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MODELING THE DETERMINANTS OF SEMI-SUBSISTENT AND COMMERCIAL LAND USES IN AN AGRICULTURAL FRONTIER OF SOUTHERN MEXICO: A SWITCHING REGRESSION APPROACH

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The authors analyze the consequences of imperfect output markets for the land-use decisions of semi-subsistence farmers in an agricultural frontier of southern Mexico. The approach is motivated by previous applications of the agriculture household model establishing that the farm household's production and consumption decisions are analytically nonseparable when markets are not used. Econometric results generated by a switching regression model suggest the importance of distinguishing the discrete choice of market participation from that of area cultivated.

Keywords: *agricultural household models; separable models; switching regression*

Tropical deforestation is significant to a range of themes that have relevance for the study of environmental change and economic development, including global warming, land degradation, species extinction, and sustainability issues. Recognition that both the *location* and *pattern* of forest clearance are often as important as its *magnitude* has motivated an increasing number of empirical studies aimed at modeling the spatial dimensions of deforestation processes (e.g., Chomitz and Gray 1996; Nelson and Hellerstein 1997; Cropper, Griffiths, and Mani 1999; Pfaff 1999). A majority of these studies assume that agents are fully engaged in markets and therefore that their production behavior can be empirically specified using a profit-maximizing framework. However, as much tropical deforestation occurs in developing countries in areas often characterized by underdeveloped markets, the assumption of full market participation by land managers is tenuous at best. Consequently, the results from these models may be biased, implying that policies derived therefrom may be misinformed. In this article, we draw on the example of an

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agricultural frontier from southern Mexico to analyze the land-use decisions of farmers operating in a context of thin markets. Our focus abstracts from the deforestation process per se to address the agricultural land uses that result in land clearance, as it is this underlying behavior that can be influenced through conservation programs. Applying lessons from a growing body of studies in the agricultural development literature (e.g., Huang, Raunikar, and Misra 1991; Goetz 1992; Sadoulet, de Janvry, and Benjamin 1998; Key, Sadoulet, and de Janvry 2000), we suggest that modeling land-use decisions necessitates distinguishing the discrete choice of participation in agricultural product markets from the continuous choice of area cultivated. Accordingly, our empirical approach advances the existing literature on land-use modeling by employing a switching regression that partitions households according to their participation in output markets while simultaneously controlling for biases emerging from sample selectivity.

Review of Previous Literature

Although some of the spatial deforestation models show divergences in empirical results according to the commercial versus semi-subsistence agricultural land-use distinction, the maintained modeling assumption for both land-use types is of profit maximization. For example, using the profit-maximizing framework, Chomitz and Gray (1996) for Belize and Cropper, Griffiths, and Mani (1999) for Thailand showed that the effect of roads on deforestation levels tend to be greater for commercial crops.[1] These studies also identified the effect of soil quality on deforestation to differ by the market orientation of the crop grown. However, as these authors only had available aggregate socioeconomic data, they imposed the commercial versus semi-subsistence designation; in Chomitz and Gray, this was done by crop type; and in Cropper, Griffiths, and Mani, it was inferred by geographical region.

Similarly, previous household-level models of land use in developing regions do not directly question the validity of the profit-maximization framework, but the evidence from many studies suggests that the framework may not be appropriate for understanding land-use choices. For example, Jones et al. (1995) discovered possible evidence of the divergence between profit and utility maximization in several

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subsistence crops among farmers in Brazil. Monela (1995), Godoy et al. (1997), and Pichón (1997) identified demographic effects on deforestation in Tanzania, Honduras, and Ecuador, respectively, which should not be the case under profit maximization.

While it is generally recognized that the existence or absence of markets is profoundly linked to the land allocation decision (Godoy et al. 1997; Omamo 1998a, 1998b), there has been little research on this linkage in frontier regions where markets for goods and factors remain underdeveloped or missing. With few exceptions, spatial microeconomic models of deforestation assume a full and complete set of markets, thereby justifying the analysis of the farm household's production decisions in isolation from its consumption decisions. At the same time, there exists a long-standing recognition within the agricultural development literature that such an analytical division is often inappropriate in regions with underdeveloped markets. This recognition has stimulated the development agricultural household models that explicitly incorporate the interdependency of the household's production and consumption decisions on the allocation of household resources (e.g., Wharton 1969; Barnum and Squire 1979; Singh, Squire, and Strauss 1986). Given the ability of these models to explain the sometimes sluggish—and even perverse—response of peasants to changes in relative prices, this approach represents a potentially important analytical tool for assessing the effects of price-based policy measures in curtailing deforestation.

Background of the Region

In this article, we draw on a spatially explicit data set from a sample of Mexican farm households to test the implications of using the agricultural household model for land-use choices. Our research focuses specifically on the *ejido* sector of Mexican agriculture as this is currently the predominate form of land tenure in the study region. This sector was created following the Mexican Revolution (1910-17), a political and social upheaval with roots in inequitable land distribution. Within ejido communities, land is communally regulated by an elected committee, but in this area of southern Mexico, ejido members *(ejidatarios)* typically enjoy usufruct access to a single parcel that is permanently allocated to their use.[2] This tie between households and parcels permits land-use decisions to be linked to the geographical locations in which they have impact.

