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A spatial analysis of common property deforestation ☆

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Abstract

This paper develops and tests a theory of common property deforestation over space. The model examines both the spatial distribution of forest loss and the total amount of deforestation within a given community, showing how these outcomes are jointly determined. The model equations are estimated in a four-step process using data from 318 Mexican common properties. In contrast to previous deforestation theories, this paper shows that the allocation of deforestation across space is dependent upon both the absolute and relative quality and location of each hectare of land in the same community and on the overall deforestation decision of the community. Simultaneously, total deforestation depends upon the value of deforested land, which is determined by its physical attributes, as well as the characteristics of the community that affect its collective choice problem. Smaller group size, higher secondary education, and greater inequality correspond to lower deforestation.

Keywords: Deforestation; Common property resources; Spatial analysis; Inequality

1. Introduction

The depletion of forests in developing countries, particularly tropical forests, has been of increasing concern to policymakers over the past 25 years. This focus has largely been due to the fear of species and carbon sequestration loss, in addition to local negative externalities such as decreased water quality and increased soil erosion. Pinpointing the location of forests at risk of deforestation provides a crucial piece of information for developing effective forest protection policy. Vulnerability to forest loss, combined with knowledge of the value of each piece of forest, tells policymakers exactly which forests to prioritize for interventions [1,36,18].

Mexico finds itself at the heart of the deforestation debate as it considers new policy options to regulate its high rate of forest loss, which at 1.3% per year is similar to that of Brazil [41]. According to the Mexican National Forestry Commission (CNF), 80% of the country's forests are located in ejidos, communities

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resulting from the postrevolution land reform which hold their forest lands as commons. Their large forest holdings make them the fundamental place to address the deforestation problem. The common property nature of Mexico's deforestation dilemma is far from unique. Though an exact measure of the total amount of world forest in common property is not available, two recent reports by Forest Trends estimate that 370 million ha (compared to the 470 million ha worldwide in preserves) qualify as "community-managed"[1] [27,47]. These forests are not limited to developing countries, though they are more abundant there, and can be found in the US and Europe as well.

Deforestation studies have preoccupied social scientists for some time. Much early research focused on cross-country determinants of deforestation. Cropper and Griffiths [19] estimate the effect of population and economic growth on deforestation in tropical countries, finding a positive effect for the former, though only in Africa, and a small but positive effect of the latter. Further evidence of the positive effect of population growth on deforestation can be found in Allen and Barnes [3] and Rudel [40]. Deacon [21] illustrates the importance of political instability and population growth in determining deforestation rates in the 1980s, and presents a convincing case for the importance of ownership security in Deacon [22]. Vincent has written extensively on trade, forest management, and deforestation, pointing out both situations where government policies distort market signals [45,46] and where they can be applied to increase efficiency [10,11]. A useful review of this literature is given in Barbier [7].

The empirical microlevel literature on deforestation using satellite imagery is relatively recent. Panayotou and Sungsuwan [33] conducted one of the earlier studies, linking satellite images of Thailand with population, price, and infrastructure data, and finding population density to be the most important determinant of deforestation. Nelson and Hellerstein [30] provide another early example of the use of geographical data to analyze land use decisions. A particularly influential paper was Chomitz and Gray [14]. The model they present, that of a profit-maximizing farmer who chooses to put a given piece of land into its most profitable activity has, with minor modifications, been the basis of many subsequent papers. Analysis at the municipal or pixel level (where a pixel is the smallest possible unit of geographical analysis determined by the resolution of the available data) has been used to operationalize this approach. Papers with pixel-level analysis include Puri and Griffiths [38], Monroe et al. [28], Godoy and Contreras [24], and Vance and Geoghegan [43], while Deininger and Minten [23] and Pfaff [35] are municipal level studies, and Chomitz and Thomas [15] use census tract level data. The empirical strategy in this case generally takes the form of a probit (or tobit) of deforestation on absolute physical attributes of a pixel, such as slope, altitude, and distance to a road or city center. In addition, municipal or household characteristics are sometimes included to control for their effect on demand for forest conversion. While most empirical papers consider each piece of land in isolation, one important exception is Stavins and Jaffe [42], who take considerable effort to show how heterogeneity in land quality affects conversion of individual wetland areas. More recently, Robalino and Pfaff [39] look at interactions between neighboring hectares of forest and find that, using the attributes of neighboring parcels as an instrument, actions taken on adjacent pieces of land influence the deforestation decision of a given piece of forest.

This paper's strategy differs in two ways from the established literature. First, the unit of analysis is chosen to be the de jure unit of decision-making, in this case the community. Second, I construct a structural model that allows us to explore the questions of both *where* within community boundaries and *how much* deforestation occurs in total in a given ejido. These decisions are jointly determined within the community.

I will show that the first innovation implies that in addition to the absolute physical attributes of individual hectares of land, the relative attributes of the land within the decision-making community are key determinants of the location of deforestation. The model indicates that the probability of deforestation for 2 ha of forest with equivalent characteristics located in different communities may differ for two reasons. First, each hectare may be located in a different place within the community's land distribution. Second, the solution to the collective demand for forest conversion may be different in the two communities, which changes the probability of deforestation for every parcel within ejido boundaries. Simultaneously, this overall deforestation decision varies both with the quality of the best hectares of land and with variables,

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[1] This category includes both government owned forested lands allocated for use to local communities and those owned directly by "local community groups" [47, p. 5–6].

like group size and inequality, that affect the community collective choice problem, which can range from non-cooperative to socially optimal.

The theory suggests a system of equations which are estimated using data from 318 ejidos surveyed in 2002 to explain the probability of deforestation of a given hectare of land and total deforestation in the community, where these two relationships are interdependent. A four step strategy is used to estimate the system with bootstrapped standard errors to account for the inclusion of predicted values. I also examine some of the implications of spatial dependence for this estimation technique.

The results corroborate the predictions of the theory. In brief, they show that given an aggregate deforestation level, it is the characteristics of a piece of land relative to all of the other hectares considered jointly within the decision-making community that drive the deforestation decision across space. Increases in the demand for new pasture land result in the conversion of increasingly less profitable hectares of forested land. On an aggregate level, forest conversion decreases with the average distance, slope, altitude, and the variance of the slope of the relatively more profitable parcels. The effect of group size on deforestation is positive, consistent with Olson's [32] finding that cooperation is hindered by larger groups, while that of secondary education is negative. Finally, in contrast to Cardenas [12] and Dayton-Johnson [20], the estimates show that inequality is associated with a significant and substantial decrease in overall deforestation.

