# Seeing the Forest and the Trees: 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 two outcomes are jointly determined. We estimate the equations of the model in a four step process using data from 318 common properties in Mexico. In contrast to previous deforestation theories, we find that the allocation of deforestation across space is dependent not upon the absolute quality and location of each parcel, but rather upon a parcel's quality and location relative to others in the same community and on the overall deforestation decision of the community. Simultaneously, total deforestation depends upon the value of the land deforested, which is determined by its physical attributes, as well as the characteristics of the community that affect its collective choice problem. Increases in secondary education and inequality decrease deforestation, while larger membership size increases it.

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# 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 biodiversity and carbon sequestration loss, in addition to local negative externalities such as decreases in water quality and increases in 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 (Alix-Garcia, de Janvry & Sadoulet 2004).

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 (Segura 2000). According to the Mexican National Forestry Commission (CNF), 80 percent of the country's forests are located in *ejidos*, communities resulting from the post-Revolution 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 a good estimate of the total amount of world forest in common property is not available, a recent report by Forest Trends estimates that 370 million hectares (compared to the 470 million hectares worldwide in preserves) qualify as "community-managed"(Molnar, Scherr & Khare 2004). These forests are not limited to developing countries, though they are certainly more abundant there, and can be found in the U.S. and Europe as well.

The empirical literature on deforestation is relatively recent, beginning with work by Chomitz & Gray (1996) and increasing rapidly since. 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 pixel or the municipal 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 [1] . The empirical strategy in this case generally takes the form of a probit 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

[1] Papers with pixel-level analysis include Puri & Griffiths (2001), Monroe, Southworth & Tucker (2002), Godoy & Contreras (2001), Vance & Geoghegan (2002), Chomitz & Thomas (2003) while Deininger & Minten (1999), Pfaff (1999) are municipal level studies

characteristics are sometimes included to control for their effect on land conversion demand.

This paper's strategy differs in two ways from the established literature. First, it looks at a community level decision, which implies that relative, not absolute, physical attributes of parcels are key determinants of the location of deforestation. Second, we estimate a structural model that allows us to differentiate between factors which affect overall deforestation and those which change its distribution over space within a community. In short, we explore the questions of both *where* within community boundaries and *how much* deforestation occurs in total in a given *ejido*. We present a model showing that these decisions are jointly determined within the community. Our model implies that the probability of deforestation for two parcels of forest with equivalent characteristics located in different communities may differ for two reasons. First, each parcel may be located in a different place within the distribution of parcels in its community. 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 parcels of land and with variables, like group size and inequality, that affect its collective choice problem, which can range from the non-cooperative to socially optimal.

The theory suggests a system of equations which we estimate using data from 318 *ejidos* surveyed in 2002 to explain the probability of deforestation of a given parcel (pixel) and total deforestation in the community, where these two relationships are interdependent. We use a four step strategy to estimate the system with bootstrapped standard errors to account for the inclusion of predicted values. We 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 it is the characteristics of a given parcel of land relative to all of the other hectares within a community that drive the deforestation decision across space. A test of the predictive power of absolute versus relative physical characteristics comes out clearly in favor of the latter. Increases in the demand for new pasture land result in the conversion of increasingly less profitable, that is, relatively more distant and lower quality parcels of forested land. On an aggregate level, forest conversion is decreasing with the average distance, slope and altitude of the relatively more profitable parcels. The effect of group size on deforestation is positive, consistent with Olson's finding that cooperation is hindered by larger groups, while that of secondary education is negative. Finally, we find,in contrast to Cardenas (2003) and Dayton-Johnson (2000), that inequality has a significant and substantial negative effect on overall deforestation.

Our general community model suggests that the characteristics of the community members, education and land distribution in particular, are important determinants of deforestation, but the aggregate nature of the estimation does not allow us to see the mechanisms that might be driving this behavior. Therefore, we use household level data to shed some light into the black box of "community behavior". In particular, we examine whether the inequality effect operates through increasing cooperation or by changing the distribution of individual constraints to forest conversion in a manner that decreases the total amount of deforestation. Simple summary statistics show us evidence for both hypotheses. We also look at individual use of the commons area in order to identify potential deforesters in these communities. An instrumental variables estimation shows that use of the common forest may result from the role of cattle as a savings mechanism. Using the information regarding the identity of commons users, we examine the hypothesis that a group within an *ejido* might cooperate, even in the presence of others that do not, and show empirically that a larger potential cooperating group has a positive effect on forest conservation over the time period that we consider.

The paper is organized as follows: we begin by describing the data and some key characteristics that motivate the design of our model. Section 3 gives a qualitative description of the deforestation decision in the *ejidos*. Section 4 presents a simple spatial/common property deforestation model, section 5 the empirical strategy and section 6 results of the estimations. Section 7 analyzes the household level characteristics in order to disentangle some of the community dynamics hidden in our aggregate estimation. The final section concludes.

