-resource collection. This cross-sector relationship has important implications for how economic development affects natural-resource stocks. If higher agricultural productivity leads to increased (decreased) resource use, it could intensify (reduce) pressure on natural-resource stocks. An analytical model demonstrates that the impact of increased agricultural productivity on natural-resource collection is ambiguous and depends on the net impact of changes in household valuations of time and natural resources. We empirically test this cross-sector relationship and find that more efficient agricultural producers supply less labor to natural-resource collection.[1] This finding is robust to sample selection and implies that economic development policies could reinforce traditional resource management approaches because they incentivize households to spend fewer days collecting natural resources.

Our analysis makes three contributions. First, it provides a theoretical model that demonstrates the complex mechanisms through which market signals influence nonmarket resource collection through household-specific shadow prices. We demonstrate that rural households' opportunity cost of time in resource collection is largely derived from the economic returns to market activities rather than the market wage. Thus, market signals can influence nonmarket resource collection. Given that the cost of resource collection depends on other sectors, households respond to incentives in ways that are consistent with economic theory. Conventional natural-resource economics often assumes a fixed opportunity cost of effort across households, but that assumption may produce counterintuitive behavior in an imperfect-market setting.

Second, the agriculture-resource linkage demonstrated here reveals a new way to potentially influence CPR exploitation in developing countries by nudging the opportunity cost of collection.

Third, the empirical method develops a two-step procedure using technical efficiency from stochastic frontier analysis to explain behavior across economic sectors. This procedure could be applied to other settings in which efficiency in one activity influences the allocation of labor to another.

Literature

In practice, common-property resources (CPRs) often are overused, leading to a "tragedy of the commons" (Hardin, 1968). Reducing collection effort in a commons can be challenging in

[1] Agricultural efficiency refers to the value of total factor productivity, including labor, land, and other inputs.

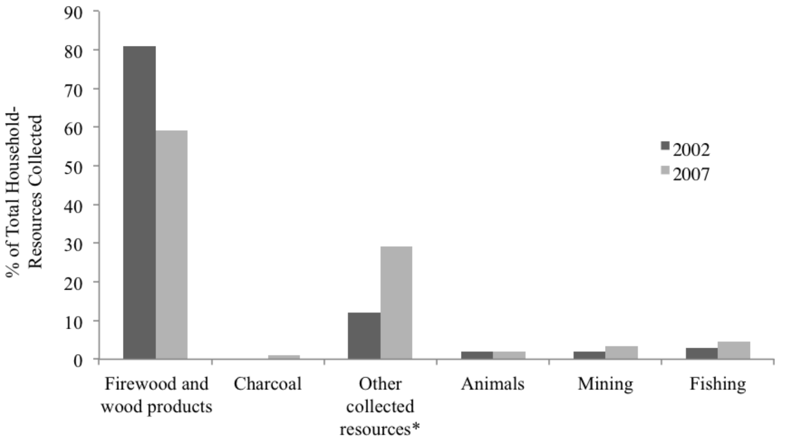

Figure 1. Important Natural Resources in Rural Mexico

Notes: N= 1,141 in 2002; N = 1,678 in 2007.
*Other collected resources include, for example, fruits, plants, and mushrooms.

developing countries where resource users depend on resources for survival. The existence of agriculture-resource linkages opens up the possibility that improvements in agricultural value and productivity can influence the amount of effort invested in collecting resources. This, in theory, could either aid or hinder resource management efforts.

Natural-Resource Institutions in Rural Mexico

Land in rural Mexico is predominantly *ejido*, or communal land that was established as part of land reforms carried out in the early part of the twentieth century. *Ejido* land is typically divided among housing lots, individual agricultural parcels, and common-use areas that consist of mostly shared pasture, agricultural land, and forest (Barnes, 2009). Common-use areas cover the most ground of the three land-use types (around 66% of total certified land), but according to Pérez Martín del Campo (2004), only 10% of this land is used for forest products. Agrarian communities, slightly different from *ejidos*, also manage shared property in rural Mexico (see Merrill and Miró, 1997; Assies, 2008) for an in-depth discussion of the evolution of land tenure in rural Mexico). Of around 105 million certified hectares in rural Mexico, 3.2 million hectares belong to agrarian communities that are not *ejidos*.[2]

A large body of research examines variations in the abilities of communities to successfully manage common-property resources (e.g., Ostrom, 1990; McKean, 1992; Feeny, Hanna, and McEvoy, 1996; Ostrom, 2008, 2009). In rural Mexico, most communities do not sell or regulate nontimber common-property resources used by community members,[3] so it is likely that an individual community member allocates too much effort to resource collection from common property. Although community members' collection is not usually regulated, outsiders are not allowed to remove resources from communal land. Therefore, the resources are not pure open access, but rather common-property resources. As seen in figure 1, firewood is the most common natural resource collected in rural Mexico, followed by other wild products such as fruits and mushrooms.

[2] Land certification took place as part of the federal PROCEDE program that began in 1992. Large parts of Mexico (e.g., Oaxaca) did not fully participate (Barnes, 2009).

[3] SEMARNAT, the Ministry of Environment and Natural Resources, requires sustainable forest management plans from communities that participate in timber extraction (there is variation in compliance with this law—see Klooster (2000) for a case study).

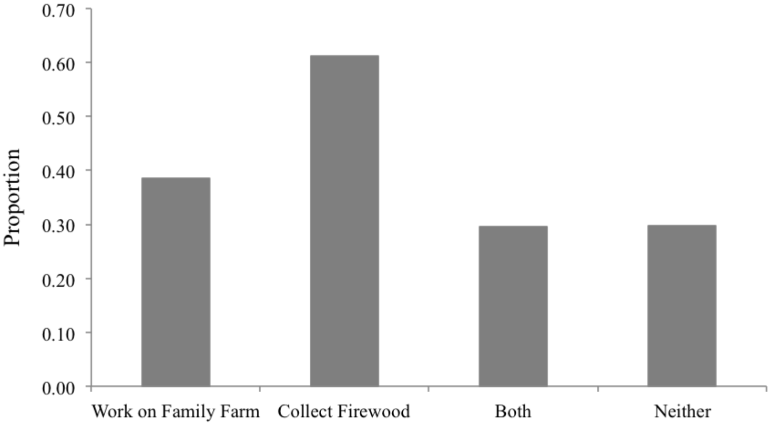

Figure 2. Proportion of Households in Rural Mexico Working on Family Farm and Collecting Resources, 2007

Notes: N=1,480.
Source: ENHRUM.