The study region, located in the southern portion of the Yucatán peninsula (see Figure 1), is part of the largest continuous expanse of tropical forests remaining in Central America and Mexico and has been identified as a "hot spot" of forest and biotic diversity loss (Achard et al. 1998). For the first half of the twentieth century, economic activity here was minimal and centered on the selective logging of tropical woods, particularly mahogany and cedar, as well as on the extraction of chicle, a tree resin used in the production of chewing gum. More extensive deforestation followed with the construction of a two-lane highway paved east-west across the cen-

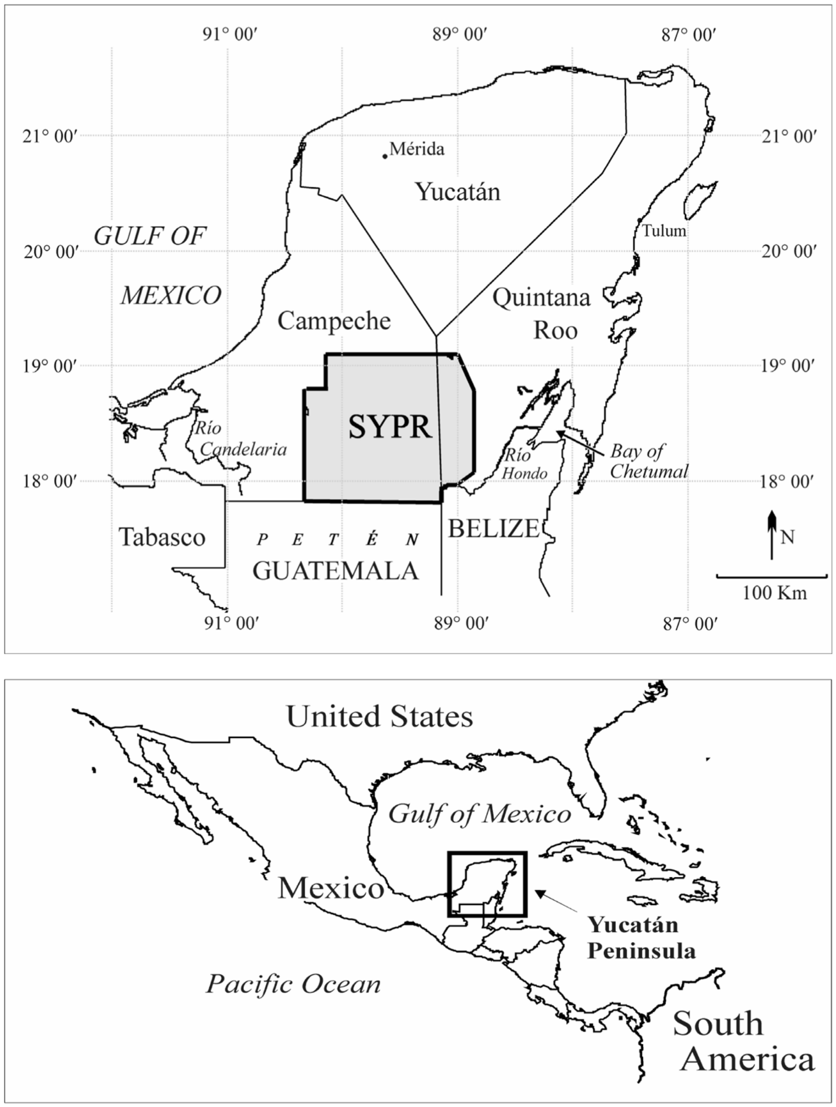

FIGURE 1. The Southern Yucatán Peninsular Region (SYPR)

ter of the region in 1967, which opened the frontier to agricultural colonization via the extension of *ejidal* land grants, as sanctioned by Article 27 of the Mexican constitution.[3]

Most early settlers of the region arrived in the mid 1970s from neighboring regions of Mexico where there was a scarcity of land. They practiced predominantly subsistence-oriented systems of land-use management as exemplified by the *milpa*, a centuries-old form of Maya agriculture dominated by maize and typically intercropped with beans and squash (Turner 1983). In recent years, however, there has been a trend toward land-use diversification that features the expansion of cash crop production, most notably the cultivation of chili peppers. Based on the accounts of various respondents, chili peppers seem to have first appeared in the region in the late 1970s. In contrast to maize, which is grown primarily for subsistence but a portion of which is occasionally sold, the entire output of chili peppers is marketed. This distinction affords an opportunity to explore whether a different economic behavior underlies the production of these two crops. We have available individual household survey data, including information on demographics, crop choices, the area planted, and if the crops were sold, that allow us to examine the implications of incomplete markets in the spatial modeling of agricultural expansion leading to tropical deforestation.

THEORETICAL CONSIDERATIONS

Two broad classes of the agricultural household model have been developed to explain differing production strategies of farm households depending on market opportunities (Singh, Squire, and Strauss 1986). The first class of models, called the *separable model*, exists when all input, output, and insurance markets fully function. These conditions make it optimal for the utility-maximizing farmer to apply a production logic that is independent of consumption considerations. With prices for factors of production and output exogenously given, utility and profit-maximizing production calculations converge. Such models are sometimes referred to as *recursive* because there is a one-way effect of the optimizing production decision on consumption via the level of income obtained. Empirically, this implies that an econometric specification based on profit-maximization is sufficient to model the farmer's allocation of factors of production.

The second class of models is *nonseparable*, where the consistency of utility and profit-maximizing behavior no longer holds. This can occur when the transaction costs of market exchange are sufficiently high to induce the household to opt for self-sufficiency, as may result, for example, from prohibitively costly transport due to poor infrastructure connecting farms with regional market centers (Omamo 1998a, 1998b). When the household chooses not to participate in the market, its production and consumption decisions cannot be analytically separated: production decisions will incorporate subsistence and/or leisure considerations. Empirically, this implies that a profit-maximizing specification comprising only prices and technology will yield biased estimates. Correcting this bias necessitates incorporating variables that also measure the consumption side of household decision making.