## 2 Data

The data come from a survey of 450 *ejidos* conducted throughout Mexico in 2002. The survey consisted of two sections, a community questionnaire and a household questionnaire. In both cases, respondents were three to four members of the community council, who are elected by popular vote and serve various functions to be discussed in section 3. Basic characteristics of the community, forest exploitation and governance were collected. The second part of the survey was an indirect household questionnaire applied to 50 randomly chosen *ejidatarios* (members of the *ejido*), where the information was collected from one key informant. It includes data about participation in government programs, household size, migration, age, employment, land and cattle-holdings, and use of the commons. Out of the entire sample, we use only the 324 communities that do not have forestry projects. It is our belief that communities that undertake active wood exploitation are subject to a different deforestation dynamic than those that do not (this dichotomy is detailed in Alix-Garcia, de Janvry & Sadoulet (forthcoming)).

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, Mas & Palacio (2002). Slopes and altitudes have 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.

## 3 Stories with Statistics

### 3.1 Reasons for deforestation in *ejidos*

Table 1 shows summary statistics on deforestation. Although there were 324 *ejidos* not practicing forestry in the sample, because we are not interested in the behavior of outlying communities, we cut 3 observations from each tail, leaving us with 318 communities. The rejected observations include communities with over 8,000 hectares of forest loss over the period and those with over 2,500 hectares of forest increase. Overall increase in pasture land per community between 1994 and 2000 is 234 hectares, with a wide variance, and a substantial portion of the communities (41%), do not deforest at all, or have increases in their forest cover over the period. The total forest coverage in our sample in 1994 is 919,959 hectares, 73,848 (8%) of which are lost in the period between 1994 and 2000. According to the earlier forest inventory, 72% of the Mexican territory, or over 141 million hectares, is covered with forest. The overall deforestation rate in Mexico over this period is about 1.3% (Segura 2000), while in our sample it is about 1.4% per *ejido* per year.

See Table 1.

How does this deforestation happen and who decides that it will happen? All *ejidos* have the same basic institutional structure: every two years they elect a community council whose minimal composition includes a president, treasurer, secretary and 'comité de vigilancia', which is essentially a combination of ombudsman and policeman. The same person cannot serve on the council for two consecutive terms although they can be reelected after a one-term hiatus. Communities make decisions in general assemblies which occur on a monthly or bimonthly basis, and they vary in their voting structure; some take decisions by majority rule and others by unanimity. It is also important to understand that *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 is a feature that was determined at the founding of each *ejido*. Rights to a parcel and use of the commons are passed on to only one family member per *ejidatario* (member of the *ejido*), so membership has been constant over time. There is one caveat to this statement, however. 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, we use the pre-reform membership size and land distribution characteristics in our study.

In order to guide our thinking regarding the driving forces of deforestation, we asked the survey participants *why* they deforested and who made the decision. This question was not responded to by all participants, but rather only those that experienced deforestation, and even in these cases there were some non-responses. There were, however, sufficient responses for us to present some of them here. Table 2 lists the "two main reasons" why a given area of the *ejido* was deforested between 1994 and 2000. Not all respondents gave two reasons (i.e. the columns do not add up to 200), but what is clear from the responses is 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 - forest fires and wood extraction. 50% of respondents gave these as their main reasons for conversion, with forest fires come in a distant third with 9%, and deforestation for wood extraction practically non-existent. This latter outcome results from the fact that none of these *ejidos* possess forestry permits, and hence their extraction is limited to wood for domestic use.

See Table 2.

The last set of questions, the responses to which are shown in table 3, addressed who made the decisions regarding forest conversion. 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. Within 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 the fact that permission must be granted by the council president. The last row of table 3 shows the percentage of communities where deforestation “just happened” who 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.

See Table 3.

The first conclusion that we draw from these tables is that deforestation is driven by expansion of the agricultural frontier, not by wood extraction for sale. We also see that in a sizable number of cases, communities make a concerted decision to approve deforestation activities. Those communities where deforestation “just happens” and there are no existing rules have made a conscious decision *not* to regulate conversion and leave this choice up to individual farmers. In the middle, between full cooperation and no regulation, we find the 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 planner to a nearly complete lack of regulation.