The paper is organized as follows: it begins by describing the data and some key characteristics that motivate the design of the model. Section 3 presents a simple spatial/common property deforestation model, Section 4 the empirical strategy, and Section 5 results of the estimations. The final section concludes.

2. Data description and background on ejidos

Ejidos are composed of both private and commons land. By law, the forest must be in the commons. The size and distribution of the private parcels are features determined at the founding of each ejido, the date of which varies from community to community. Rights to a parcel and use of the commons are passed on to only one family member per ejidatario, so membership has been constant over time. There is one caveat to this statement. A 1992 land reform law allowed for the integration of new members and the allocation of land to them. In order to circumvent the possible endogeneity of this group expansion or land redistribution, I use the pre-reform membership size and land distribution characteristics in this study.

All ejidos have the same basic institutional structure: every 2 years they elect a community council whose minimal composition includes a president, treasurer, secretary, and 'comité de vigilancia', which is a combination of ombudsman and policeman. A person cannot serve on the council for two consecutive terms although he can be re-elected after a one-term hiatus. Communities make decisions in general assemblies which occur on a monthly or bimonthly basis, where decisions are taken by majority rule or, in some cases, by unanimity.

The ejido data come from a survey of 450 forest-holding ejidos conducted throughout Mexico in 2002. These communities were selected at random from all the ejidos in the country with forest holdings greater than 100 ha in 1994. A map of the sample is shown in Fig. 1. The survey consisted of two sections, a community questionnaire and a household questionnaire. Respondents were three to four members of the community council. The community questionnaire collected basic characteristics of the community, including information on forest exploitation and governance. The household questionnaire, applied to 50 randomly chosen ejidatarios (members of the ejido), was an indirect survey where information was collected from one key informant. The relevant individual level data for this study is household size, age of household head, land and cattle holdings, and use of the commons. Out of the entire sample, I use only the 324 communities that do not have forestry projects. Communities that undertake active wood exploitation are very likely subject to a different deforestation dynamic than those that do not (this dichotomy is detailed in [2]).

Mexico's National Ecology Institute (INE) provided the National Forestry Inventories for 1994 and 2000 which are used to calculate forest loss. The inventories are based upon maps of scale 1:250,000 and 1:125,000, respectively. Though initially not comparable, the maps have been reinterpreted for comparability by the Institute of Geography at the Autonomous University of Mexico. The details of this process are described in Velasquez et al. [44]. A grid of 1 ha squares over the forested area serves as the primary spatial unit of analysis. These units are referred to as 'hectares of land' or 'hectares' in the text that follows. Slopes and altitudes have

Fig. 1. Map of survey sample.

Table 1
Summary statistics on deforestation, 1994–2000

Characteristic	Mean	SD
Number of ejidos	318	
Increase in pasture/agricultural land, 1994–2000 (ha)	234	562
Area in pasture, 1994 (ha)	998	1701
Total ejido area (ha)	3888	5956
Percentage of ejidos with deforestation (%)	59	

been calculated using digital elevation models of scale 1:250,000. Municipal data for 1990 and 2000 come from the National Institute of Statistics and Geography (INEGI), and state-level agricultural prices from CIMMYT's online data base [16].

Table 1 shows summary statistics on deforestation. Although there were 324 ejidos not practicing forestry in the sample, in order to focus on the majority rather than the outliers, 3 observations (1% of the sample) were cut from each tail of the distribution overall deforestation, leaving us with 318 communities. The rejected observations include communities with over 8000 ha of forest loss over the period and those with over 2500 ha of forest increase.[2] Overall increase in pasture land per community between 1994 and 2000 is 234 ha, with a wide variance, and a substantial portion of the communities (41%) do not deforest at all, or have increased in their forest cover over the period. The total forest coverage in the sample in 1994 is 919,959 ha, 73,848 (8%) of which are lost in the period between 1994 and 2000. According to the 2000 Forest Inventory, around 50% of the Mexican territory is covered with forest. The overall deforestation rate in Mexico between 1994 and 2000 is 1.3% [41], which is similar to the 1.4% per ejido per year found in the sample.

In order to guide the analysis of the forces driving deforestation, survey participants were asked to report up to two reasons why a given area of the ejido was deforested and who made the decision. Although there is missing information in some of the ejidos with deforestation, the results are instructive. The responses clearly show that the expansion of agriculture and pasture land are equally important as sources of forest conversion. The felling of forest for these uses dominates the other two possibilities. Fifty percent of respondents gave

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[2] The 2% trimming was tested against trimming off 5% of the total observations. Both produced coefficients within the same confidence intervals.

Table 2
Positive responses to the question: "Who decided to expand the pasture/agricultural land?"

Decision-maker	Pasture expansion (%)	Agricultural expansion (%)
Community assembly	31.5	40.7
Committee decision	2.2	4.6
Just happened	65.2	54.6
Just happened and have rules	20.0	44.7
Observations	88	86

expansion of agriculture and 51% pasture as their main reasons for conversion. Forest fires came in a distant third with 9%, and deforestation for wood extraction is practically non-existent (4%).

Respondents also reported who made the decisions regarding forest conversion. The results are summarized in Table 2. In the case of both agricultural and pasture expansion, the majority of respondents said that conversion "just happened," suggesting a community choice not to explicitly regulate forest management. In the communities where expansion of the agricultural frontier "just happened," there is often some sort of formal regulation—either a limit on the allowable heads of cattle or a permission that must be granted by the council president. The last row of Table 2 shows the percentage of communities where deforestation "just happened" that have some explicit existing rules governing agricultural or pasture expansion—20% in the case of former and 44% for the latter. In addition, a sizable number of communities, 32% in the case of pasture and 48% for agriculture, also responded that permission was given by the community assembly, which implies that it was decided by a formal vote. For those that had expansion due to both factors, 89% of the time the same decision rule was used in both cases.

Table 2 shows a range of cooperation more complicated than the traditional prisoner's dilemma dichotomy. In a sizable number of cases, communities make a concerted decision to approve deforestation activities. This process could be characterized as a high level of cooperation. Those communities where deforestation "just happens" and there are no existing rules have chosen *not* to regulate conversion and leave this decision up to individual farmers. In this case there is zero cooperation. In the middle, between full cooperation and no regulation, there are communities where deforestation "just happened" and rules have been implemented. These facts suggest that there is a continuum of community control over activities in the commons which ranges from a centralized planning approach to a nearly complete lack of regulation. One model that explains this kind of partial cooperation continuum in common property deforestation can be found in Alix-Garcia et al. [2]. McCarthy et al. [26] develop an alternative model of partial cooperation in ejido pastures. A similar phenomenon was observed by Newbery [31] in the context of acid rain in Europe. Newbery's insight inspired a large literature on partial cooperation in global environmental agreements [8,9,13,34], with the basic result being that subcoalitions of cooperators can exist even in the presence of non-cooperators. The ejidos, small communities where social pressures can be powerful, can often have quite effective mechanisms for enforcing cooperative agreements (see [5] for examples of these types of mechanisms in other countries). The model and estimation strategy proposed here reflect the fact that the choice of cooperation level may be continuous, rather than one of distinct regimes.