Two types of transaction costs—*fixed* and *proportional*—may result in the decision not to participate in the market (Key, Sadoulet, and de Janvry 2000). Fixed

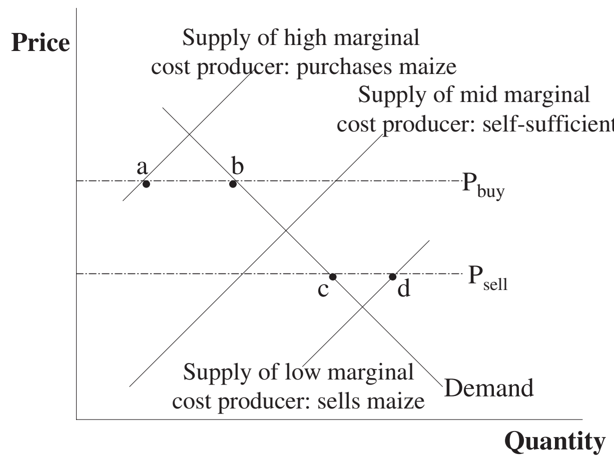

FIGURE 2. Illustrating Separability

transaction costs are invariant to the quantity of the good traded and include search, bargaining, and labor supervision costs. Proportional transaction costs, by contrast, vary with the extent of market participation and typically arise from the per-unit costs of trading in markets and imperfect information. Both types of cost lead to a low farm gate price at which farmers can sell their crop and a higher price at which they can buy that crop at the market. Figure 2 illustrates this circumstance for the case of proportional transaction costs, with the exogenously given price band P_{buy} and P_{sell} (de Janvry, Sadoulet, and Gordillo de Anda 1995).

There are three market participation choices for a household depending on the position of their supply curve and demand curve relative to the price band. Self-sufficiency will occur if the intersection of these curves falls within the price band. In this case, the household's endogenous valuation of maize (i.e., the shadow price) is lower than the price it would pay were it to purchase maize in the market but higher than the price it would receive were it to sell maize. As the equilibrium price is no longer parametric, but rather is determined endogenously by the choices of the household, production of this nontraded good is directly linked to its consumption. Therefore, the household will allocate that amount of land to maize that ensures the equilibrium of its marginal cost and marginal benefit schedules, implying that the food consumption requirement will affect production decisions. For a household with a relatively high marginal cost of production, the shadow price will be above the market purchase price and the household will purchase in the market the quantity *ab*. Conversely, for a low-marginal-cost household, the equilibrium is below the lower limit, and they will sell the quantity *cd*. In either of these instances, the food consumption requirement is expected to have no effect on the production decision.

Several theoretical and empirical studies have applied the above framework to focus on the implications of missing or thin markets for labor (Lopez 1986; Benjamin 1992; Jacoby 1993; Sadoulet, de Janvry, and Benjamin 1998), food (de Janvry, Fafchamps, and Sadoulet 1991; Goetz 1992; Omamo 1998a, 1998b), and insurance (Roe and Graham-Tomasi 1986; Saha 1994).[4] A fundamental result emerging from this body of literature is that if a complete set of markets exists, the optimal land-use portfolio is one that equalizes the marginal revenue product of the land across all uses. Since this outcome is a function of exogenously given market parameters and is independent of household characteristics, measures of demographic composition should have no statistically significant effect in explaining land use for households that participate in all markets, even if these households consume a portion of their output. This observation is the basis for the empirical tests pursued in this article. Drawing on the framework provided by the agricultural household model, hypotheses are formulated that relate demographic structure to both semi-subsistence and commercially based land-use choices under different market participant regimes.

The Survey Design and Questionnaire

Selection of respondents for the household survey proceeded according to a stratified, two-stage cluster sample (Warwick and Luinger 1975; Deaton 1997), with ejidos as the first-stage unit and ejidatarios as the second-stage unit. Using maps and population censuses published by the Mexican government's national institute of statistics and geography (INEGI 1985-87, 1991a, 1991b), the region was partitioned into eleven geographic strata, and one ejido (or *cluster*) was randomly selected from each of the strata. Each ejido was assigned a probability of selection equal to the ratio of its population to the population of the stratum. In the second stage, the survey respondents were randomly selected, whereby the target number of households surveyed from each ejido was approximated such that the corresponding stratum was represented in roughly the same proportion as its share of the total population of the study zone. In the empirical analysis that follows, the data were weighted to adjust for deviations from this target.

A standardized questionnaire, administered to the household head, was used to elicit the socioeconomic and land-use data. The first section covered migration history, farm production and inputs, off-farm employment participation, and the demographic composition of the household. Completion of the second section involved a guided tour of the agricultural plot of the respondent. Using a global positioning system (GPS), the interviewer created a geo-referenced sketch map detailing the configuration of land uses, including the area allocated to commercial and subsistence crops. In combination with available satellite imagery, topographic maps published by INEGI (1985-87), and rainfall data, this information was entered into a geographic information system (GIS), thereby enabling the calculation of spatially explicit indices such as distance to road and ecological measures.

EMPIRICAL SPECIFICATIONS

Two econometric models are specified, the first for maize, which is cultivated by the entire sample, but is sold by slightly less than half; and the second for chili peppers, which is only cultivated by approximately half of the sample, but is produced strictly for the market. Both models use a form of the two-stage switching regression model to test hypotheses concerning which parameters are statistically significant in explaining land-use choices in an environment of potentially imperfect markets. Our approach follows an empirical methodology originally formulated by Lee (1982) and used by Goetz (1992) to study marketed surplus of food grains in Senegal conditional on market participation. Variants of the methodology were subsequently applied by Sadoulet, de Janvry, and Benjamin (1998) and by Key, Sadoulet, and de Janvry (2000) in studies from Mexico of labor market participation and agricultural household supply response, respectively. In this article, we apply the general version of the switching regression to study maize cultivation. A special case of the technique, Heckman's (1974) sample selection model, is applied to chili cultivation as in that case the dependent variable is censored at zero.