### 3.2 Physical characteristics

Here we consider the physical features of the parcels that *ejidos* choose to deforest. Table 4 gives us the ranks of deforested forest parcels as opposed to non-deforested forest parcels across the entire sample. “Pixel rank” refers to the rank of a forested pixel within a given ejido, with the lower rank being assigned to the pixel with the lowest distance, slope or altitude within the forested pixels of the ejido. Because each pixel is one hectare, this number gives the number of other forested hectares that have a value less than the observed pixel. Ties in the ranking are given the same rank. The rank reflects the number of one hectare forest parcels with distance, slope or altitude less than or equal to corresponding value of the parcel in question. We also show the absolute value of distance from the nearest cluster of houses in kilometers, of slope in degrees and of altitude in meters. In Mexico, rural housing is generally clustered into a village as opposed to dispersed on farmers' fields. In all cases, we see that the deforested pixels are much closer, lower and less sloped that those that are untouched. In the empirical section, we compare the predictive power of absolute versus relative measures of these characteristics within *ejidos.*

See Table 4.

Table 4 suggests features that should be included in the modeling of the choice of deforestation across space. While a traditional model might focus on the absolute values of slope, distance and altitude in determining the probability of deforestation at a pixel level, we see here that the relative values of these variables within a community also have a potential role to play in the decision of where to deforest. Keeping in mind the conclusions of this section and the previous one, we move on to describe a general model of community deforestation over space.

## 4 Model

As was mentioned above, 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, which is the case we present in this section. We use this section to give a general intuition for the model. The inspiration for our model's vision of spatial distribution comes from two papers outside of the deforestation literature. These consider the problem of pollution distribution given heterogeneity in firms (Xabadia, Goetz & Zilberman (2003)), and location (Goetz & Zilberman (2003)) in a continuous time optimal control framework. Due to the small value-added of a dynamic model for our purposes, however, we use a static approach.

The model contains two jointly determined components, total deforestation level and the spatial allocation of this decision. The decision of which parcels to deforest depends both upon their value in agriculture/pasture relative (heretofore abbreviated as pasture land) to the value of other parcels 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 parcels of forested land and the community variables which affect members' demand for new agricultural land (like secondary education and distance from markets)and, since we are in a common property, features that impact collective action (group size and inequality). This gives us a system of equations describing equilibrium deforestation for each community.

The main insights of the model are as follows: two parcels with exactly the same physical characteristics may have different probabilities of deforestation for two reasons. First, because their relative standing amongst all the other parcels in a community is different. For example, a parcel that is three kilometers away from houses may have a very high probability of deforestation if it is the closest parcel available, and a very low one if there are many parcels that are less than this distance from the same houses. Second, even if both parcels 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 their productivity in agricultural versus forest activities differs. 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.

The next sections formalize this logic.

### 4.1 Spatial allocation

For the first stage we consider the conditional decision that is made over space - that is, whether to deforest or not a parcel with a specific combination of distance and quality characteristics, given that the community wants to convert a particular amount of forest land into pasture. The notation and assumptions are as follows:

1. Each piece 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 $D$.

2. Quality, distance, and prices determine an index of profitability of the forested land in pasture

or agricultural production $\pi^p(p^p, q, d)$ and in forest production $\pi^f(p^f, q, d)$, where $p^p$ and $p^f$ are prices of pasture and forest products, respectively. Profitability in pasture is more sensitive to both land quality and distance, because of the frequent travel required to oversee animals or crops. Thus we assume $\frac{\partial \pi^p}{\partial q} > \frac{\partial \pi^f}{\partial q} > 0$ and $\frac{\partial \pi^p}{\partial d} < \frac{\partial \pi^f}{\partial d} < 0$ for all values of $q$ and $d$.

3. Let $\delta_p(q, d)$ be the proportion of land $q, d$ converted to pasture from the standing forest.

4. The optimal amount of conversion from forest to pasture is denoted $C^p$, given initial area in pasture written as $T^p$ and forest $T^f$, with $T^p + T^f = T$, the total land area.

Given these conditions, the optimal allocation of converted land $C^p$ over space is the result of a spatial profit maximization problem. For each parcel of forested land, one must choose what percentage of it to convert pasture and what percentage to leave in forest. The sum of these choices must equal the total desired new pasture land.

$$\max_{\delta^p} \int_0^D \int_{q_L}^1 [\delta_p(q,d)\pi^p(p^p,q,d) + (1-\delta_p(q,d))\pi^f(p^f,q,d)]T^f g(q,d)dqdd$$

$$s.t. \int_0^D \int_{q_L}^1 \delta_p(q,d)T^f g(q,d)dqdd = C^p$$

$$\text{and } 0 \leq \delta_p(q,d) \leq 1$$

The first order condition of the associated Lagrangian is:

$$\pi^p(p^p,q,d) - \pi^f(p^f,q,d) - \gamma = 0 \;\; \forall q, d$$

where $\gamma$ is the is the Lagrange multiplier associated with the total conversion constraint. The optimal allocation consists of corner solutions, which means that a community either converts an entire parcel or leaves it as forest.