3. Model

The standard deforestation model is appropriate for the case where there is one landowner making a decision over one plot. In the situation where a group of people must decide what to do over a large, well-defined space composed of many plots, the model must be extended. The intuition for the model discussed in this paper is as follows. It contains two jointly determined components, total deforestation level and the spatial allocation of this decision. The decision of which hectares to deforest depends both upon their value in agriculture/pasture (heretofore abbreviated as pasture) relative to the value of other hectares of land in the community as well as upon the aggregate demand for pasture in the ejido. This overall demand is determined both by the quality of the most profitable hectares of forested land and the community variables which affect members' demand for new agricultural land (like secondary education and distance from markets) and, since this paper considers common property, features that impact collective action (group size and inequality). These relationships give a system of equations describing equilibrium deforestation for each community.

The main insights of the model are as follows: 2 ha with exactly the same physical characteristics may have different probabilities of deforestation for two reasons. First, their relative standing amongst all the other forested hectares in a community is different. For example, a hectare that is 3 km away from houses may have a very high probability of deforestation if it is the closest forested hectare available, and a very low one if there are many hectares of land that are less than this distance from the same houses. Second, even if both hectares have the same relative physical characteristics, one may have a higher probability of deforestation because the overall demand for pasture in that community is higher. Similarly, two communities' overall deforestation demand may differ for two reasons. The characteristics of their individual members and their aggregate community characteristics may differ, thus changing their collective choice problem, or one may have a higher productivity in agricultural activities. Even in two communities with equivalent social characteristics, however, the total deforestation decision may be different because the physical characteristics of their available land are distinct.

Formally, each ejido is concerned with maximizing the revenue from converting forest land to pasture. Revenues from deforestation depend upon the amount of land deforested, C, the amount of land in forest and in pasture in the base period, T^{f} and T^{p}, the prices of goods produced in the forest or pasture, p^{f} and p^{p}, and assets useful in the production of forest products, X^{f}, and pasture products, X^{p}. Since the forested area is common property, revenue generation is also dependent upon community characteristics, Z, which make cooperation more difficult, such as group size or income inequality. Finally, the revenues depend upon the relative value of the land for pasture or forest production. This is expressed as a net gain in pasture quality, $\bar{\pi}^{\mathrm{p}} - \bar{\pi}^{\mathrm{f}}$, where $\bar{\pi}^{\mathrm{p}}$ and $\bar{\pi}^{\mathrm{f}}$ are the average quality of the land in pasture and forest production. Given this notation, the revenue function can be written as

$$R(C, T^{\mathrm{p}}, T^{\mathrm{f}}, p^{\mathrm{p}}, p^{\mathrm{f}}, X^{\mathrm{p}}, X^{\mathrm{f}}, Z, \bar{\pi}^{\mathrm{p}} - \bar{\pi}^{\mathrm{f}}).$$

Each hectare of forested land is characterized by quality q and distance d to the population center (transactions costs). Let $g(q,d)$ be the joint distribution of these two traits over the forested land. In a given community, q ranges from q_L to 1 and d from 0 to D. Quality and distance of the forested land determine an index of quality in pasture or agricultural production $\pi^{\mathrm{p}}(q,d)$ and in forest production $\pi^{\mathrm{f}}(q,d)$. The pasture index is more sensitive to both land quality and distance, because of the frequent travel required to oversee animals or crops. The assumptions are: $\frac{\partial \pi^{\mathrm{p}}}{\partial q} > \frac{\partial \pi^{\mathrm{f}}}{\partial q} > 0$ and $\frac{\partial \pi^{\mathrm{p}}}{\partial d} < \frac{\partial \pi^{\mathrm{f}}}{\partial d} < 0$ for all values of q and d. Let $\delta(q,d)$ be the proportion of a hectare of land with qualities q, d converted to pasture from the standing forest. This allows us to write the average quality of deforested land in pasture as

$$\bar{\pi}^{\mathrm{p}} = \int_0^d \int_{q_L}^1 \delta(q,d)\pi^{\mathrm{p}}(q,d)g(q,d)\,dq\,dd.$$

A similar expression denotes the productive quality of this same land were it to have remained in forest:

$$\bar{\pi}^{\mathrm{f}} = \int_0^d \int_{q_L}^1 \delta(q,d)\pi^{\mathrm{f}}(q,d)g(q,d)\,dq\,dd.$$

The problem for the ejido is therefore to maximize total revenue by choosing the amount of forest to convert into pasture, C, the proportion of each parcel of land to convert, $\delta(q,d)$, $\bar{\pi}^{\mathrm{p}}$, and $\bar{\pi}^{\mathrm{f}}$:

$$\max \quad R(C, T^{\mathrm{p}}, T^{\mathrm{f}}, p^{\mathrm{p}}, p^{\mathrm{f}}, X^{\mathrm{p}}, X^{\mathrm{f}}, Z, \bar{\pi}^{\mathrm{p}} - \bar{\pi}^{\mathrm{f}}) \tag{1}$$

s.t.

$$\bar{\pi}^{\mathrm{p}} = \int_0^d \int_{q_L}^1 \delta(q,d)\pi^{\mathrm{p}}(q,d)g(q,d)\,dq\,dd, \tag{2}$$

$$\bar{\pi}^{\mathrm{f}} = \int_0^d \int_{q_L}^1 \delta(q,d)\pi^{\mathrm{f}}(q,d)g(q,d)\,dq\,dd, \tag{3}$$

$$\frac{C}{T^{\mathrm{f}}} = \int_0^d \int_{q_L}^1 \delta(q,d)g(q,d)\,dq\,dd \tag{4}$$

and

$$0 \leqslant \delta(q,d) \leqslant 1. \tag{5}$$

Eq. (4) simply indicates that the sum of the deforested hectares must equal the total deforestation in the ejido. The Lagrangian of the problem is written as

$$\begin{aligned} L = {} & R(C, T^{\mathrm{p}}, T^{\mathrm{f}}, p^{\mathrm{p}}, p^{\mathrm{f}}, X^{\mathrm{p}}, X^{\mathrm{f}}, Z, \bar{\pi}^{\mathrm{p}} - \bar{\pi}^{\mathrm{f}}) + \mu^{\mathrm{p}}\left(\int_0^d \int_{q_L}^1 \delta(q,d)\pi^{\mathrm{p}}(q,d)g(q,d)\,dq\,dd - \bar{\pi}^{\mathrm{p}}\right) \\ & + \mu^{\mathrm{f}}\left(\int_0^d \int_{q_L}^1 \delta(q,d)\pi^{\mathrm{p}}(q,d)g(q,d)\,dq\,dd - \bar{\pi}^{\mathrm{f}}\right) + \lambda\left(\int_0^d \int_{q_L}^1 \delta(q,d)g(q,d)\,dq\,dd - \frac{C}{T^{\mathrm{f}}}\right). \end{aligned}$$