Economic Linkages in Developing Country Households

Understanding the linkages between agricultural efficiency and natural-resource exploitation requires accounting for the within-household allocation of scarce inputs (e.g., labor) across multiple activities. Altering returns to agricultural production can influence natural-resource collection (as in Bluffstone, 1995; Liese, Smith, and Kramer, 2007).

Economists have long understood the importance of viewing farmers in developing countries as both producers and consumers (Singh, Squire, and Strauss, 1986). In rural Mexico, as in other developing economies, households make labor-allocation decisions across multiple activities, including farming and natural-resource collection (see figure 2). In practice, many factors can lead to imperfect market integration and household-specific shadow prices. A common example includes the imperfect substitutability of family and hired agricultural labor (Sadoulet, de Janvry, and Benjamin, 1998). This implies a shadow value for family time distinct from a market wage. Household-specific shadow prices have been shown to influence household labor supply (Jacoby, 1993; Skoufias, 1994) and can result in unexpected changes in input allocations because households do not use market signals for their decisions (Dyer, Boucher, and Taylor, 2006). In the extreme case, a household can be cut off from the labor market (de Janvry, Fafchamps, and Sadoulet, 1991; Taylor and Adelman, 2003).

Several studies have investigated resource use in the context of multiple activities but without simultaneously modeling household labor allocation and consumption decisions. For example, Pattanayak and Sills (2001) show that Brazilian households use nontimber forest products as insurance when private activities experience shocks. Others (Delacote, 2007, 2009; Baland and Francois, 2005) discuss how common resources operate as both insurance and portfolio diversification to cope with risk in private activities.

López-Feldman and Taylor (2009) show that the average returns to labor in agriculture influence the collection of a local nontimber forest product (*Xate*) in southern Mexico. Amacher, Hyde, and Kanel (1996) show a connection between labor market opportunities and firewood collection in Nepal. These studies highlight the existence of strong linkages between natural-resource use and returns in other economic activities and imply that imperfect market access is a real possibility in the resource settings of developing countries.

Analytical Model

A stylized household-producer model (Singh, Squire, and Strauss, 1986) can be used to illustrate the potential for agriculture-resource linkages. In the natural-resource literature it is common to assume an exogenous valuation for labor and the natural resource (e.g., Gordon, 1954; Smith, 1968; Campbell and Lindner, 1990; Robinson, Albers, and Williams, 2008). Yet, as seen in table 1, there is relatively little market participation in the resource sector of rural Mexico. Therefore, we model a household that allocates labor between farming and resource collection and is not perfectly integrated into resource or labor markets. About a third of rural Mexican households fall into this category (see figure 2).

In the context of common property, a household has little incentive to account for the resource stock when making labor allocation decisions. Therefore, the resource stock is treated as exogenous to a given household. This assumption is consistent with long-run Nash competition and the existence of a large number of resource collectors (López-Feldman and Taylor, 2009; Brooks et al., 1999; Bluffstone, 1995).[4] The common-property nature of resource collection means that households within a village face the same resource stock, but stocks may differ across villages.

The household-producer consumes a store-bought commodity, c, and a resource output, f_c. The household also allocates its time endowment, $\overline{L}$, among consuming leisure, l, doing on-farm work, L_A^F, and collecting resources, L_f^F. The store-bought commodity has a market price of p_c. Household land and capital (e.g., tools) are assumed fixed, and so labor is allocated conditional on available land.

Resource production is described by the function $f(L_f^F;\overline{X}_v)$, where $\overline{X}_v$ is the level of the resource stock in village v, exogenous to the household's decisions. Agricultural production value, with price p_A, is given by $p_A\theta g(L_A^F)$, where θ is a household-specific measure of agricultural efficiency (or output per unit of total input use). This parameter is assumed to vary across households with the quality of land or market access. Households with better land quality and access to rainfall produce more agricultural output from the same application of inputs. Also, better market access can increase agricultural efficiency in terms of value. We make the standard assumptions on the curvature of the production functions: $f'(L_f^F;\overline{X}_v) > 0$, $f''(L_f^F;\overline{X}_v) < 0$, $g'(L_A^F) > 0$, and $g''(L_A^F) < 0$.

The household maximizes utility of consumption, $u(c,f_c,l)$, with $\frac{\delta u}{\delta c} > 0$, $\frac{\delta u}{\delta f_c} > 0$, $\frac{\delta u}{\delta l} > 0$, and u concave. It is assumed that households participate in agricultural output markets because agricultural traders from other areas often travel to villages to buy and sell produce.

As is common in rural Mexico, the household does not buy or sell the natural resource on the market. This is an extension of the model in López-Feldman and Taylor (2009), in which labor markets are imperfect but the collected resource sells at an exogenous price. Cooke (1998), on the other hand, assumes that labor markets exist but environmental goods can only be produced in the home. Here, the extreme of no labor market participation is modeled; the lessons learned apply whenever markets are not perfectly integrated. This means that all labor and leisure must come from the household labor endowment: $l + L_A^F + L_f^F = \overline{L}$. Consumption of natural resources must equate to production, or $f_c = f(L_f^F;\overline{X}_v)$. If the household also has exogenous income, $\overline{y}$, the Lagrangian for the household optimization problem takes the following form:

$$
\begin{aligned}
\max_{c,f_c,l,L_f^F,L_A^F,\lambda,\mu,\,\rho} L \;=\; & u(c,f_c,l) - \lambda\left(p_c c - p_A\theta g(L_A^F) - \overline{y}\right) \\
& -\mu(l + L_A^F + L_f^F - \overline{L}) - \rho\left(f_c - f(L_f^F;\overline{X}_v)\right)
\end{aligned} \tag{1}
$$

[4] This result holds under reasonable assumptions, including that the sole-owner profit be bounded.

with household-specific multipliers λ, μ, and ρ on the budget, labor, and resource constraints. Assuming an interior solution, the first-order conditions imply:

(2a) $$p_A\theta g'(L_A^F) - \frac{\mu}{\lambda} = 0;$$

(2b) $$\tfrac{\rho}{\lambda} f'(L_f^F;\overline{X}_v) - \frac{\mu}{\lambda} = 0;$$