$$\begin{aligned} \delta_p(q,d) = 1 \;\; &\Leftrightarrow \;\; \pi^p(p^p,q,d) - \pi^f(p^f,q,d) \geq \gamma \\ \delta_p(q,d) = 0 \;\; &\Leftrightarrow \;\; \pi^p(p^p,q,d) - \pi^f(p^f,q,d) < \gamma \end{aligned} \tag{1}$$

The threshold value at which a piece of land changes from forest to pasture, or vice versa, is denoted by $\gamma$, that can be either positive or negative. This is the shadow value of land demanded for conversion, and is determined by

$$\int_0^D \int_{q_L}^1 \delta_p(q,d) g(q,d) dq dd = \frac{C^p}{T^f} \tag{2}$$

.

Hence land units are ranked by decreasing value of the differential potential for pasture and forest, and land with the highest relative potential for pasture, i.e., with a better combination of distance and quality, will be the first converted into pasture. As the total demand for new pasture rises, the frontier moves towards more remote areas, possibly of lower quality. This gives us the formal presentation of our first hypothesis: *The probability of deforestation for a given parcel depends upon its position in the distribution of all the forested parcels in the ejido.* A second conclusion derived from equation (2) is *deforestation probabilities increases with the price of pasture and decreases with the price of forest products.*

From this optimal spatial allocation of pastures, one can derive an average value index for land converted to pasture by:

$$\overline{\pi}^p = \int_0^d \int_{q_L}^1 \delta_p(q,d) \pi^p(p^p, q, d) g(q,d) dq dd = \overline{\pi}^p \left( g^c(\cdot), p^p, p^f \right) \tag{3}$$

where $g^c(\cdot)$ is the distribution of land quality and distance over the area that is deforested. This value index, $\overline{\pi}^p$, is also a function of prices and implicitly of $C^p$, since the total area converted determines the area of land deforested. A similar expression can be written for the value of the same land were it to remain in forest.

### 4.2 Ejido level pasture allocation

In this section we consider the optimal choice of new pasture land in any time period, given that this land will be optimally allocated over space. In the interest of not obscuring our point, we do not specify an explicit way in which demand aggregation within the community occurs, instead applying a simple "black-box" social planner problem. Both pasture and forest are sources of income. Write the additional income generated by new pasture $R^p$ as a function of the amount of land converted to pasture, $C^p$, the value of that land in pasture, $\overline{\pi}^p$, the land previously in pasture, $T^p$, and the stock of cattle in the village, $X^p$ (this may include other variables affecting revenue generation):

$$R^p = R^p(C^p, T^p, \overline{\pi}^p, X^p)$$

Similarly, the income that would have been generated by this land were it to remain in forest, $R^f$ is function of the conversion level, land allocated to the forest, its value, and community characteristics that affect revenue generation in forest, $X^f$:

$$R^f = R^f(C^p, T^f, \overline{\pi}^f, X^f)$$

The common property nature of the forest is captured by the function $\psi(Z)$, which ranges from $\epsilon$ to 1. When $\psi(Z) = 1$, the community behaves like a social planner, taking full account of the value of the public good - the forest. Smaller values of $\psi(Z)$ indicate that the entire value of the common property forest is not being taken into account, reflecting lower levels of cooperation. This function is decreasing in community characteristics that negatively affect cooperation. The collective action literature, and this paper, consider features like group size, land endowments and inequality as determinants of cooperation, though the actual direction of these effects is an empirical question. This specification consequently accounts for different qualities of collective action, ranging from a social planner ($\psi(Z) = 1$) to a tragedy of the commons situation ($\psi(Z) = 0$).

The optimal allocation of the total *ejido* land converted to pasture maximizes the net revenue due to conversion, which is just the difference between the revenue generated by the newly converted pasture land minus the revenue this same land would have generated were it to have remained in forest:

$$\max_{C^p} R^p(C^p, T^p, \overline{\pi}^p(g^c(\cdot), p^p, p^f), X^p) - \psi(Z)R^f(C^p, T^f \overline{\pi}^f(g^c(\cdot), p^f), X^f)$$

The solution gives a semi-structural equation:

$$C^p = C^p(+T^f, -T^p, +\overline{\pi}^p, -\overline{\pi}^f, +X^p, -X^f, +Z) \quad (4)$$

This equation gives us several testable hypotheses:

1. *Decreasing in the baseline pasture area,*
2. *Increasing in the value of pasture land, which is decreasing in distance and increasing in quality*
3. *Increasing in characteristics that negatively impact cooperation.*
4. *Decreasing in characteristics that positively affect revenue generation in pasture.*

To summarize, the choice of how much pasture to convert depends upon the profitability of the land converted and the profitability of land not converted, which themselves are increasing functions of land quality and prices, and decreasing functions of distance. Pasture conversion is decreasing with the amount of already established pasture. The latter results from the decreasing marginal returns to pasture land. Characteristics which inhibit cooperation lower the value of standing forest to the *ejido* and therefore increase 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.