The theoretical framework outlined above indicated that the determinants of maize cultivation are contingent on the decision of the household to participate as a seller in the market. As the decision to sell maize is itself an endogenous choice, however, there may be unobservable variables that affect both the probability of being a seller as well as the area of maize planted. To account for the potential simultaneity bias arising from the existence of such variables, the empirical specification employs a two-stage, switching regression model with endogenous switching (Lee 1982; Maddala 1983).

The model considers that observations are ordered into two regimes. In the context of the present example, these regimes correspond to the area allocated to maize cultivation among the sellers and nonsellers, represented by the following equations:

$$\text{Regime 1 (sellers): } y_i = \beta'_1 X_{1i} + u_{1i} \text{ if } \tau' Z_i \geq u_i \tag{1}$$

$$\text{Regime 2 (nonsellers): } y_i = \beta'_2 X_{2i} + u_{2i} \text{ if } \tau' Z_i < u_i. \tag{2}$$

In this system, the X_i are the exogenous determinants of area cultivated, the Z_i are the determinants of seller status, and the β' and τ' are vectors of the associated parameters to be estimated. The error term u_i is assumed to be correlated with the errors u_{1i} and u_{2i}, and all three terms are assumed to have a trivariate normal distribution.

The first stage defines a dichotomous variable indicating the regime into which the observation falls:

$$S_i = 1 \text{ if } \tau' Z_i \geq u_I \qquad (3)$$
$$S_i = 0 \text{ otherwise.}$$

After estimating the parameters τ using the probit maximum likelihood method, the expected values of the residuals, u_i, are calculated. As the u_i are normally distributed, with mean $\sigma_{1u}u_i$ and variance $\sigma_1^2 - \sigma_{1u}^2$, these values are given by the standard formula for the expected value of a truncated distribution (Greene 1997):

$$E(u_{1i} \mid u_i \leq \tau' Z_i) = E(\sigma_{1u}u_i \mid u_i \leq \tau' Z_i) = -\sigma_{1u}[\varphi(\tau' Z_i)/\phi(\tau' Z_i)] \qquad (5)$$

$$E(u_{2i} \mid u_i \geq \tau' Z_i) = E(\sigma_{2u}u_i \mid u_i \geq \tau' Z_i) = \sigma_{2u}[\varphi(\tau' Z_i)/(1 - \phi(\tau' Z_i))]. \qquad (6)$$

The bracketed terms on the right hand side of equations 5 and 6 of the above equations represent two variants of the inverse Mills ratio, defined by the ratio of the density function of the standard normal distribution, φ, to its cumulative density function, ϕ. When appended as an extra regressor in the second-stage estimation, this ratio is a control for potential biases arising from sample selectivity. Denoting the two variants of the inverse Mills ratio as w_1 and w_2, the second-stage regressions can then be written as

$$y_{\text{seller}} = \beta'_1 X_{1i} - \sigma_{1u}[w_1] + \varepsilon_{1i} \text{ if } \tau' Z_i \geq u_i \qquad (7)$$

$$y_{\text{nonseller}} = \beta'_2 X_{2i} - \sigma_{2u}[w_2] + \varepsilon_{2i} \text{ if } \tau' Z_i < u_i, \qquad (8)$$

where the estimated coefficients—σ_{1u} and σ_{2u}—give covariance estimates of the unobserved effects on the selling and planting decisions (Killingsworth 1983). If significant, these estimates indicate that sample selectivity is present. Because the residuals of the second-stage regressions are heteroskedastic, they are estimated by weighted least squares using the Huber/White estimates of variance.

As in the case of maize, the problem of estimating the area cultivated in chili peppers needs to distinguish between the determinants of market participation and those of area cultivated. The decision to produce chili simultaneously represents a decision to participate in the market as the entire output is sold, but because 48 percent of the sample produced no chili whatsoever, a modified version of the switching regression, the Heckman sample selection model, is used. The model considers that there is an index, s_i^*, that determines whether the observation y_i (the area allocated to chili pepper cultivation) is observed:

$$s_i^* = \tau' Z_i + u_i,\ s_i = 1 \text{ if } s_i^* > 0 \text{ and 0 otherwise, and} \qquad (9)$$
$$y_i = \beta' x_i + \varepsilon_i \text{ observed when } s_i = 1. \qquad (10)$$

Under the assumption that u_i and ε_i are jointly normally distributed, the expected value of y_i can be written by inserting the inverse Mills ratio, as in equation 5:

$$E[y_i \mid y_i \text{ is observed}] = \beta' x_i + E[\varepsilon_i \mid u_i < \tau' Z_i] = \beta' x_i + \rho[\varphi(\tau' Z_i)/\phi(\tau' Z_i)], \quad (11)$$

where ρ represents the correlation between u_i and ε_i. The model, which comprises an equation determining sample selection and a regression model, can be estimated using the maximum likelihood technique, with estimates of the inverse Mills ratio used as starting values in the iteration process.

Model Identification and Control Variables

To identify both empirical models requires the selection of variables that uniquely determine the discrete decision (e.g., whether to participate in the market) but not the continuous decision (e.g., area cultivated). In the present example, this selection can be informed by the work of Goetz (1992) and of Key, Sadoulet, and de Janvry (2000), where these authors demonstrated that the market participation decision depends on both fixed and proportional transaction costs while the extent of participation depends on proportional transaction costs only. Identification of the model can therefore be achieved by including in the selector equation variables that proxy for fixed transaction costs. We include five such variables: a dummy variable for vehicle ownership, the on-road distance from the ejido to the nearest market and its square, a dummy variable indicating one of the sampled ejidos that is situated on the main highway and serves as a depot for local produce, and a dummy variable indicating whether the head of the household is a native Spanish speaker.[5] The descriptive statistic for these and the other variables of the model are presented in Table 1. Following the work of Goetz, the identifying variables are intended to control for the fixed costs of information gathering and of accessing the market. We expect that the dummies for vehicle ownership, the favorably situated ejido, and first language in Spanish positively affect the probability of market participation as they reduce information and access costs. Conversely, distance is predicted to have a negative effect, with the squared term included to allow for potential nonlinearities.