Note that L is linear in $\delta(q,d)$, which implies that the solutions are corner solutions: $\delta(q,d) = 0$ or 1. Assuming interior solutions for C, $\bar{\pi}^{\mathrm{p}}$, and $\bar{\pi}^{\mathrm{f}}$, the first order conditions are as follows:

$$\mu^{\mathrm{p}}\pi^{\mathrm{p}}(q,d) + \mu^{\mathrm{f}}\pi^{\mathrm{f}}(q,d) + \lambda \geqslant 0 \;\Leftrightarrow\; \delta(q,d) = 1, \tag{6}$$

$$R_C(C, T^{\mathrm{p}}, T^{\mathrm{f}}, p^{\mathrm{p}}, p^{\mathrm{f}}, X^{\mathrm{p}}, X^{\mathrm{f}}, Z, \bar{\pi}^{\mathrm{p}} - \bar{\pi}^{\mathrm{f}}) - \frac{\lambda}{T^{\mathrm{f}}} = 0, \tag{7}$$

$$R_\pi(C, T^{\mathrm{p}}, T^{\mathrm{f}}, p^{\mathrm{p}}, p^{\mathrm{f}}, X^{\mathrm{p}}, X^{\mathrm{f}}, Z, \bar{\pi}^{\mathrm{p}} - \bar{\pi}^{\mathrm{f}}) = \mu^{\mathrm{p}} = -\mu^{\mathrm{f}}, \tag{8}$$

where R_π is the derivative of R with respect to $\bar{\pi}^{\mathrm{p}} - \bar{\pi}^{\mathrm{f}}$.

Since μ^{p}, μ^{f}, and λ are all ejido level variables, the hectare by hectare choice of where to deforest (6) shows that deforestation will proceed from the plots with the highest indicator function $\pi^{\mathrm{p}}(q,d) - \pi^{\mathrm{f}}(q,d)$ until the optimal value C is reached. Hence, forested hectares are ranked by decreasing value of the differential potential for pasture and forest, and land with the highest relative potential for pasture will be the first to be converted into pasture.

$$\pi^{\mathrm{p}}(q,d) - \pi^{\mathrm{f}}(q,d) \geqslant -\frac{\lambda}{\mu^{\mathrm{p}}} = \lambda^* \;\Leftrightarrow\; \delta(q,d) = 1, \tag{9}$$

where λ^* is defined by: $\frac{C}{T^{\mathrm{f}}} = \int_0^d \int_{q_L}^1 \delta(q,d)g(q,d)\,dq\,dd$. This decision can be rewritten as

$$\delta(q,d) = 1 \;\Leftrightarrow\; \operatorname{rank}(\pi^{\mathrm{p}}(q,d) - \pi^{\mathrm{f}}(q,d)) \leqslant \frac{C}{T^{\mathrm{f}}}.$$

In other words, whether a hectare is deforested or not depends upon its rank in terms of relative quality for pasture and forest, and on the optimal amount to be converted relative to the total area in forest. As the total demand for new pasture rises, the frontier moves towards more remote areas, possibly of lower quality. This implies that the probability of deforestation for a given parcel depends upon its position in the distribution of all the forested parcels in the ejido. This result is similar to Stavins and Jaffe's [42] insight into wetland conversion across counties in the United States. In fact, one could imagine applying a slightly modified version of the model presented here in order to accommodate individual landholders with heterogeneous areas of land. The prediction would still be that relatively more valuable hectares within the individual's land area would be cleared first.

Given this allocation decision rule, and the derived average $\bar{\pi}^{\mathrm{p}}$, $\bar{\pi}^{\mathrm{f}}$ (from (2) and (3)), the optimal area converted from forest to pasture, C, is given by

$$\frac{R_C(C, T^{\mathrm{p}}, T^{\mathrm{f}}, p^{\mathrm{p}}, p^{\mathrm{f}}, X^{\mathrm{p}}, X^{\mathrm{f}}, Z, \bar{\pi}^{\mathrm{p}} - \bar{\pi}^{\mathrm{f}})}{R_\pi(C, T^{\mathrm{p}}, T^{\mathrm{f}}, p^{\mathrm{p}}, p^{\mathrm{f}}, X^{\mathrm{p}}, X^{\mathrm{f}}, Z, \bar{\pi}^{\mathrm{p}} - \bar{\pi}^{\mathrm{f}})} = \lambda^*. \tag{10}$$

Total forest conversion is thus a function of the area of land in forest and pasture, the net gain in quality of the deforested land, community assets, prices, and community characteristics affecting the collective decision problem. The choice of how much forest to convert to pasture depends upon the profitability of the land that could be converted relative to its profitability in forest, where both are increasing functions of land quality and prices, and decreasing functions of distance. Decreasing marginal returns to pasture land imply that conversion is decreasing with the amount of already established pasture. Characteristics which increase cooperation increase the value of standing (common property) forest to the ejido, and therefore decrease forest conversion. The effect of total forest area on overall deforestation is ambiguous and depends upon returns to scale in the production of forest products.

This model does not allow for interactions between hectare decisions, which might occur if as clearing increased, marginal revenues decreased due to the effect on local output markets, or, alternatively, marginal costs increased through changes in labor or other input costs on local markets. There is no way of testing for these effects empirically, however, the "small player" assumption for the ejidos seems reasonable when one considers their size relative to the municipalities in which they reside. For example, the ratio of the average ejido membership to the working age population (ages 15–64) in their municipality is 0.019 (SD 0.06), and the ratio of the average deforested area between 1994 and 2000 to the total municipal area is 0.003 (SD 0.02). In the latter case one would like to use the ratio of the deforested area to arable land in the municipality, but this number is not available. It is certainly true that, for the ejidos in our sample that reported the number, agricultural productivity in the deforested areas is considerably lower than the averages available through the Ministry of Agriculture (SAGARPA) in Mexico. All of these facts together suggest that the likelihood of costs increasing due to the influence on local goods markets of the deforestation activities of particular ejido is quite low.