Overall, the main features of the model can be described by four equations:

1. The overall deforestation level: equation (4)

$$C^p = C^p(T, T^p, \underbrace{\overline{\pi}^p, \overline{\pi}^f}, X^p, X^f, Z)$$

2. Two functions describing the value of the deforested land in alternative uses:

$$\overline{\pi}^p = \overline{\pi}^p(\underbrace{g^c(q,d)}, p^p)$$

$$\overline{\pi}^f = \overline{\pi}^f(\underbrace{g^c(q,d)}, p^f)$$

3. where

$$g^c(q,d) = g(q, d|\underbrace{\delta_p = 1})$$

,the distribution of quality and distance within the deforested area.

4. The deforestation risk for a given parcel, which is a combination of equations (1) and (2) that we will call (1'):

$$\delta_p = f(\underbrace{C^p}, T^f, rank(g(q,d)), p^p, p^f)$$

where $rank(g(q,d))$ denotes the relative position of the parcel in the forested area.

The bracketed terms highlight the simultaneity of these relationships. These four equations lead us directly to our econometric strategy.

## 5 Empirical Strategy

The empirical strategy parallels the equations derived above and is implemented in the following manner.

1. We begin with the reduced form probit of equation (1') for parcel $j$ in ejido $i$:

$$Pr(\delta^p_{ji} = 1) = f(rank_j(g(q,d)), E_{j\in i}(g(q,d)), p^p_i, p^f_i, T^p_i, X^p_i, X^f_i, Z_i)$$

2. Because there is no aggregate variable in the data that summarizes the value of the converted land, we substitute for these functions prices and the average values of quality (proxied by slope and altitude) and distance over the parcels that are predicted to be deforested. For this we use the predicted probabilities from the first step and calculate replacements for:

$$\overline{\pi}^p = \overline{\pi}^p(\overline{d}^c, \overline{q}^c, p^p) \text{ and } \overline{\pi}^f = \overline{\pi}^f(\overline{d}^c, \overline{q}^c, p^f)$$

where $\overline{d}^c = \frac{1}{\sum_j Pr(\delta^p_{ji}=1)} \sum_j Pr(\delta^p_{ji} = 1) d_{ji}$ and $\overline{q}^c = \frac{1}{\sum_j Pr(\delta^p_{ji}=1)} \sum_j Pr(\delta^p_{ji} = 1) q_{ji}$

3. In the next stage we estimate the aggregate deforestation level in *ejido* $i$ using OLS:

$$C^p_i = C^p_i(T^f_i, T^p_i, \overline{d}^c_i, \overline{q}^c_i, p^f_i, p^p_i, X^p_i, X^f_i, Z_i)$$

4. And in a final stage we use the predicted values from this equation to estimate the structural form of (1'), the parcel by parcel decision, using a probit.

$$Pr(\delta^p_{ji} = 1) = f(C^p, T^f, rank(g(q,d)), p^p, p^f)$$

The standard errors are 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 between neighboring parcels. Given that our estimation strategy requires bootstrapping of the standard errors, we are unable to implement the typical solution to this problem - a weighting matrix whose entries reflect some estimate of the covariance between neighbors (see Conley (1999) for a good example of one of these techniques). These sorts of adjustments are generally taken when one is either concerned about the nature of the covariance itself, or in the name of greater precision. In our case, our focus is not the covariance term, and the estimates we achieve are quite precise even without adjusting for spatial correlation. There is the additional problem, however, that the spatial correlation in the probit will bias the point estimates of the coefficients (Anselin 1999). In order to assess the severity of this problem in our case, we 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.

## 6 Results

Before showing the main estimations, we present a suggestive test of the predictive value of relative versus absolute physical characteristics at the pixel level. 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 parcels. Our model points out that the value of these features relative to the qualities of other potentially deforestable parcels is also important. Table 5 considers a fixed-effect regression (linear probability model) of deforestation on physical attributes as generally expressed in the deforestation literature, compared to the same regression in column two using the rank of these parcels' characteristics relative to all the other forested parcels in the *ejido*. The third column uses the residuals from the first equation to see if the ranked values are able to explain some of the remaining variation in the data. We see that the variables in column (1) are able to explain 2.6% of the variation in the data, and that the relative characteristics explain 3.8% of the variation. The third column is the most interesting, as it shows that the relative characteristics explain an additional 4% of the variation in the data after having run estimation (1).

See Table 5.