Among the other exogenous regressors presented in Table 1 are variables theoretically expected to affect the continuous land-use decision: demographic indices, travel costs to the plot, time allocated to off-farm labor, available liquidity, farm capital (human and physical), and ecological factors. With regard to the demographic indices, we hypothesize that the sellers of maize and chili, having made the decision to participate in the market, will reach their production decision for each of these two crops with reference to the associated farm-gate prices. Consequently,

TABLE 1. Descriptive Statistics of Variables Used in the Regressions

Variable	M	SD
Dependent variables		
Hectares planted in maize	4.332	4.001
Hectares planted in chili among those planting	1.444	1.447
Explanatory variables		
Consumption index	2.198	1.799
Labor index	4.171	3.096
Age of head	46.326	15.124
Education of head (highest grade)	2.775	3.153
Distance to plot (kilometers)	6.586	6.163
Area of plot (hectares)	85.384	51.586
Elevation (meters)	168.919	78.355
Good soil (1, 0)	0.770	0.422
Access to chain saw (1, 0)	0.369	0.484
Number of cattle	3.364	11.146
Months of off-farm labor	6.634	8.141
Government credit (thousands of pesos)	2.835	2.898
Identifying variables		
First language Spanish (1, 0)	0.701	0.459
Depot *ejido* (1, 0)	0.166	0.373
Distance to nearest market (kilometers)	26.745	21.583
Vehicle ownership (1, 0)	0.155	0.363

there should be no statistically significant relationship between area of maize or chili planted and the consumption requirement of the household. Such a relationship, however, is expected among households producing maize solely for subsistence. As their valuation of that crop is determined endogenously as a function of demographic composition, we expect to observe a positive effect of the household consumption requirement on the area of maize cultivated.[6]

To distinguish between household supply of labor and consumption demand effects, demographic structure is decomposed into two mutually exclusive variables that were constructed on the basis of educational attainment and age. The first variable measures the number of household members greater than or equal to twelve years of age who have less than nine years of schooling and is intended to measure the potential pool of domestic on-farm labor (Sadoulet, de Janvry, and Benjamin 1998).[7] The second variable, comprising children under twelve and members with nine or more years of schooling, measures the remainder of the household. Since young children and highly educated members are assumed to not contribute to field labor, this variable is taken to be a consumption measure that is purged of an on-farm supply-side effect.[8] No a priori prediction is made for the coefficient on the household labor force measure other than to exclude a negative sign. Given the existence of thin labor markets, the measure would be expected to have a positive coefficient, reflecting nonseparability in production and consumption as a consequence of the household's endogenous valuation of its time endowment.

Aside from the consumption index defined above, we have no theoretical basis for expecting differential effects of the remaining control variables according to whether the crop is sold. The travel cost of plot access, measured by the walking distance from the household, is expected to reduce the area planted as it detracts from labor hours available for cultivation and also effectively reduces the farm-gate price received for the crop. Likewise, to the extent that off-farm employment diverts household labor away from cultivation and may additionally relax pressures to generate cash and food from farm activities, this measure is also expected to have a negative effect on area cultivated for maize and chili (Godoy et al. 1997; Pichón 1997).

To control for available liquidity, the total aid in government credit received since 1996 and the number of cattle owned are included. While credit may be directed to land-improving investments (e.g., fertilizer) that reduce the area cultivated, it may also be directed to labor-saving investments (e.g., tractors) that increase area cultivated. Hence, the net effects are unclear. The effects of cattle are also ambiguous. In the case of a poor harvest, cattle can either be sold or consumed to supplement staple requirements, an insurance mechanism that could be expected to increase the extent of commercialized nonfood crops such as chili peppers. Cattle also may have, however, a negative effect across maize and chili since large tracts are required for grazing, thereby reducing the area available for other land uses.

Three variables control for the effects of ecological factors: the total land endowment, a dummy variable indicating favorable soil quality, and the average elevation of the plot. The total land endowment is expected to have a positive coefficient since, all else equal, greater access to land promotes more extensive (and labor-saving) farming practices. With regard to expectations on the remaining variables, we simply note that while more favorable ecological conditions would increase the probability that a given plot is cultivated, it is not possible to predict their effect on the actual size of the plot.

The education and age of the household head and a dummy for access to a chainsaw are included as measures of available human and physical farm capital. More education not only may enhance labor productivity through increased managerial talent and the adoption of modern farm technologies (Godoy et al. 1997; Tao Yang 1997) but also implies a higher opportunity cost of on-farm labor due to increased wage earning potential. Hence, it is expected to exert a negative effect on the area cultivated. Similar effects of managerial talent could be expected for the age of the household head. The effects of access to a chainsaw are hypothesized to be positive through lowering of the labor costs in forest clearance.

TABLE 2. Probit and Weighted Least Squares (WLS) Models of Seller Status and Hectares Planted in Maize