(2c) $$\frac{\delta u}{\delta c} - \lambda p_c = 0;$$

(2d) $$\frac{\delta u}{\delta f_c} - \rho = 0;$$

(2e) $$\frac{\delta u}{\delta l} - \mu = 0;$$

(2f) $$p_c c = p_A\theta g(L_A^F) + \overline{y};$$

(2g) $$l + L_A^F + L_f^F = \overline{L};$$

(2h) $$f_c = f(L_f^F;\overline{X}_v).$$

This set of eight equations implicitly defines the solution for the eight choice variables in the model as a function of exogenous parameters. Labor and the resource have shadow prices $\frac{\mu}{\lambda}(p_A,p_c,\overline{L},\overline{X}_v,\theta)$ and $\frac{\rho}{\lambda}(p_A,p_c,\overline{L},\overline{X}_v,\theta)$, respectively. Notice that both sides of equation (2b) are divided by the marginal utility of income, λ, which serves as a household-specific exchange rate between utility and money. The household behaves as if it faces a price of $\frac{\mu}{\lambda} \equiv \omega$ for labor and $\frac{\rho}{\lambda} \equiv \rho_f$ for the resource. Our variable of interest is

(3) $$L_f^F(p_A,p_c,\overline{L},\overline{X}_v,\overline{y},\theta).$$

The form of this function and the role of θ are estimated in the econometric section of this paper. Note the dependence of L_f^F on $\overline{L}$. This linkage is tested in the empirical analysis below; a nonzero coefficient on $\overline{L}$ provides evidence of imperfect market integration (Benjamin, 1992).

To determine the theoretical relationship between θ and L_f^F, equations (2c), (2d), (2e), (2g), and (2h) are used to eliminate λ, ρ, μ, L_A^F, and f_c. This produces a three-equation system:

(4a) $$\frac{p_A}{p_c}\frac{\delta u}{\delta c}\theta g'\left(\overline{L} - (l + L_f^F)\right) - \frac{\delta u}{\delta l} = 0;$$

(4b) $$\frac{\delta u}{\delta f_c} f'(L_f^F;\overline{X}_v) - \frac{\delta u}{\delta l} = 0;$$

(4c) $$p_c c - p_A\theta g\left(\overline{L} - (l + L_f^F)\right) - \overline{y} = 0.$$

This cannot be further simplified because the remaining endogenous variables appear implicitly in the utility function derivatives. Through total differentiation and Cramer's rule,

(4d) $$\frac{dL_f^F}{d\theta} = \frac{A(-FH) - B(DI - FG) + C(DH)}{|Hessian|},$$

where $A = \frac{p_A}{p_c}\frac{\delta^2 u}{\delta c^2}\theta g' - \frac{\delta^2 u}{\delta c \delta l}$, $B = -\frac{p_A}{p_c}\frac{\delta u}{\delta c} g'$, $C = \frac{p_A}{p_c}\left(\frac{\delta^2 u}{\delta c \delta l}\theta g' - \frac{\delta u}{\delta c}\theta g''\right) - \frac{\delta^2 u}{\delta l^2}$, $D = \frac{\delta^2 u}{\delta f_c \delta c} - \frac{\delta^2 u}{\delta c \delta l}$, $F = \frac{\delta^2 u}{\delta f_c \delta l} f' - \frac{\delta^2 u}{\delta l^2}$, $G = p_c$, $H = p_a g$, and $I = p_A\theta g'$.

It is challenging to analytically sign comparative statics in household producer models (Taylor and Adelman, 2003). In this case, the denominator is the determinant of a Hessian matrix of a

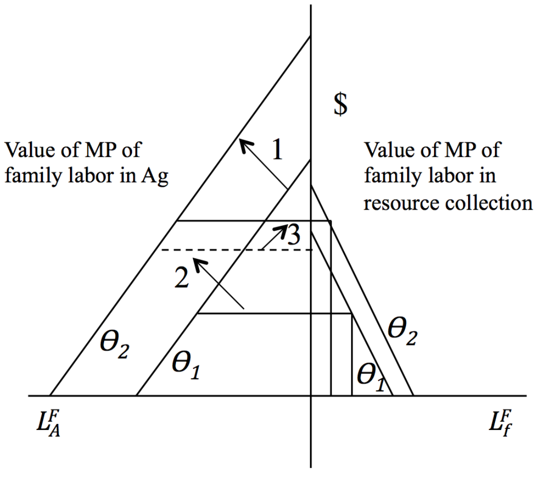

Figure 3. Agricultural Efficiency-Resource Linkage: No Labor Market

Notes: With higher returns to labor in agriculture, the cost of resource collection increases. At the same time, increased household wealth increases the demand for resources. The impact on labor allocation is ambiguous.

concave objective function. Although it is negative, the signs of A, C, D, and F are indeterminate and depend on how a household trades off consumption of different goods. Below we intuitively explore the channels through which θ influences the supply of natural-resource labor. An analysis of impacts of full-time allocation is available upon request.

Two effects work in opposite directions. First, a rise in θ leads to an increase in the opportunity cost of time, or ω. This occurs because labor becomes more valuable in agriculture and leisure demand increases (because leisure is assumed to be a normal good). As costs increase, labor supplied to resource collection decreases. The second effect results from the change in demand for the resource that occurs as household full income rises. Normality of the resource good implies that higher income likely leads to an increase in ρ_f. As θ increases, this (weakly) lowers the marginal value of income, or λ. Since λ is in the denominator of the resource shadow price, the change in λ puts upward pressure on ρ_f. Intuitively, higher income results in a greater willingness to pay for normal goods. Inferiority implies the opposite. Therefore, the net impact of θ on CPR labor supply depends on the relative magnitudes of these two effects.

Figure 3 demonstrates graphically how the two effects shape the household's labor allocation. First, the value of labor in agriculture increases and causes the marginal value product of labor to shift outward. The lack of a labor market implies that the household shifts labor from resource collection to farming. However, the endogenous resource valuation implies that the value marginal product of labor in resource collection also shifts outward. This lessens (and could reverse) the shift of labor from resource collection to agriculture. The net impact of these two effects determines how agricultural productivity influences the household's labor supply to CPR collection.

The model presented here demonstrates that, with market imperfections, shadow prices form linkages across production activities so that the labor supplied to resource collection depends on agricultural efficiency. The sign of this relationship is theoretically ambiguous and must be explored empirically. We use detailed survey data from rural Mexico to investigate the within-household linkages between agriculture and labor supplied to common property natural-resource collection.