Eqs. (9) and (10) illustrate the simultaneous nature of the decision of how much and where to convert forest land into pasture. These two equations are the heart of the empirical strategy presented in the next section.

4. Empirical strategy

The equations to be estimated come directly from the model derived above. A linear specification of system (9)–(10) can be written as follows:

$$\delta^* = f(\mathrm{rank}(\pi^{\mathrm{p}} - \pi^{\mathrm{f}}), C, T^{\mathrm{f}}) = Q\beta^{Q} - C\beta^{C} + T^{\mathrm{f}}\beta^{\mathrm{f}} + \varepsilon \text{ and } \delta = 1 \quad (\delta^* \geqslant 0), \tag{11}$$

$$C = f(T^{\mathrm{p}}, T^{\mathrm{f}}, \bar{\pi}^{\mathrm{p}} - \bar{\pi}^{\mathrm{f}}, X^{\mathrm{p}}, X^{\mathrm{f}}, p^{\mathrm{p}}, p^{\mathrm{f}}, Z, \lambda^*) = \tilde{Q}\alpha^{Q} + T\alpha^{T} + X\alpha^{X} + p\alpha^{\mathrm{p}} + Z\alpha^{Z} + \mu, \tag{12}$$

where Q are variables representing the rank of a given plot in terms of relative quality for pasture and forest among forested plots, $\tilde{Q}$ includes variables that characterize the distribution of relative quality of the land among converted plots, p represents the vector $(p^{\mathrm{p}}, p^{\mathrm{f}})$, and X the vector $(X^{\mathrm{p}}, X^{\mathrm{f}})$.

Note that Eqs. (11) and (12) constitute a system in δ and C. In (11), C is identified through any of the variables that affect deforestation with the exception of quality—$X^{\mathrm{p}}, X^{\mathrm{f}}, p^{\mathrm{p}}, p^{\mathrm{f}}, Z$. The hectare-level probability of deforestation, δ, determines $\bar{\pi}^{\mathrm{p}} - \bar{\pi}^{\mathrm{f}}$, which is replaced by $\tilde{Q}$. The exclusion variables here are therefore those which proxy for quality—distance, slope, and altitude. We can thus proceed to the estimation of the deforestation equation (11) as one would in the general context of two-stage least squares, although in our case (11) is a set of probits for each ejido:

1. Estimate a reduced form probit for the individual hectare conversion. This is done by substituting (12) for C in (11) which gives the reduced form equation for hectare-level deforestation:
$$\delta^* = Q\gamma^{Q} + T\gamma^{T} + X\gamma^{X} + p\gamma^{\mathrm{p}} + Z\gamma^{Z} + \eta \text{ and } \delta = 1 \quad (\delta^* \geqslant 0). \tag{13}$$
2. Use predicted probabilities of deforestation to compute predicted values for $\tilde{Q}$ (in this case, substituting the average and standard deviation of the quality variables among plots that are expected to be deforested).
3. Estimate total converted land (12).
4. Eq. (11) can then be estimated using predicted converted land.

Steps 1, 3, and 4, with adjustment of the standard errors, are an efficient way of estimating a probit with a continuous endogenous variable [25,48]. The entire process is bootstrapped to account for the inclusion of predicted values into the main equations. In estimations of this type, it is quite reasonable to worry about spatial correlation of the error terms between neighboring hectares of forest. In a standard regression model, this correlation does not bias the coefficient estimates but does create inefficiency. The standard solution to this problem involves a weighting matrix whose entries reflect some estimate of the covariance between neighbors (see [17] for a good example of this). In a probit model spatial correlation does bias the point estimates of the coefficients in much the same way as heteroskedasticity does [4]. Although currently searching for a way to correct the potential bias introduced by this autocorrelation, existing techniques have not proved readily implementable in a data set the size of the one used in this study (for a discussion of spatial autocorrelation in the probit, tests, and estimation strategies, see [37]). In order to assess the severity of this problem, I present results from some diagnostic tests on the residuals from the model, and compare a linear probability model's coefficient estimates to that of the marginal effects of the probit.

5. Results

The traditional deforestation model suggests that slope, altitude, and distance from housing affect the probability of deforestation in the same way regardless of the slope, distance, and quality of neighboring hectares. The model presented here points out that the value of these features relative to the qualities of other potentially deforestable parcels is also important, holding constant overall demand for deforestation, which depends upon the average values of available parcels in the ejido.

Table 3 shows the results for the reduced form spatial allocation equation (13), where the dependent variable is equal to one if a given hectare area was deforested between 1994 and 2000. The results here validate our instruments for C: several of those which determine overall deforestation are significant. The number of ejidatarios in the baseline year has a positive and significant effect, the number of non-members living in the ejido has a negative and significant effect, while inequality as measured by land distribution has a negative effect. A higher bean price in 1993 significantly decreases the probability of deforestation, as do larger individual parcels and higher household education. Further interpretation of these effects will be undertaken below.

Table 4 shows the estimation of Eq. (6), the change in pasture area, C, from 1994 to 2000. Physical variables are important in both significance and magnitude in determining pasture expansion. An increase of a thousand hectares in the total area of the ejido increases conversion to pasture by about 43 ha. The effect of average distance to converted hectares is negative as expected, and large—a one standard deviation increase in distance decreases deforestation by about 68 ha. An increase in the standard deviation of slope, which suggests land less appropriate for agriculture or grazing, also decreases the overall deforestation level.

With regards to the community level variables, an increase in the number of ejido members has a positive effect, with a one standard deviation increase in membership (holding the density of the ejido population constant) causing a 137 ha increase in pasture expansion. The Gini coefficient of private land parcels within the ejido—the land division which was established at the founding of the ejido, where land and rights can only be passed on to one child—is used as the measure of inequality. A one standard deviation increase in inequality decreases pasture demand by 58 ha, an effect which is even more pronounced as the size of number of ejido members increases.