			WLS of Hectares Planted in Maize			
Variable	*Probit of Seller Status*		*Sellers*		*Nonsellers*	
Consumption index	–0.030	(–0.357)	–0.443	(–0.732)	1.134	(3.447)***
Labor index	–0.041	(–1.822)	0.257	(2.086)*	0.384	(2.914)**
Age of head	–0.002	(–0.256)	0.055	(2.347)*	0.004	(0.157)
Education of head	–0.466	(–1.144)	0.168	(1.137)	–0.051	(–0.542)
Distance to plot	0.024	(1.678)	–0.101	(–1.729)	–0.078	(–4.044)***
Area of plot	0.004	(3.109)**	0.002	(0.229)	0.011	(1.650)
Elevation	0.002	(1.831)	–0.007	(–1.208)	–0.002	(–0.550)
Good soil	–0.163	(–0.480)	1.938	(2.336)*	0.777	(1.978)*
Access to chainsaw	–0.030	(–0.171)	0.107	(0.088)	–0.527	(–0.665)
Number of cattle	–0.015	(–1.902)*	–0.026	(–0.987)	0.057	(0.860)
Months of off-farm labor	0.005	(0.753)	0.180	(1.909)*	–0.067	(–0.865)
Government credit	0.061	(2.642)**	0.530	(2.510)**	0.332	(2.857)**
First language Spanish	–0.548	(–2.134)**				
Depot *ejido*	1.212	(1.985)*				
Distance to nearest market	0.074	(2.524)**				
Distance squared	–0.001	(–2.045)*				
Vehicle ownership	0.504	(2.812)**				
Selectivity term (sell = 1)			0.447	(0.273)		
Selectivity term (sell = 0)					–2.274	(–2.612)**
Constant	–2.210	(–2.565)*	–0.352	(0.19)	1.394	(0.92)
R^2			.45		.37	
Observations	187		78		109	

Note: T-statistics appear in parentheses.
*Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1% level.

ECONOMETRIC RESULTS

STAGE 1: THE DETERMINANTS OF SELLER STATUS FOR MAIZE

Results from the first-stage probit analysis used to identify the determinants of seller status are presented in Table 2. Turning first to the identifying variables, it is seen that the signs on most of the coefficient estimates are consistent with intuition. The dummy variables indicating the favorably situated ejido and vehicle ownership are both positive, likely reflecting the lower costs of information gathering and increased accessibility. The other measure of information-gathering costs, the Spanish language dummy, unexpectedly has a negative and significant coefficient. This finding may be a consequence of cultural attributes that make Mayan farmers, from whose ancestors the milpa system of maize cultivation evolved, more likely to sell that crop. Distance to market has a nonlinear effect on the probability of seller status, first increasing and then decreasing.

The signs on most of the remaining variables are also consistent with intuition. Access to credit and a larger land endowment positively affect the probability of seller status, with the latter result likely due to the fact that with more land, farmers are able to extend the fallow period, thereby increasing the land's productivity for future use in the cycle. Cattle ownership decreases the probability of seller status, which is probably a consequence of pasture creation removing land from the maize fallow cycle. Finally, the labor endowment and the distance from the household to the plot are statistically insignificant.

Stage 2: The Determinants of Area Cultivated in Maize

With the inverse Mills ratio included as a regressor to control for selectivity bias, the next two models in Table 2 test hypotheses concerning the determinants of maize cultivation for the sellers and nonsellers of that crop, respectively. Sample selectivity appears to be an issue only in the nonseller regression, with the negative coefficient on the inverse Mills ratio likely reflecting the influence of unobservable variables that lead a nonseller to plant less maize than a household selected at random (Goetz 1992). The most noteworthy distinction revealed by the model is the asymmetric effect of the consumption index. This variable is significant in the nonseller regression while it is insignificant among the sellers, thereby lending support to the hypothesis that the latter regime reaches their production decision independent of consumption considerations.[9]

Other than the consumption index, however, there are few variables that suggest a distinctly different behavior between the two regimes. Consistent with intuition, the dummy variable indicating favorable soil and the credit index are positive and significant in both models. Likewise, the labor index is also seen to be positive and significant in the two models. Although in this case we had no a priori predictions, this finding likely reflects the household's endogenous valuation of its own labor due to some combination of limited opportunities for off-farm employment, limited availability of labor for hire, and potentially higher monitoring costs associated with hired labor. Differential effects are seen with respect to the variables measuring the total family months allocated to nonfarm labor in the previous year, the age of the household head, and the distance separating the household from its agricultural plot. The former two are positive and significant for the sellers only, while the latter is negative and of roughly the same magnitude for both groups but significant for the nonsellers only.

Chili Peppers

The final model investigates the determinants of commercial chili pepper production with an application of Heckman's sample selection model. To allow for

TABLE 3. Heckman Model of Producer Status and Hectares Planted in Chili Peppers

Variable	*Selector Equation*		*Regression Equation*	
Consumption index	0.277	(1.669)*	–0.310	(–1.095)
Labor index	0.075	(1.146)	0.092	(1.827)*
Age of head	–0.030	(–2.522)***	0.008	(0.629)
Education of head	–0.147	(–2.361)**	0.090	(1.006)
Distance to plot	0.029	(1.225)	0.009	(0.409)
Area of plot	–0.001	(–0.332)	0.003	(1.179)
Elevation	–0.006	(–2.260)**	0.001	(0.577)
Good soil	0.171	(0.484)	0.048	(0.175)
Access to chain saw	0.092	(0.324)	0.547	(1.868)*
Number of cattle	–0.019	(–1.781)*	–0.029	(–1.305)
Months of off-farm labor	–0.056	(–2.785)***	0.030	(0.822)
Government credit	0.105	(2.351)**	0.122	(1.592)
First language Spanish	0.184	(0.681)		
Depot *ejido*	–0.371	(–0.484)		
Distance to nearest market	–0.015	(–0.501)		
Distance squared	0.000	(0.205)		
Vehicle ownership	0.612	(1.351)		
Constant	2.455	(2.022)**	–0.264	(–0.327)
Selectivity term			–0.548	(–1.620)*
Log-likelihood = –30,248				
Wald chi-square = 35.76*				
Observations = 187				

Note: *Z*-statistics appear in parentheses.
*Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1% level.