Data

Rural Mexico provides an ideal setting to investigate the linkages between agricultural efficiency and natural-resource collection. We use panel data from the Mexico National Rural Household Survey (Spanish acronym ENHRUM), which was carried out jointly by the *Colegio de Mexico* and the

University of California, Davis. The survey is described at http://precesam.colmex.mx. The Mexican government defines as "rural" villages with fewer than 2,500 people. Dispersed populations and hamlets of fewer than fifty inhabitants were excluded for budgetary and logistical reasons. INEGI, Mexico's information and census office, designed the original ENHRUM sample to be representative of all rural Mexican households in villages that had between 50 and 2,500 inhabitants as of 2002. The sample includes eighty villages in fourteen states in Mexico's five census regions. Households were surveyed in 2003 and 2008, creating a matched panel with data on the year prior to each survey (2002 and 2007). A third round of the survey took place in 2011, but the results are not used in base models in this paper due to a lack of representativeness. Surveyors were not able to enter some states due to safety concerns stemming from high incidences of drug-related violence. However, our results are robust to the inclusion of the 2011 survey data.

Households were asked to report the number of days worked in agriculture per season (planting, harvest, and in between) for both hired and family workers. For resource collection, the individuals reported the number of days per week and months per year that collection took place. This information was aggregated across individuals and used to create annual data on household labor allocation.

The means and standard errors of the variables used in this analysis are presented in table 2. The final column indicates whether t-tests reveal significant differences in the variable over time. Several interesting patterns emerge. First, labor in agriculture and resource collection has remained stable across the sample period, as have the number of hectares planted and the value of agricultural output. Village wage, education level, capital payments, and household size increased across the survey years. Agricultural workdays average between six and eight hours, while the average number of hours in a person-day collecting natural resources is approximately three. If two people collect on a given day, this counts as two person-days. Interestingly, a higher proportion of households lived in communities with common property in 2007 than in 2002. For this analysis we focus on households in villages that collected common-property resources in both survey years. An increase in the proportion of households with a head that speaks an indigenous language suggests that nonindigenous households dropped out of the sample at a higher rate than indigenous ones.

Our analysis of the agricultural efficiency-resource link focuses on agricultural households in villages where natural resources are collected from common (*ejido*, communal, or agrarian community) property. Agricultural households are defined as having a positive value of agricultural output. Agricultural output is aggregated by value, using reported constant-peso market prices when possible. If households do not sell to the market, village median prices are used to value output. Common crops include corn and beans. In rural Mexico, it is not unusual for agricultural traders from outside the village to buy and sell produce. This means that a market for agricultural goods may exist where there is not a well-developed labor or resource market. The sample contains 688 agricultural households in villages with common property; our analysis focuses on agriculture-resource linkages for this subset of the population. Because of possible selection concerns, extrapolation of results should be interpreted with caution.

In rural Mexico, a household that collected natural resources in 2002 spent an average of 134 person-days doing so. Agricultural households spent more time on average collecting natural resources than nonagricultural households (147 person-days versus 116 person-days in 2002). In this analysis, the outcome of interest is the number of days a household spends collecting all natural resources.

Empirical Methods

We estimate household-specific agricultural production functions assuming Cobb-Douglas and Translog functional form and household-specific total factor efficiency (θ in the theoretical model) to test how household resource collection decisions depend on agricultural efficiency.

Table 2. Description of Variables, All Rural Households

	Mean			Significantly
	Overall	2002	2007	Different
Family Natural Resource Labor (Days per Year)	70.51	66.05	75.61	
	(170.89)	(193.47)	(140.57)	
Hired Resource Labor* (Days per Year)	0.50	0.54	0.45	***
	(8.41)	(8.13)	(8.74)	
Agricultural Labor (Days per Year)	45.93	47.47	44.16	
	(128.11)	(124.59)	(132.05)	
Land Planted in Agriculture (Hectares)	2.25	2.29	2.20	
	(5.59)	(5.70)	(5.46)	
Capital (Payments in 2002 Pesos)	539.67	477.29	611.02	*
	(2, 056.99)	(43.10)	(58.68	
Value of Agricultural Output (2002 Pesos)	8, 808.58	8, 796.07	8, 822.90	
	−38, 867.52	−38, 701.09	−39, 069.57	
Village Median Wage (2002 Pesos)	66.72	62.11	71.98	***
	(29.78)	(27.64)	(31.24)	
Average Education (Years)	5.22	5.00	5.47	***
	(3.03)	(2.97)	(3.08)	
Household Size (Count)	4.56	4.45	4.69	***
	(2.41)	(2.28)	(2.53)	
Proportion in Communties with Common Property	0.29	0.23	0.37	***
	(0.46)	(0.42)	(0.48)	
Proportion Indigenous	0.18	0.17	0.20	*
	(0.39)	(0.38)	(0.40)	
Transfer Income (2002 Pesos)	4, 187.77	3, 713.74	4, 730.01	***
	(8, 626.38)	(8, 898.02)	(8, 274.39)	
Observations (N)	3, 308.00	1, 765.00	1, 543.00	

Notes: An outlier of 28,800 person-days in 2007 is dropped for hired resource labor. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level for two-tailed test of differences over time. Standard errors are in parentheses.
Source: ENHRUM.

Estimating Agricultural Efficiency

The first step in our econometric strategy is to estimate an agricultural production frontier and obtain a measure of household-specific agricultural efficiency. Following Greene (2008) and using subscript i to indicate household, a panel stochastic frontier model is specified with the following form:

$$P_{A,t}y_{i,t} = f(x_{it},\beta)\theta_i e^{\epsilon_{i,t}}, \tag{5}$$

where $y_{i,t}$ is observed output from agricultural production; $P_{A,t}$ is the output price; and x_{it} includes land (hectares), capital (payments), and agricultural labor (days). We use the value of agricultural output on the LHS because households cultivate multiple crops. To construct a household measure of agricultural efficiency, we aggregate output by value. Output prices can vary across time and are in 2002-constant pesos. In addition to the conventional error term, $\epsilon_{i,t}$, which is assumed to have zero mean, there is an unobserved component of the production function, θ_i, or technical efficiency. This term captures relative household-specific total factor productivity or efficiency, in that it reflects a household's value of output for a given set of inputs. We refer to this as agricultural efficiency and use it as a measure of household total factor productivity.