Table 6 shows the results for the reduced form spatial allocation equation (equation 6), where the dependent variable is equal to one if a given hectare area was deforested between 1994 and 2000. Table 7 gives the results from the structural equation (6). The first column shows the marginal effects from the structural probit, while the second includes the absolute values of distance, slope and altitude to see how they affect the coefficients of the ranked values. The coefficients have the expected signs - the probability of deforestation decreases in the rank of distance, slope and altitude, although the interaction terms are oddly positive. 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 $C^p$ increases the probability that any one pixel will be converted. Here a one standard deviation increase increases the deforestation probability by 0.11, which is nearly twice the impact of the changes in physical characteristics.

In comparing estimations (1) and (2), we see that inclusion of the absolute values of slope, altitude and distance do little to change the point estimates or significance of the relative measures, except in the case of slope, which remains significant but with about half of its previous magnitude. The price coefficients are not significant perhaps because, while we would have liked to have had these prices at a local level, here they are only at the state level.

The third column shows the OLS linear probability model estimates for the specification in equation (1). The purpose of this exercise 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 (Anselin 1999). In the probit, however, spatial autocorrelation acts analogously to heteroskedasticity, introducing a potential bias in the point estimates. Moran's I for spatial autocorrelation for the nearest neighbors in the generalized error terms for equation (1) gives a value of -.004 (relative to the value under the null hypothesis of -.000001), with an associated p-value of essentially zero. This is a clear indication of positive spatial correlation of the error terms. Although currently searching for a way to correct the potential bias introduced by this autocorrelation, current techniques have not proved readily implementable in a dataset our size, so we content ourselves for the moment with assessing the magnitude of the problem (for a discussion of spatial autocorrelation in the probit, tests and estimation strategies, see Pinkse & Slade (1998)). Comparing the point estimates from equations (1) and (3) gives us some sense of the size of the bias introduced into the probit equation. As we can see, none of the coefficient estimates is significantly different at the 5% level between the two equations, although one must keep in mind that the standard errors are not corrected for spatial autocorrelation and are thus somewhat large.

See Table 7.

In order to emphasize the point regarding the importance of relative characteristics, it is interesting to consider the movement of deforestation across space given changes in overall demand. Table 8 shows how increases in the predicted amount of deforestation changes the rank characteristics of the area deforested. The first column is the average distance, slope and altitude rank of the deforested pixels given the initial level of deforestation. The following two columns show the same rank given simulated increases in overall forest loss of 50 and 100 percent. The differences here are large and significant, indicating that as deforestation increases, it progresses to more remote areas of higher slope and altitude.

See Table 8.

A visual representation of this phenomenon can be seen in figures 1, 2, and 3. The first figure shows the actual areas deforested in *ejido* A between 1994 and 2000 in red. Houses are shown in black, while pasture in the base year is in yellow. The actual deforestation in this community was 279 hectares, while the predicted total value was 220. The yellow areas are agricultural or pasture areas in the base year, and the black houses represent the location of housing within the community. Figure 2 shows the predicted deforestation at a parcel level using the baseline level of forest loss. The pink areas are forest at risk, with darker colors indicating higher probabilities of deforestation. Figure 3 simulates a 50% increase in predicted demand. Comparing these two figures we can see how an increase in overall deforestation increases the risk for areas at an increasing distance, slope and altitude from the houses.

See figures 1, 2 & 3.

Table 9 shows the estimation of equation (8), the change in pasture area, $C^p$, from 1994 to 2000. Confidence intervals are bootstrapped because of the presence of predicted values in the equation. In the data, 129 of the 318 ejidos do not increase their pasture area. 101 of these had no change while the rest actually had reforestation. 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 45 hectares. The effect of average distance to converted pixels is negative as expected, and large - a one standard deviation increase in distance decreases deforestation by about 112 hectares. An increase of the same magnitude in slope decreases the area deforested by 120 hectares, while a similar increase in altitude decreases it by 141. The F-test for non-significance of all of the physical variables has a p-value of .007.

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 causing a 77 hectare increase in pasture expansion. We measure inequality using the Gini coefficient of private land parcels within the *ejido* - that is, the land division which was established at the founding of the *ejido*, where land and rights can only be passed on to one child. Changes in this variable have quite strong effects, with a one standard deviation increase in inequality decreasing pasture demand by 88 hectares. One hypothesis for why this occurs might be that sub-coalitions form to regulate the commons at high levels of inequality ((Munoz-Pina 2001) 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 (see Baland & Platteau (1997) for a thorough treatment of this argument). We will examine these hypotheses in a later section, though at this point it is important to note that the effect is significant even holding wealth constsant - represented by municipal level marginality. Although these community effects are not nearly as large in magnitude as the effects of the physical variables, given the mean deforestation level of 234 hectares, their impact is substantial.