qualitative comparisons, the specification includes the same variables in the selector and regression equations that were used in the model for maize. The results presented in Table 3 suggest that the many of the factors determining both the participation and production decisions for chili are different from those of maize. Included among the statistically significant determinants of the market participation decision for chili are the consumption index, the age and education of the household head, months allocated to off-farm labor, and the elevation of the plot, none of which were significant determinants of the market participation decision for maize. The remaining two statistically significant variables, cattle ownership and credit, are also significant for the case of maize and of the same sign. Overall, it appears that the household's pool of available labor, as captured by the demographic indices and by the months allocated to off-farm labor, is an important factor in determining the decision to enter the chili market. This finding may relate to the fact that the harvest for chili occurs over a highly concentrated time span during which the family must harness its entire stock of labor, both skilled and unskilled. Those households heavily committed to the off-farm labor market may thus be deterred from planting chili. It is also notable that the coefficient on distance to market and its square are statistically insignificant. This may result from differences in the marketing networks of maize and chili. Whereas maize is generally transported by the farmers themselves, chili is transported by marketing intermediaries locally referred to as *coyotes* who typically purchase the harvest at or near the site of the farmer's field. While none of the identifying variables are individually significant, the overall appropriateness of the selector equation specification is supported by a significant estimate for the sample selection parameter.

Turning to the regression results, only two variables are seen to be statistically significant in explaining the area planted in chili: the labor index and ownership of a chainsaw, the former of which was also significant for the case of maize. Consistent with expectation that the household's valuation of chili is determined exogenously by the market price, the consumption index has no statistically significant effect in determining the area cultivated. That the chainsaw dummy is positive and significant, contrasting with the case of maize, underscores the reports of many farmers to only clear plots having mature trees for planting chili.

Marginal Effects and Policy Implications

The above models have demonstrated that households facing idiosyncratic differences in the transaction costs of market participation will exhibit differences in production behavior according to seller status. Returning to the land-use and deforestation policy question raised in the introduction, it is of interest to move beyond assessing the statistical significance of the coefficient estimates to also consider their magnitude. To this end, we focus on two variables that potentially could serve as policy tools, credit and travel distance to the farm plot, both of which were identified as significant determinants of maize cultivation. Specifically, we wish to compare our results to those based on a framework that ignores the possibility that households are differentially integrated into product markets, as is the common approach in the land-use literature.

We begin by noting that when the exogenous variables of interest appear in both the selector equation and regression equations of the switching regression model, there are a number of alternative approaches to calculating their associated marginal effects (Maddala 1983; Dolton and Makepeace 1987; Huang, Raunikar, and Misra 1991; Goetz 1992). One approach is to simply refer to the coefficient estimate of the regression equation itself. This estimate has been euphemistically referred to in the literature as the potential or "desired" effect, though whatever economic content such an interpretation carries generally receives little elaboration. More relevant interpretations are derivable by calculation of what are called the *conditional* and *unconditional* marginal effects. The former is calculated separately for each regime, using information conditional on the observation being in that regime. As such, this estimate is used when the objective of the analysis is to understand decision making for a specific subset of observations while adjusting for selectivity biases. Conversely, the unconditional marginal effect is calculated based on information from the entire sample and is appropriate when the objective is to assess the effect of an exogenous variable irrespective of the regime. This effect can further be decomposed into a quantity response from those already in one of the two regimes and an adjustment factor for selectivity bias resulting from entry or exit from the regimes (McDonald and Moffitt 1980; Huang, Raunikar, and Misra 1991).

We examine these different interpretations by focusing on maize, as this is the crop that virtually all farmers in the region cultivate but that less than half choose to sell. With respect to the two policy variables noted above, Table 4 compares the coefficient estimates from an identically specified "straw man" ordinary least squares (OLS) regression that pools the sellers and nonsellers with the potential, conditional, and unconditional marginal effect calculations from the switching regression model. While comparison of the OLS and conditional coefficients reveal only minor differences, more substantial discrepancies emerge with reference to the unconditional effects. This is particularly the case with the travel distance to plot measure, which undergoes a counterintuitive sign shift for the seller regime. The source of this shift is revealed by the decomposition of effects into quantity and selectivity adjustment components. The selectivity adjustment is positive and of higher absolute magnitude than the quantity response, which retains the intuitive negative sign. The unconditional marginal effect for the sellers thus suggests that increased travel distance unexpectedly increases the area in maize cultivated. To the extent that travel distance proxies for the farm-gate price received by the household, this result may reflect the perverse supply response that is often said to characterize farm systems in the intermediate stages of market integration (e.g., Medellin, Apedaile, and Pachico 1994). Therefore, from a policy perspective, it is quite possible that measures to reduce travel costs (e.g., road building) will elicit outcomes that are not predicted by models predicated on the assumption of profit-maximizing farm households. While there is not the dramatic sign shift for the credit variable, the magnitudes are different, leading to different predictions of the responsiveness of farmers to exogenous changes in government credit availability.

Conclusions

The empirical results presented in this article highlight the analytical advantages of distinguishing the determinants of land-use decisions according to the household's relationship with the market. By controlling for the endogeneity of the market participation decision and subsequently estimating separate regressions by seller status, the switching regression model revealed a number of differences in land-use determinants that otherwise would not have been detected. Moreover, the methodology permitted these effects to be assessed in terms of both conditional and unconditional effects.

TABLE 4. Comparing Marginal Effects

Variable	Ordinary Least Squares Regression: Entire Sample	Conditional Effects		Unconditional Effects = Quantity Response + Selectivity Adjustment	
		Sellers[a]	*Nonsellers*[b]	*Sellers*[c]	*Nonsellers*[d]
Distance to plot	–.075	–.083	–.087	.014 = –.036 + .050	–.077 = –.050 + –.027
Government credit	.507	.577	.308	.319 = .189 + .130	.143 = .214 + –.071

a. $E(y_1 \mid S = 1)/\partial x = \beta_1 + \tau\sigma_{1u}[(\tau' Z_i)w_1 + w_1^2]$.
b. $E(y_2 \mid S = 0)/\partial x = \beta_2 - \tau\sigma_{2u}[(\tau' Z_i)w_2 - w_2^2]$.
c. $E(y_1)/\partial x = \beta_1\phi(.) + \tau\varphi(.)[\beta'_1 X_{1i} + (\tau' Z_i)\sigma_{1u}]$.
d. $E(y_2)/\partial x = \beta_2[1 - \phi(.)] - \tau\varphi(.)[\beta'_2 X_{2i} + (\tau' Z_i)\sigma_{2u}]$.