One hypothesis for the inequality effect might be that subcoalitions form to regulate the commons at high levels of inequality ([29] provides several interesting case studies of this phenomenon). A second possibility is that high inequality reflects an unequal distribution of constraints, which, at a given wealth level, causes users at the low end of the land-holding distribution to exploit less land than they would like, resulting in an overall decrease in deforestation even in the absence of cooperation. To see how the latter might work, consider an example given by Baland and Platteau [6] describing how inequality in the distribution of credit constraints among fishermen can decrease the total number of boats they put in the water. Assume that one unit of credit allows for one unit of effort, which is exactly the Nash equilibrium level of effort. Think about a disequalizing redistribution of credit, such that some users must reduce their individual effort while others have their non-binding credit constraints relaxed. The total amount of credit remains unchanged. The users who have had their constraints tightened will reduce their effort while the second set of users will appropriate at the

Table 3
Reduced form of spatial deforestation decision

Characteristic	Variable	Marginal effect
Pixel distance rank (/10,000)	d	−0.03 (0.02)
Pixel slope rank (/10,000)	q	−0.06 (−0.02)***
Pixel altitude rank (/10,000)		−0.04 (0.03)
Distance $*$ slope rank (/1,000,000)		0.0004 (0.0001)***
Distance $*$ altitude rank (/1,000,000)		0.0001 (0.0001)
Parcels with lower slope and distance (/10,000)		−0.01 (0.03)***
Total ejido area (1000s ha)	T	−0.002 (0.001)
Agricultural/pasture land, 1994	T^{p}	−0.003 (0.02)
Average private parcel	X	−0.0006 (0.0003)**
Proportion of households with secondary education		−0.06 (0.03)**
Number of ejidatarios, 1990	Z	0.00005 (0.00003)*
Number of non-members, 1990		−0.00002 $(8.0\times10^{-6})^{**}$
Gini coefficient of private parcels		−0.09 (0.04)***
Municipal marginality index, 1990		−0.001 (0.008)
Chile price, 1993 (1000s)	p^{p}	−0.001 (0.001)
Bean price, 1993 (1000s)		−0.04 (0.02)**
Growth in bean prices, 1993–2000		−0.02 (0.08)
Southern region		0.07 (0.04)**
Gulf region		0.11 (0.08)*
Pacific region		0.09 (0.06)*
Observations		931,812
Pseudo R-squared		0.14
Log-likelihood		−292,636

Dependent variable = 1 if pixel deforested between 1994 and 2000.
This regression also includes the proportion of overall forest in secondary vegetation, hours to nearest town, number of ejidatarios per ejido hectare, marginality index growth, 1990–2000, municipal population growth, the number of ejidatarios × Gini, dummy variables for the Yucatan, Northwest, and Northeast regions, none of which were significant. The comparison region is Central Mexico. Also included are the average distance to forested area, average slope of forested area, and average altitude of forested area. *,**,*** represent significance at the 10%, 5% and 1% levels.

same Nash equilibrium level. The total amount of exploitation thus decreases, even in the absence of cooperation. Since *ejido* land cannot be collateralized, the constraint in our case is not credit. The dynamic may operate through the fact that those with smaller private parcels have lower income, which results in less investment in cattle.

Table 4
OLS Estimation of Eq. (12)—overall pasture demand

Characteristic	Variable	Coefficient	Mean
Total ejido area	T	42.9 (11, 75)**	3.9 (5.9)
Total agricultural/pasture land, 1994 (1000s ha)	T^{p}	−71.9 (−16.3, −1.2)**	1.0 (1.7)
Mean distance to pixels with predicted deforestation	$h^{\mathrm{c}}(\cdot), g^{\mathrm{c}}(\cdot)$	−17.9 (−28.7, −3.4)**	8.3 (3.8)
Mean slope of pixels with predicted deforestation		−7.6 (−21, 11)	9.3 (6.4)
Mean altitude of pixels with predicted deforestation		57.9 (−32, 146)	0.75 (0.85)
Standard deviation of distance		17.4 (−23, 61)	1.3
Standard deviation of slope		−27.6 (−60, −7)**	5.9
Standard deviation of altitude		−180.2 (−1125, 608)	0.09
Hours to pueblo by bus	X	−1.13 (−72, 7)	1.1 (1.0)
Average private parcel size		−1.42 (−3.4, 2.7)	12.6 (23.3)
Proportion of households with secondary education		−189.4 (−326, −27)**	0.53 (0.26)
Marginality index, 1990		−62.9 (−114, −5)**	−0.13 (0.93)
Number of ejidatarios, 1990	Z	0.50 (0.08, 90)**	153 (275)
Gini coefficient of parcels		−323.2 (−535, −72)**	0.25 (0.18)
Ejidatarios $*$ Gini		−0.92 (−2.3, −0.02)**	41.8 (101.3)
Number of non-members, 1990		−0.07 (−0.13, 0.03)	143.5 (633)
State-level bean prices, 1993	p^{p}	−0 .18 (−0.29, −0.06)**	2476 (541.5)
Yucatan region		557.5 (103, 885)**	0.10
Southern region		224.3 (58, 348)**	0.29
Observations		318	
Adjusted R-squared		0.23	

Dependent variable = hectares in ejido deforested between 1994 and 2000.
Confidence intervals are computed by bootstrapping 1000 times. ** indicates significance at the 5% level. These are partial results. The estimation also includes the interaction of slope and distance, the interaction of altitude and distance, the proportion of forested land in secondary forest in 1994, ejido hectares per ejidatario, municipal level population growth, change in the municipal marginality index, chile prices (1993), the growth in bean prices (1993–2000), and a constant, none of which are significant. There are also six regional dummy variables of which the two significant ones are shown.

It is important to note that the effect of inequality on deforestation is significant even holding constant the distribution of the initial level of poverty across municipalities (represented by the 1990 marginality index) as well as economic growth (represented by the change in the index from 1990 to 2000). A higher initial poverty level is associated with lower deforestation, an outcome which might result from the fact that poorer communities have more constraints to converting forest land to pasture. A final community variable of interest is the proportion of households with secondary education, which has a negative and significant effect. This negative sign is the opposite of what one might expect if education increased productivity in agricultural activities; however, it is likely the case that this measure of average education in the community reflects a decrease in the need for deforestation as a result of outside working opportunities. Although these community effects are not nearly as large in magnitude as the effects of the physical variables, compared to the mean deforestation level of 234 ha, their impact is substantial.

Two of the regional dummy variables, the Yucatan Peninsula and Southern Mexico, showed positive and significant effects on overall deforestation. These positive effects may come from a variety of sources, including variation in the quality of state and regional forestry offices and the illegal extraction of expensive tropical hardwoods from the Southern ecosystems. The positive coefficient for Southern Mexico might also reflect some of the insecurity in land tenure in the states of Chiapas and Oaxaca, where land conflicts are quite common. This would be similar to the findings of Deacon [22], although the same argument cannot be made for the Yucatan, where land tenure is generally well defined.