A final community variable of interest is the proportion of households with secondary education, which has a negative and significant effect. It is important to note that these effects are significant even while 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).

See Table 9.

# 7 Community behavior

The results show that aggregate measures of household characteristics affecting productivity and cooperation, $X^p$ and $Z$, in the revenue maximization problem have substantial effects on deforestation behavior at the community level. The aggregate nature of the model, however, does not shed much light on the exact form of these mechanisms. In this section we examine both community data on governance as well as household data collected in the survey and describe the channels through which these characteristics may be affecting overall deforestation. The first subsection analyzes hypotheses about how inequality might affect participation and decision-making in our communities, the second the individual characteristics of those using the commons and the third presents a more concrete theory and test of partial cooperation within these communities.

## 7.1 Simple statistics on inequality

One of the most striking results in terms of the overall deforestation estimation is the negative effect of inequality on forest loss. As we saw above, changes in this variable have quite a large impact, with a one standard deviation increase in inequality decreasing forest conversion by 88 hectares. We also briefly mentioned how inequality might operate through either the community's overall ability to cooperate or directly through household constraints. To see the latter, consider an example given by Baland & Platteau (1997) describing how inequality in the the distribution of credit constraints among fishermen (holding overall wealth constant) can decrease the total number of boats they put in the water. To see this, 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 is left constant. The users who have had their constraints tightened will reduce their effort while the second set of users will appropriate at the same Nash equilibrium level. The total amount of exploitation thus decreases, even in the absence of cooperation.

Given that our specification does not allow us to disentangle the cooperation versus constraint effects of inequality, this section is dedicated to using simple summary statistics to shed some light on this mystery by examining commons use, political participation and rule-making. Our data does not enable us to examine the levels of conversion of different members of the *ejido*, however, we can see who is using the commons and what they are using it for. If the constraint hypothesis above holds in our case, and those with relatively smaller holdings are constrained in their use of the commons, then we should see more intensive use of the commons by those with larger private landholdings.

Recalling that we measure inequality using land endowments, table 10 shows summary statistics on commons use for parcel owners in the upper and lower 20 percent of the parcel distribution for each ejido. We have no measure of intensity, given that our questions merely asked if a member used the commons for agriculture, pasture, or both, not how much land they converted over a given period. However, livestock husbandry requires more land than growing corn for subsistence use, and so one might consider this use a proxy for higher appropriation. Table 10 shows some evidence in support of the Baland/Platteau hypothesis. In communities with low inequality, there is no difference between the lowest and highest quintile of landowners in their likelihood of not using the commons at all, while in high inequality communities, we see that the land poor have a significantly higher "non-use" than those with more abundant land. Also in the most unequal communities, it is much more common for land-rich households to have cattle or both cattle and agriculture in the commons than it is for those in the lowest quintile. There is no significant difference between these propensities in the more egalitarian villages, though the sample size here is quite small to be able to make an unequivocal statement. It is also useful to note that the lower deforestation in the high inequality communities does not result from their having fewer cattle - these villages have average sized herds of 9.1, as opposed to 5.5 for low inequality villages (t-test for difference = 3.4). Obviously, these numbers should be taken as suggestive, since we are not holding wealth constant here.

See Table 10.

The other possibility is that inequality works through the decision-making process of the community over the commons, which usually takes place in community assemblies headed by an elected council- this is the "Z", or cooperation effect we discussed above. Table 11 suggests that some mitigation of appropriation may operate through this mechanism. First, we see that more unequal ejidos are considerably larger that more egalitarian ejidos (as measured by the distribution of their parceled land) - on average 70 members larger. Normally, one would expect larger *ejidos* to have more deforestation, not less. We also see that less egalitarian *ejidos* seem to have a greater concentration of power in the hands of certain families or *ejido* members; on average, 41 percent of ejidatarios or their family members have been in leadership positions in these communities, while this number is 49 percent for those with lower inequality. In addition, participation in meetings, as measured by the proportion of members who always attend (a household variable) and the proportion who attended the last meeting (a community observation), is lower in the unequal communities. It is interesting to note that if we look at participation according to the divisions presented in table 10, by land-holding quintile, we see that 63% of *ejidatarios* in the lowest 20% of the land distribution always participate, while 74% *ejidatarios* in the highest 20% always participate (t-test for difference, 5.4). This combination of facts suggests that a relatively smaller proportion of ejido members are participating in the collective decision making process in unequal *ejidos*, and that this proportion is dominated by larger land holders.

See Table 11.

The above statistics imply that inequality in land distribution within the *ejidos* may operate through both mechanisms - directly by constraining the conversion tendencies of small landholders and indirectly through the formation of a group to manage the use of the commons.