Because agricultural value is used to aggregate across crops, we interpret technical efficiency as a measure of agricultural value (total-input) efficiency. This parameter accounts for the fact that different farms do not have the same input efficiency due to factors such as differing land quality, market access, or experience. Market imperfections in developing countries allow differing technical inefficiencies to persist. This parameter is assumed to be time-invariant, capturing variation in land, labor, and other input quality as well as access to markets and higher prices, inasmuch as the LHS variable is the value of output. Both higher physical efficiency and higher net output prices can increase a household's agricultural efficiency.

We specify both a Cobb-Douglas and a Translog production function (Boisvert, 1982) for flexibility. The log-log version of the Translog production function can be interpreted either as an exact production function or as a second-order approximation to a more general form. In both regressions, explanatory variables include agricultural land (in hectares), labor (in days), and capital payments (using reported rental rates). We present results from these two specifications, but second-stage results are robust to a range of functional forms and the inclusion and exclusion of additional explanatory variables.

The empirical specification takes the following form:

$$\ln P_{A,t}y_{i,t} = f(x_{it},\beta) + \gamma_t + \varepsilon_{i,t} - u_i, \tag{6}$$

where $u_i > 0$, $\theta_i = \exp(-u_i)$, and γ_t is a year fixed effect. The household-specific intercept, u_i, represents a measure of production inefficiency in terms of output per level of inputs used. We use θ_i as estimated in equation (6) in subsequent steps to investigate the impacts of agricultural efficiency on labor allocated to natural-resource collection.

Frontier estimation is executed using maximum likelihood; a truncated normal distribution is assumed for the parameter u_i and a mean-zero normal distribution is assumed for $\varepsilon_{i,t}$. Given these two distributions, the log-likelihood function can be constructed for this problem using the distribution of $\varepsilon_{i,t} - u_i$.[5]

Unobserved household characteristics present challenges for production function estimation. Panel fixed effects control for these unobserved characteristics while estimating time-invariant household efficiency parameters. Some endogeneity likely remains, as the panel methods do not control for time-varying unobserved variables. Despite this, second-stage results are robust across multiple specifications, including a Cobb-Douglas functional form, the use of other inputs, and

[5] The analysis is repeated with panel fixed effects and household-specific intercepts. Using household-specific intercepts as measures of productivity produces qualitatively similar results.

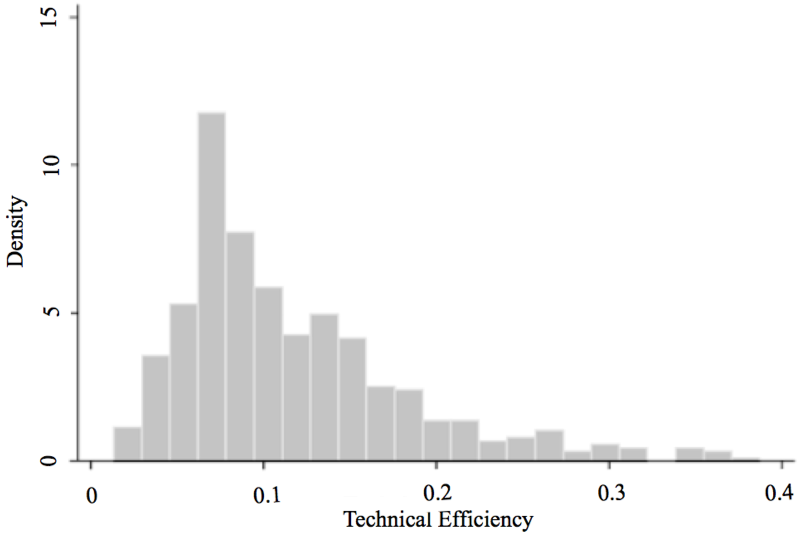

Figure 4. Distribution of Relative Technical Efficiency

random effects estimation. For a detailed description of first-stage functional forms and regression results, see Appendix A.

From the first-stage regression we obtain a household-specific technical efficiency measure. Higher technical efficiency corresponds to a higher value of output per total inputs used. This estimated parameter is the measurement of agricultural efficiency (θ_i) we use to investigate the existence of linkages between agricultural production and resource collection. figure 4 presents the distribution of the technical efficiency parameter estimated using the Translog production function.

The Impact of Agricultural Efficiency on Natural-Resource Collection

This paper's main empirical objective is to test for a qualitative link between households' relative agricultural efficiency and natural-resource collection, measured by the amount of time spent collecting natural resources. To do this, we estimate the following model, grounded on equation (3) in the theoretical model:

$$\ln Days_{i,t} = \alpha_i + \beta \ln \theta_i + \delta p_v^A + \eta \overline{L}_{i,t} + X_{i,t}\gamma + \phi_t + \psi_v + \varepsilon_{i,t}, \tag{7}$$

where $\ln \theta_i$ is the natural log of each household's agricultural efficiency shifter estimated in stage one as technical efficiency. The LHS variable is the natural log of the number of person-days per year a household spends collecting natural resources.[6] Therefore, β is the cross-sector elasticity capturing the linkage between agriculture and natural-resource collection. The other explanatory variables include p_v^A, the village mean corn price; $\overline{L}$, household size (used as a proxy for household time endowment); and $\boldsymbol{X_{i,t}}$, a vector of controls including average education (average number of years of schooling per adult member), village median wage, household transfer income,[7] and a dummy equal to 1 if the household head speaks an indigenous language. Transfer income represents income from government programs such as Progresa/Oportunidades or PROCAMPO. We also control for a time fixed effect (ϕ_t) that allows for common shocks to all households as well as village fixed effects (ψ_v). The village fixed effects are important due to variation in resource quality, management institutions, and access across different villages. Conditional on controls and household-specific intercepts,

[6] Results are robust to the use of total labor instead of household labor on the LHS.

[7] The use of transfer plus remittance income does not affect results. We exclude remittances from the base model because of the potential for endogeneity.

we test whether the supply of labor to resource collection depends on agricultural efficiency. We estimate this regression using a panel random-effects model to identify the impacts of time-invariant agricultural efficiency. This controls for the fact that households may differ in their preferences for the output of resource production.