Finally, one might wonder, given the different categories of decision-makers detailed in Table 2, if all these communities truly belong to the same estimation. In particular, those communities who claimed no regulation of activities in the commons (i.e., those without rules and for whom deforestation "just happened") might reasonably be thought to be operating under a different decision-making regime. Therefore, I estimated the system of equations without these observations; the results are shown in Table 5. Though the point estimates vary slightly, none of them is significantly different from those in Table 4.

Table 6 gives the results from the structural equation (11). The first column shows the marginal effects from the structural probit, the second column results from using the traditional deforestation regressors, and the third column combines both the relative measures of slope, distance, and altitude with their absolute values. Column (4) shows the OLS linear probability model estimates for the equation in column (1). The purpose of this final column is to assess the degree of bias introduced to the probit by the spatial autocorrelation of the error terms. Under the standard OLS assumptions, spatial autocorrelation in the error results in unbiased, but inefficient coefficient estimates [4]. A Lagrange multiplier test against a spatial error model gives a value of 368, and an associated p-value of essentially zero, which clearly indicates spatial correlation of the error terms. Comparing the point estimates from Eqs. (1) and (4) gives us some sense of the size of the bias introduced into the probit equation. All coefficient estimates are very similar, suggesting that bias should not be a concern in this case.

The coefficients have the expected signs—the probability of deforestation decreases in the rank (column (1)) and the absolute value (column (2)) of distance, slope, and altitude. The effects are small even for large changes, with a one standard deviation increase in rank of distance decreasing the probability of deforestation by 0.04 and similar change in the slope rank decreasing the probability by 0.06. We also see that holding constant the total forest area, demand for conversion C increases the probability that any one forested hectare will be converted. A one standard deviation increase in C corresponds to an increase in the probability of deforestation of 0.11, which is nearly twice the impact of the changes in hectare-level characteristics.

Eqs. (1) and (2) have similar explanatory power—the pseudo-R-squared values are identical and the log-likelihood measures very similar, which begs the question of whether or not the rank of the values measures anything distinct from the absolute values. Column (3) answers this question in the affirmative. Including both the relative and the absolute values in the estimation increases the explanatory power significantly—the pseudo-R-squared goes up by 20%. In addition, the point estimates of the relative regressors remain unchanged—with the exception of relative slope which decreases. In the presence of the variable measure relative distance, the measure of distance to the village loses significance. The slope rank becomes less significant and slightly smaller, while slope becomes insignificant, probably reflecting the high correlation between the two variables (Pearson's correlation coefficient = 0.45). The altitude measures and the interaction terms, both relative and absolute, remain significant and of the same magnitude. All this evidence together support the hypothesis that the decision across space does indeed depend upon the characteristics of a hectare of land relative to the characteristics of other pieces of land amongst which decision-makers are choosing.

Table 7 shows how increases in the predicted amount of deforestation changes the rank characteristics of the area deforested. Column (1) reports the average distance, slope, and altitude rank of the deforested pixels given the initial level of deforestation. The following two columns show average ranks given simulated increases in overall forest loss of 50% and 100%. The differences here are large and significant, indicating that as deforestation increases it progresses to more remote areas of higher slope and altitude.

Table 5
OLS Estimation of Eq. (12)—overall pasture demand, restricted sample[a]

Characteristic	Variable	Coefficient	Mean
Total ejido area	T	52.1	3.7
		(12.3, 81.2)**	(5.8)
Total agricultural/pasture land, 1994 (1000s ha)	T^p	−91.3	1.0
		(−181.5, −20.4)**	(1.7)
Mean distance to pixels with predicted deforestation	$h^c(\cdot), g^c(\cdot)$	−18.7	8.1
		(−30.3, −3.1)**	(3.9)
Mean slope of pixels with predicted deforestation		−7.5	7.8
		(−24, 10)	(5.0)
Mean altitude of pixels with predicted deforestation		50.7	0.76
		(−52.2, 145.5)	(0.86)
Standard deviation of distance		9.8	1.3
		(−35.9, 57.6)	
Standard deviation of slope		−31.3	5.9
		(−59.0, −11.3)**	
Standard deviation of altitude		−42.1	0.10
		(−1117.7, 186.0)	
Hours to pueblo by bus	X	−33.6	1.0
		(−75.5, 9.8)	(1.1)
Average private parcel size		−1.9	12.2
		(−4.4, 3.8)	(23.5)
Proportion of households with secondary education		−223.7	0.54
		(−374.5, −48.0)**	(0.26)
Marginality index, 1990		−70.3	−0.11
		(−134.0, −9.3)**	(0.92)
Number of ejidatarios, 1990	Z	0.43	157
		(0.02, 0.80)**	(283)
Gini coefficient of parcels		−342.0	0.25
		(−583.7, −16.8)**	(0.18)
Ejidatarios * Gini		−0.86	42.5
		(−2.3, 0.25)*	(104.2)
Number of non-members, 1990		−0.07	149.2
		(−0.13, 0.04)	(652)
State-level bean prices, 1993	p^p	−0.16	2465
		(−0.29, −0.02)**	(534.5)
Yucatan region		561.0	0.09
		(6.1, 903.6)**	
Southern region		227.9	0.29
		(52.1, 361.1)**	
Observations		293	
Adjusted R-squared		0.24	

Dependent variable = hectares in ejido deforested between 1994 and 2000.

[a] Removed from the sample are those communities that responded that deforestation "just happens" and have no rules governing use of the commons. Confidence intervals are computed by bootstrapping 800 times. ** indicates significance at the 5% level, * at the 10% level. These are partial results. The estimation also includes the interaction of slope and distance, the interaction of altitude and distance, the proportion of forested land in secondary forest in 1994, ejido hectares per ejidatario, municipal level population growth, change in the municipal marginality index, chile prices (1993), the growth in bean prices (1993–2000), and a constant, none of which are significant. There are also six regional dummy variables of which the two significant ones are shown.

Final evidence of the additional explanatory power of relative characteristics is given in Table 8, which presents an experiment.[3] In this experiment individual hectares of land are randomly assigned to new groups, which changes the values of the rank variables but not the measured values of slope, distance, and altitude of each hectare. Within these new groups, each parcel receives the average values of C and T^f across the new

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[3] I would like to thank Alexander Pfaff for suggesting this experiment.