The most general finding of the article is that the agricultural household's relationship with the market is important for explaining how it reaches both semi-subsistence and commercial land-use decisions. In the case of the semi-subsistence crop, maize, the significance of the consumption index was argued to be a result of market imperfections for output; while in the case of the commercial crop, chili, the consumption index was, as predicted, an insignificant determinant of area cultivated. In both the models of maize and chili, the household's labor endowment was positive and significant, likely reflecting the existence of thin markets for labor.

While the findings presented here address the land uses that displace forests rather than the clearance process itself, they do have important implications for forest conservation policies. Most important, they suggest that policy instruments that rely on market-based parameters may not have the intended effect in influencing peasant land-use choices if they are not complemented by policies that also reduce the transaction costs of market participation. The reason, as illustrated by the nonseparable agricultural household model, is the prohibitive transaction costs that restrict peasants in their responses to market incentives and constrain them to reach their production decisions with reference to household-specific supply and demand conditions. In this regard, this study complements the existing literature that focuses on forest clearance by illuminating the underlying behavioral incentives and constraints of frontier land managers, which in turn suggests a reexamination of some well-established empirical findings.

The positive effect of roads on deforestation, for example, has almost exclusively been analyzed as a consequence of profit-maximizing behavior. Building new roads is said to exacerbate the rate of deforestation by making access to remote, forested areas less costly, thereby increasing the farm-gate price received for agricultural outputs and the resulting returns to clearing lands for agricultural use. This effect, however, may be more a story of migration than one of locational rents defined by profits from production. The road subsidizes the costs of encroachment and clearance, regardless of whether this is in response to subsistence or market incentives. While the outcome, deforestation, may be the same, the behavior that results in this outcome is not, and this has important implications for policy over the longer run once initial access is established. If the decision rules that drive land-use change are primarily subsistence-based, then standard policy measures to influence the rate of this change may have a muted or unintended effect that could not be predicted by the profit-maximizing framework.

In a broader sense, this research has demonstrated that the conditions on which the separable model rests for its validity—profit-maximizing agents operating in competitive markets—may be too stringent for the conditions that typically prevail in agricultural frontiers. This is not to argue for the complete rejection of the separable model but rather to suggest that deforestation should not necessarily be analyzed as a consequence of profit-maximizing behavior for the purpose of policy formulation. Robust models of land-use change necessitate theoretical and empirical approaches that are sensitive to the local market conditions faced by land managers. This sensitivity can be achieved through a careful scrutiny of whether existing market constraints, if there are any, require the use of a nonseparable framework to understand land-use decision making.

NOTES

1. Cropper, Griffiths and Mani (1999) used a measure of road density to capture the effect of roads. In this regard, the authors identify their model as nonspatial (p. 60), in contrast to the spatial model of Chomitz and Gray (1996), which includes a measure of distance to road. However, in both cases, the authors are controlling for the spatial issue of market access.

2. Roughly 7 percent of households had access to multiple, noncontiguous plots. In the majority of these cases, cultivation occurred on only one of these plots for the year of questioning.

3. Article 27 was promulgated following the peasant-led revolution of 1910 and sanctioned the return of lands that had been appropriated by large haciendas to peasant communities. In 1992, reforms were enacted that terminated the continued extension of *ejidal* land grants. In addition, the reforms gave *ejidatarios* the right to rent or sell their land and to enter into business arrangements with outside investors, all of which were prohibited under the original terms of Article 27. While the long-run consequences of these reforms are potentially profound, research by Klepeis (2000) suggests that they have had minimal impact on smallholder farmers in the region to date.

4. Of these studies, Omamo's (1998a, 1998b) are the only ones that investigate implications for land use, focusing on the relationship between the transaction costs of market participation and the mix of commercial and staple crops.

5. Thirty-one percent of household heads spoke an indigenous language, usually of Mayan origin, as their native language.

6. Strictly speaking, the separable model predicts the insignificance of demographic variables on maize cultivation for both the seller and buyer categories of households. While 26 percent of the households in the sample reported themselves to have occasionally purchased maize for the survey year, the analysis merges these households with the self-sufficient producers under the assumption that the two categories apply an identical operating logic to the productive resources available. Maize cultivation is the principal occupation of most household heads, particularly among the buyers. As a result, we assume that any purchases of maize were more likely to be the result of unexpected shortages relative to domestic consumption rather than of planned production targets.

7. In a study of labor markets in Mexico's *ejidatario* sector, these authors present persuasive theoretical and empirical evidence to support the proposition that skilled labor (defined by nine or more years of schooling) only works in off-farm employment.

8. Following Pichón (1997), children were weighted by one-third to approximate their consumption requirement relative to adults.

9. One caveat regarding this finding is that no distinction was made between the ex ante decision of how much maize to plant and the ex post decision of how much to sell. The latter decision is partly determined by the quantity of realized output, an amount the farmer cannot be sure of at the time of planting. Hence, the observance of market participation ex post is not a sufficient condition for the specification of a non-recursive (i.e., profit-maximizing) model, since ex ante the farmer may still be reaching his decision on the basis of the consumption requirements of the household. A high level of risk aversion could exacerbate this problem by leading households to plant an area far larger than that required to feed the family in an average year, thereby increasing the likelihood that they have a surplus for sale. One empirical implication of this feature is that the seller category may consist partly of households that are reaching their decisions with reference to consumption considerations, which would increase the chance of falsely rejecting separability for this group.

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