This estimation procedure permits identification of the impact of agricultural efficiency on resource collection through changing shadow prices. For this effect to be identified, it is assumed that within a village, conditional on controls, the distribution of agricultural efficiency is not correlated with unobserved determinants of resource collection. This may be a strong assumption, as noted in Dercon (2004), but it is necessary here because household technical efficiency does not vary over time and cannot be identified using a household fixed-effect model. The assumption needed for random effects impacts to be identified could be violated, for example, if households with different preferences for resources own or manage land that is systematically different from that of other households. This is unlikely in rural Mexico, as land markets are not well developed and most smallholders historically were allocated a fixed area of land during the *ejido* reforms. We assume that the above assumption holds and interpret results as the connection between resource collection and agricultural efficiency that forms because of the impact on household time and resource valuations. A nonzero value of η provides evidence of imperfect market integration (Benjamin, 1992).

Our estimation procedure consists of two stages. In the second stage, an estimated parameter from the first stage (technical efficiency) is used as an explanatory variable and is therefore a random variable (Murphy and Topel, 1985). In order to account for this and obtain proper standard errors in the second stage we use bootstrapping, in which households are drawn from the original sample with replacement and the two-stage model is estimated. This is repeated 100 times, and the distribution of estimated coefficients is used to obtain standard errors. The bootstrapped standard errors are reported for our base regressions in table 3.

Based on the theoretical model, we expect agricultural labor to depend on agricultural efficiency as well. To test this, we use panel seemingly unrelated regression (SUR) (Biørn, 2004) to jointly estimate equation (7) for household resource collection and agricultural labor. However, no efficiency gains exist for SUR in this case because the RHS variables do not vary across equations (Cameron and Trivedi, 2005).

Results

Our results appear in table 3. Higher agricultural efficiency is associated with a significant decrease in time allocated to natural-resource collection across all model specifications. This relationship holds with the use of village fixed effects (regressions 2 and 7), indicating that within a village, more efficient agricultural producers spend less time collecting natural resources. If resource consumption preferences across households are not correlated with efficiency (conditional on the household random intercept), this result implies that raising agricultural efficiency can lead to decreased resource collection. Because efficiency is measured in terms of agricultural value, efficiency could be increased through better output market integration, access to inputs, and/or physical improvements to the land. If fewer days collecting resources lead to lower levels of extraction, efficiency could result in improved resource stocks over time.

Our preferred specification uses the Translog technical efficiency and controls for village fixed effects. This specification (regression 2 from table 3) gives a cross-sector elasticity of −0.55, implying that if a household experiences a 10% increase in agricultural efficiency there is a 5.5% decrease in person days allocated to resource collection. The average number of days collecting resources is 138 (over both years, conditional on collecting), so an average household that is 10% more efficient spends 7.6 fewer person-days collecting CPRs. Extrapolating this decline to all households that farm and collect CPRs in rural Mexico, this implies 12.2 million fewer person-days per year spent collecting CPRs and suggests that increases in agricultural efficiency could

Table 3. Agricultural Technical Efficiency and Natural Resource Collection

	Agricultural Efficiency from Translog Production Function					Agricultural Efficiency from Cobb-Douglas Production Function				
			Random Effects SUR		IV Results			Random Effects SUR		IV Results
Variables	Family Labor Days Collecting Resources (Ln)		Family Labor Days Collecting Resources (Ln)	Labor in Agriculture (Ln)	Family Labor Days Collecting Resources (IV)	Family Labor Days Collecting Resources (Ln)		Family Labor Days Collecting Resources (Ln)	Labor in Agriculture (Ln)	Family Labor Days Collecting Resources (IV)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Technical Efficiency (Ln)	−0.959***	−0.551***	−0.536***	0.446***	−2.174*	−0.640***	−0.396***	−0.316***	0.377***	−1.652*
	(−11.060)	(−7.331)	(−4.047)	(5.017)	(−1.972)	(−7.951)	(−5.966)	(−3.569)	(6.069)	(−1.878)
Village Corn Price	−0.003	−0.001	0.161	0.061	−0.002	−0.003	−0.001	0.153	0.065	−0.001
	(−1.611)	(−0.372)	(0.509)	(0.345)	(−1.606)	(−1.500)	(−0.367)	(0.481)	(0.361)	(−0.455)
HH Size (Ln)	0.503***	0.537***	0.474***	−0.051	0.369*	0.494***	0.532***	0.452***	−0.020	0.314
	(3.982)	(4.198)	(3.576)	(−0.685)	(1.710)	(3.880)	(4.159)	(3.398)	(−0.266)	(1.267)
Village Median Wage (Ln)	−1.253***	−0.851	0.171	1.028***	−0.985	−1.218***	−0.855	0.187	0.947***	−0.816
	(−4.520)	(−1.537)	(1.077)	(6.067)	(−1.500)	(−4.349)	(−1.543)	(1.097)	(5.209)	(−1.061)
Indigenous HH Head	0.227*	−0.166	0.587	−0.010	0.033	0.259**	−0.159	0.549	−0.0159	0.083
	(1.755)	(−0.752)			(0.114)	(1.973)	(−0.723)			(0.265)
Average Education	−0.071***	−0.038	−0.053**	−0.020	−0.046	−0.071***	−0.037	−0.067***	−0.011	−0.040
	(−2.886)	(−1.451)	(−2.091)	(−1.389)	(−1.198)	(−2.881)	(−1.404)	(−2.636)	(−0.789)	(−0.957)
Transfer Income	−1.78e−06	−2.42e−06	−4.58e−07	−1.18e−05	6.35e−06	−2.08e−06	−2.86e−06	6.06e−06	−1.83e−05**	7.32e−06
	(−0.285)	(−0.322)	(−0.030)	(−1.357)	(0.835)	(−0.335)	(−0.384)	(0.397)	(−2.076)	(0.851)
Constant	6.094***	5.021**			2.541	6.154***	5.088**			1.888
	(5.092)	(2.300)			(0.634)	(5.092)	(2.338)			(0.413)
Fixed effects	Year	Village Year	Year	Year	Year	Year	Village Year	Year	Year	Year
Observations	1,011	1,011	997	997	1,011	1,011	1,011	997	997	1,011
R-squared	0.175	0.371			0.093	0.163	0.369			0.073
Number of Households	688	688			0.100	688	688			0.073

Notes: Boot-strapped standard errors for regressions 1, 2, 6, and 7; t-statistics are shown in parenthesis. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level.
Source: ENHRUM.

have an important impact on labor allocated to natural-resource collection in rural Mexico. Higher education and village wages are associated with a decrease in the use of local natural resources, but these impacts disappear when we control for village-level fixed effects. Consistent with household-specific shadow prices, larger households spend more time collecting natural resources and working on the farm.