Table 6
Structural model: estimation of Eq. (11)

Characteristic	Variable	(1) Probit	(2) Probit	(3) Probit	(4) Linear probability
Pixel distance rank (/10,000)	d	−0.07 (−0.09, −0.03)**		−0.06 (−0.09, −0.01)**	−0.06 (−0.1, −0.004)**
Distance to houses in km			−0.006 (−0.009, −0.001)**	−0.004 (−0.008, −0.0002)**	
Pixel slope rank (/10,000)	q	−0.08 (−0.1, −0.04)**		−0.02 (−0.1, 0.004)*	−0.06 (−0.1, −0.02)**
Slope in degrees			−0.002 (−0.005, 0.0001)*	−0.002 (−0.004, 0.0007)	
Pixel altitude rank (/10,000)		−0.07 (−0.1, −0.01)**		−0.07 (−0.1, 0.02)*	−0.05 (−0.07, 0.002)
Altitude in meters			−0.04 (−0.07, −0.009)**	−0.03 (−0.06, −0.002)**	
Distance rank $*$ slope rank (/10,000,000)		0.003 (0.001, 0.009)**		0.002 (0.001, 0.01)**	0.003 (0.002, 0.007)**
Distance $*$ slope			−0.0002 (−0.0005, 0.0001)*	−0.0002 (−0.0005, 0.00004)*	
Distance rank $*$ altitude rank (/10,000,000)		0.002 (0.0006, 0.004)**		0.002 (−0.001, 0.004)*	0.002 (−0.002, 0.004)
Distance $*$ altitude			0.005 (0.0001, 0.008)**	0.005 (0.0001, 0.008)**	
Converted forest, 1994–2000 (1000s ha)	C	0.16 (0.10, 0.20)**	0.14 (0.10, 0.22)**	0.13 (0.10, 0.19)**	0.16 (0.1, 0.3)**
Hectares of forest, 1994 (1000s ha)	T^f	−0.005 (−0.010, −0.002)**	−0.009 (−0.015, −0.008)**	−0.006 (−0.01, −0.003)**	−0.009 (−0.01, −0.002)**
Observations		931,812	931,812	931,812	931,812
Pseudo-R-squared		0.10	0.10	0.12	–
Log-likelihood		−303,595	−303,423	−297,856	–
R-squared					0.07

Dependent variable = 1 if pixel deforested between 1994 and 2000.
95% confidence intervals in parentheses are computed by bootstrapping 400 times. Column values are marginal effects. ** and * denote significance at 5% and 10%, respectively.

Table 7
Changes in characteristics of deforested area with changes in overall deforestation

Characteristic	Variable	Actual forest loss (1)	50% increase in forest loss (2)	Doubling of forest loss (3)	t-test between (1) and (2)	t-test (2) and (3)
Distance rank	$\bar{d}^c$	1248	1300	1343	3.4	1.6
Slope rank		989	1054	1146	5.0	3.9
Altitude rank	$\bar{q}^c$	1060	1110	1169	3.6	3.6

group members. This exercise is meant to test the assertion that the relative distance and land quality variables provide information that is specific to an actual decision-making unit—the ejido. The absolute variables—distance, slope, and altitude—remain significant. Relative slope and altitude have the same sign as in the unrandomized estimations, but are no longer significant, suggesting that decision-makers are not choosing between parcels in these reassigned "communities." This further supports the assertion of the model that relative features provide important information about deforestation choices. Finally, the variable representing relative distance is significant and positive, suggesting that as the rank of the distance from the villages gets larger, the probability of deforestation increases—the opposite of what one would expect. This variable is actually quite difficult to interpret, as the distances are calculated relative to the ejido village in which the

Table 8
Structural model: randomization experiment

Characteristic	Variable	Marginal effects
Pixel distance rank (/10,000)	d	0.008 (0.001, 0.02)**
Distance to houses in km		−0.007 (−0.01, 0.0001)*
Pixel slope rank (/10,000)	q	−0.0006 (−0.02, 0.01)
Slope in degrees		−0.004 (−0.008, −0.001)**
Pixel altitude rank (/10,000)		−0.001 (−0.03, 0.008)
Altitude in meters		−0.04 (−0.08, 0.0004)*
Distance rank ∗ slope rank (/10,000,000)		−0.00002 (−0.00005, 0.00006)
Distance ∗ slope		−0.0003 (−0.0007, 0.0001)
Distance rank ∗ altitude rank (/10,000,000)		0.00001 (−0.00006, 0.00006)
Distance ∗ altitude		0.005 (−0.001, 0.01)
Converted forest, 1994–2000 (1000s ha)	C	0.16 (0.02, 0.25)**
Hectares of forest, 1994 (1000s ha)	T^{f}	−0.009 (−0.01, −0.002)**
Observations		931,812
Pseudo-R-squared		0.05
Log-likelihood		−324,420

Dependent variable = 1 if pixel deforested between 1994 and 2000.
95% confidence intervals in parentheses are computed by bootstrapping 200 times. ** and * denote significance at 5% and 10%, respectively.

parcel was originally located. It is probable that the positive coefficient reflects the fact that those with higher ranks are from larger ejidos, which increases their likelihood of deforestation. Taken together, the results from this table indicate that, holding constant the overall demand for deforestation by a given community, the progress of deforestation across space depends crucially on the characteristics of each piece of forest relative to other forested hectares amongst which decision-makers are choosing.

6. Conclusions

I have presented and tested with data a theory of the deforestation of common property forest over space. In contrast to previous deforestation theories, this one is both structural and behavioral, specifying which features contribute to the location of forest loss and which to the overall community level demand for forest conversion. One of the main implications of the model is that at the level of an individual plot of land of uniform distance and quality, the probability of deforestation depends simultaneously upon its characteristics relative to those of other plots of land within the same community and on that community's demand for forest conversion. Total deforestation depends, through the marginal value of the converted land, on the physical characteristics of the most profitable parcels and on community features affecting the collective action problem.

The paper tests this theory using data from 318 Mexican ejidos and found support for these hypotheses. Specifically, within a given ejido, parcels of forest that are relatively closer and of lower slope and altitude in a particular community are at higher risk of deforestation. This suggests that pieces of forest with these characteristics should be targeted within ejidos by conservation projects. Similarly, at an aggregate level, ejidos with forest of lower average slope and closer to villages should also be targeted.

With regards to community variables, the data provides the encouraging result that more secondary education has a negative effect on overall forest conversion, providing further justification for the types of educational subsidy programs already in place in Mexico. A larger member population is associated with higher deforestation, which is consistent with the idea that cooperation is more difficult in larger groups. Inequality, as measured by the distribution of private parcels that are given to members at the founding of the ejido, also has an important negative effect on overall increases in pasture area. The results also show that this effect is even stronger when the membership of the ejido is larger. The policy implications of these final results provide further guidance for targeting. However, understanding the dynamics behind the group size and inequality effects constitutes a topic for future research, as it is likely to result in additional important policy insights.

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