The SUR results (regressions 3, 4, 8, and 9) demonstrate that households with higher agricultural efficiency allocate labor away from natural-resource collection and into agricultural production. While higher agricultural efficiency means fewer inputs used per unit of output, it also raises the value marginal product of inputs and the demand for family labor on the farm.

Robustness Tests

As a robustness check, we re-estimated the model using self-reported land quality as an instrument for agricultural efficiency in the second stage. Households reported whether each plot of their agricultural land was of “good” or “poor” quality. We defined an indicator variable equal to 1 if a household responded that its land is of “good” quality and 0 if not. It is assumed that land quality is correlated with the value of agricultural productivity but does not directly affect the demand for natural resources. The instrumental variables estimation is carried out to check for measurement error in stage one as well as to address other sources of endogeneity mentioned above.

The qualitative results hold using instrumental variables; the point estimate becomes larger in absolute value but standard errors increase. First-stage F-statistics of 14.23 and 17.73 indicate strong correlation between the instrument (self-reported land quality) and agricultural efficiency estimated in stage one of the instrumental variables regressions. Stage one results are reported in Appendix B and indicate a strong correlation between good land quality and technical efficiency.

As noted above, our analysis focuses on agricultural households, including some households that do not collect natural resources. Therefore, selection into natural-resource collection may be a concern. We test the robustness of our results to selection bias by using a panel Heckman Selection Model (Heckman, 1979; Kyriazidou, 1997) and allowing for censored data using a panel Tobit specification (Maddala, 1987).

Table 4 presents results using the Heckman selection and Tobit specifications. Qualitative results are robust to explicitly modeling selection or allowing for censored data. The significant coefficient on the Inverse Mills Ratio suggests that selection may be a concern, but results do not change qualitatively from those presented in table 3. Alternative models for selection into resource collection produce qualitatively similar results. The results from the selection model estimation are presented in Appendix C and demonstrate that larger households and lower average education are associated with a higher likelihood of resource collection. Finally, indigenous households are more likely to collect resources than nonindigenous households. Higher agricultural productivity increases the probability of collecting resources in addition to affecting the number of days that a household collects.

Our econometric results suggest the existence of intra-household economic linkages between agricultural efficiency and CPR collection. More efficient agricultural producers spend less time collecting CPRs and more time working in agriculture. This is consistent with an imperfectly integrated household producer for whom the effect of a higher opportunity cost of time dominates the increase in demand for natural resources.

The connection between household size and labor allocated to the two sectors provides further evidence that rural Mexican resource collectors are not well integrated into markets (Benjamin, 1992). In reality, it may be the case that even agricultural output is not a perfectly marketed sector. This could introduce error in the measurement of agricultural efficiency. Arslan and Taylor (2009) find that households value traditional corn at a price that exceeds the market price. Using market price understates the value of production for these varieties, and if the magnitude of this error does not correlate with resource demand, it produces an attenuation bias. If, on the other hand, households with higher resource demand also place a higher value on agriculture, this can bias our negative

Table 4. Agricultural Efficiency and Resource Collection, Robustness to Selection

	Translog Production		Cobb-Douglas Production	
Variables	**Heckman Selection**	**Tobit**	**Heckman Selection**	**Tobit**
Technical Efficiency (Ln)	−0.588***	−0.694***	−0.473***	−0.502***
	(−4.077)	(−3.837)	(−3.834)	(−3.506)
Village Corn Price	−0.004***	5.38e-05	−0.004***	6.63e-05
	(−8.605)	(0.0146)	(−8.142)	(0.018)
HH Size (Ln)	0.457***	0.628***	0.468***	0.623***
	(4.953)	(4.084)	(5.278)	(4.042)
Village Median Wage (Ln)	−0.941**	−0.949	−0.945**	−0.950
	(−2.249)	(−1.581)	(−2.288)	(−1.583)
Indigenous HH Head	−0.026	−0.039	0.013	−0.03
	(−0.177)	(−0.142)	−0.083	(−0.109)
Average Edufcation	−0.005	−0.045	−0.009	−0.044
	(−0.251)	(−1.540)	(−0.451)	(−1.490)
Transfer Income	−7.93e-06*	−9.35e-07	−7.46e-06	−1.42e-06
	(−1.731)	(−0.109)	(−1.550)	(−0.166)
Mills Ratio	1.328**		1.651**	
	(2.203)		(2.148)	
Constant	5.862***	4.215*	5.726***	4.271*
	(3.649)	(1.821)	(3.534)	(1.842)
Observations	773	1,095	773	1,095
Number of Households	550	714	550	714

Notes: Robust t-statistics are shown in parenthesis. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level.

coefficient estimate away from 0. While this is a concern, using physical corn output to measure efficiency for only corn-producing households produces qualitatively similar results, suggesting that price differences do not drive our findings.

Discussion and Conclusions

This study reveals that, in rural Mexico, labor supplied to CPR collection is linked to agricultural efficiency. As agricultural producers become more efficient, the value of time—and thus the opportunity cost of collecting resources—rises. While demand for the resource increases with income, the effect of the higher shadow wage dominates. This reveals a cross-sector linkage and suggests that improvements in agricultural efficiency and access to markets can lead to a reduction in pressure on local CPRs, assuming fewer days of resource collection lead to fewer extracted resources. Our findings suggest that market signals from one sector (agriculture) translate into changes in behavior in the nonmarket activity (resource collection). They open up the possibility of using economic policy to influence decisions with regard to nonmarket activities.

We have focused this analysis on marginal differences in agricultural efficiency and the connection to natural-resource collection. We have not investigated the impacts of discrete changes in agricultural technology that could fundamentally alter demands for labor and capital. If labor-saving innovations reduce the demand for agricultural labor before jobs are created elsewhere in the economy, lower opportunity costs could push households to depend more on local natural resources. We treat participation in agricultural production as exogenous. The group of households analyzed here makes up approximately 43% of the rural Mexican population of 25 million people (World Bank World Development Indicators). Our data indicate that agricultural households supply an average of thirty-one more labor-days to resource collection than nonagricultural households. If changes in agricultural productivity also cause more households to farm, this could increase the total use of the common property resource. Alternatively, reduced resource use could increase pressure to develop land for other uses, including higher-productivity agriculture (Angelsen, 1999). Modeling the decision to farm is beyond the scope of this paper. Future work is needed to understand the decision to participate in different economic activities.

This study offers insights into the manner in which resource collection fits into the broader context of household economies. Agricultural efficiency influences the value of household time, and this has an impact on how households use their time in other activities. We demonstrate the use of stochastic frontier estimation to identify the linkage between relative agricultural efficiency and the effort households spend collecting natural resources. This linkage exists because market imperfections create a trade-off between labor allocated to various household activities, causing the value of time to emerge endogenously. The value of agricultural production becomes part of the opportunity cost of natural-resource collection.

Given that nonmarketed firewood is the most commonly collected natural resource, households likely have to make up for reduced biomass energy. Therefore, in many cases access to alternative energy may be required for households to reduce resource collection. In the context of rural Mexico, liquefied petroleum gas provides a substitute for biomass energy. Most villages have access to propane through salesmen who bring tanks for sale. If resources are marketed (e.g., charcoal), higher agricultural productivity can cause households to shift labor from one market activity to another.

Our findings underline the importance of accounting for intrahousehold linkages, especially when policymakers are concerned about natural-resource conservation. They suggest that if Mexico's agricultural production becomes more intensive, households will rely less on the exploitation of local natural resources. The agriculture-resource nexus allows agricultural policy to influence the collection of local natural resources. Our findings suggest that investment in agricultural intensity can be combined with conventional natural-resource management to incentivize reductions in collection and promote the conservation of natural capital stocks in developing countries.

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Appendix A: First-Stage Regression

Our first-stage estimation equation is
Cobb Douglas:

$$\text{(A1)} \qquad \ln P_{A,t} y_{i,t} = \alpha_i + \beta_1 \ln(farmlabor_{i,t}) + \beta_2 \ln(land_{i,t}) + \beta_3 \ln(capital_{i,t}) + \gamma_t + \varepsilon_{i,t} - u_i$$

Translog:

$$\text{(A2)} \qquad \begin{aligned} \ln P_{A,t} y_{i,t} = {} & \alpha_i + \beta_1 \ln(farmlabor_{i,t}) + \beta_2 \ln(land_{i,t}) + \beta_3 \ln(capital_{i,t}) \\ & + \beta_4 \frac{1}{2} (\ln(farmlabor_{i,t}))^2 + \beta_5 \frac{1}{2} (\ln(land_{i,t}))^2 + \beta_6 \frac{1}{2} (\ln(capital_{i,t}))^2 \\ & + \beta_7 \frac{1}{2} \ln(farmlabor_{i,t}) \ln(land_{i,t}) + \beta_8 \frac{1}{2} \ln(farmlabor_{i,t}) \ln(capital_{i,t}) \\ & + \beta_9 \frac{1}{2} \ln(capital_{i,t}) \ln(land_{i,t}) + \gamma_t + \varepsilon_{i,t} - u_i \end{aligned}$$

Appendix table A1 presents the production function estimates using both panel fixed effects (1) and stochastic frontier (2) estimation. The parameters are largely robust across specifications. For the base model we use the technical efficiency parameter produced from estimation using stochastic frontier. This variable has a mean of 0.15 and standard deviation of 0.10 using the Cobb-Douglas production function and a mean of 0.21 and standard deviation of 0.10 using the Translog specification.

Table A1. Production Function Estimation

Variables (Natural Log)	Translog Production Function: Household Fixed Effects	Translog Production Function: Time-Invariant Panel Stochastic Frontier	Cobb-Doubglas Production Function: Household Fixed Effects	Cobb-Doubglas Production Function: Time-Invariant Panel Stochastic Frontier
Agricultural Labor (Days)	0.076	−0.314**	0.224***	0.249***
	(0.184)	(0.123)	(0.051)	(0.033)
Land (Hectares)	0.429**	0.763***	0.615***	0.655***
	(0.199)	(0.110)	(0.083)	(0.037)
Capital (Payments)	−0.078	−0.268***	−0.026	0.079***
	(0.096)	(0.065)	(0.021)	(0.012)
1/2*Agricultural Labor Squared	0.133*	0.105***		
	(0.068)	(0.028)		
1/2*Land Squared	0.0313	0.149***		
	(0.049)	(0.032)		
1/2*Capital Squared	−0.011	0.080***		
	(0.025)	(0.017)		
1/2*Capital*Land	0.095**	0.018		
	(0.039)	(0.022)		
1/2*Ag Labor*Land	−0.026	−0.124**		
	(0.085)	(0.05)		
1/2*Ag Labor*Capital	0.022	0.017		
	(0.026)	(0.017)		
Constant	7.414***	9.621***	7.007***	9.323***
	(0.395)	(1.279)	(0.218)	(1.608)
Observations	1,011	1,011	1,011	1,011
R-squared	0.259		0.222	
Number of Households	688	688	688	688

Notes: T-statistics are shown in parenthesis. Both regressions include year fixed effects. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level.
Source: ENHRUM.

Appendix B

Table A2. Selection into Resource Collection

Variables	Panel Probit
Technical Efficiency (Ln)	−0.944***
	(−6.418)
Household Size (log)	0.259**
	(1.967)
Village Wage	−0.167
	(−0.736)
Indigenous HH Head	0.425***
	(2.372)
Average Education	−0.053**
	(−2.253)
Transfer Income	6.19e-06
	(0.972)
Constant	−0.149
	(−0.144)
Observations	1,270
Number of Households	803

Notes: T-statistics are shown in parenthesis. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level.

Appendix C

Table A3. First Stage of Instrumental Variables Regression

Variables	Translog Production	Cobb-Douglas Production
Village Corn Price	0.0005*	0.001***
	(1.722)	(3.051)
HH Size (Ln)	−0.105**	−0.171**
	(−2.129)	(−2.552)
Village Median Wage (Ln)	0.200	0.365
	(0.963)	(1.265)
Indigenous HH Head	−0.140	−0.154
	(−1.435)	(−1.115)
Average Education	0.021**	0.031***
	(2.647)	(2.990)
Transfer Income	4.48e-06***	6.48e-06***
	(2.769)	(3.003)
Good Agricultural Land	0.131***	0.172***
	(2.854)	(2.954)
Constant	−2.540***	−3.739***
	(−3.212)	(−3.394)
Observations	1,011	1,011
R-squared	0.102	0.124

Notes: Robust t-statistics are shown in parenthesis. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level.