### 7.2 Who uses the commons?

In what follows we would like to first describe the users of the commons, and then in the following section exploit this description to form a proxy for a cooperating group in order to see if a subgroup of "cooperators" can actually have an effect on overall deforestation. Although we do not know individual levels of deforestation, we do know from our census if a given *ejido* member uses the commons for pasture or agriculture. The census is composed of a random sample of 50 members from each community. The regression shown in table 12 is a fixed effects logit for the variable equal to 1 if the member uses the commons for agricultural or pasture purposes and zero otherwise. This gives us a good deal of information about the people choosing to undertake activities in the commons. Older members who have had someone in their family as a leader in the *ejido* are more likely to use the commons, as are those with more young children. Those who have household members who have finished secondary school are also more likely to use the commons, though one might think that they would have better outside working options. Households with secondary education on average have much larger cattle herds, 9 head, compared to those without, who have an average of 6 (t-test for difference = 4.9). This positive relationship probably occurs as a result of the investment of off-farm income into cattle.

See Table 12.

Support for the remittance investment hypothesis comes from a qualitative question that was asked to participants who responded that agriculture and pasture were the main sources of land demand. As discussed before, the community council members were the respondents to the survey, and were presented the follow-up question of what were the two main factors that influenced increased demand in both categories. For pasture demand, we found that the profitability of cattle herding explains most of the drive for pasture expansion with 60%, followed up closely by the use of cattle for insurance with 48%. Although no question was asked regarding whether cattle were also used as a savings mechanism, this is clearly the implication of the correlations between secondary education, off-farm income, and cattle holdings. Because the amount of cattle held by a given family may be endogenous to the choice to use the commons, one way to test the hypothesis just presented is to use migration and education to instrument for cattle holdings. This of course requires that these two variables do not have any independent effect on commons use, which we can test for. Table 13 presents both the first stage regression and the results from a fixed-effects instrumental variables linear probability model. The overidentification test statistic is 1.6, which gives a p-value of about .79, so we cannot reject exogeneity of the instruments. The first stage regression shows us what we already suspected - having migrants to the United States and educated members in the household greatly increases the number of cattle that a family holds. The second stage confirms that cattle is a significant determinant of commons use, with increases in cattle holdings increasing the probability of using the commons. The effects of leadership experience and poverty remain qualitatively similar to before, and private land holdings maintain the same negative sign but are now significant.

See table 13.

This analysis suggests strongly that much of the use of the commons results from the investment of remittances in cattle, whether it be for savings or insurance.

### 7.3 Partial cooperation

The discussions about the mechanism through which inequality acts on deforestation and the identity of the users of the commons do not give us a definitive idea about how exactly the community organizes itself to manage its forest resource. A myriad of game theories have been proposed to explain the management of common property resources, some of them specific to the *ejidos*. One example is McCarthy, de Janvry & Sadoulet (2001)'s theory of costly cooperation, which hinges on the transactions costs of cooperating in pasture management. The outcome of this theory is that as transactions costs increase, the quality of cooperation decreases along a continuum, with all players cooperating at the same level.

A slightly different story is told in Alix-Garcia et al. (forthcoming), where instead of everyone cooperating at the same level, subgroups of cooperators and non-cooperators operate simultaneously. In many villages, one observes a core group of households who seem to work together, setting and obeying rules limiting the amount of cattle in the commons or the wood extracted for domestic use. Moreover, this group exists despite the fact that there often are people around it who are not obeying the rules. This is the concept of a sub-coalition of cooperators.

The intuition of the model is as follows. Households derive benefits from the forest. These benefits may vary across households and include current benefits such as firewood, house-building materials, and non-wood products as well as future benefits. Both current and future benefits depend upon the quality of the forest, accessibility, and its state at time zero. There may also be benefits from cutting the forest, or encroachment, which include profits from agriculture and cattle, or insurance from cattle. These benefits are decreasing with the size of parceled or private landholdings and increasing with family size, population pressure, and the quality of potential agricultural or pasture land. Finally, there is a cost to encroachment that encompasses the work needed to remove forest and the risk of punishment incurred from being caught encroaching.

The conditions derived from the model sort the households into three distinct groups as a function of land endowments, outside employment options, and the opportunities available on ejido land. These characteristics determine in which of three categories a household will derive the highest net benefits: those who have nothing to gain from encroachment, those who will always be better off encroaching than cooperating, and those who, as a group, will be better off cooperating than encroaching, even when others are encroaching.

The first group is comprised of households who have a low demand for common land because they either support themselves with outside jobs, have sufficient private land, or the potential agricultural land is too far away to make it worth the effort of going and clearing it. They accrue no gains from cutting down the forest, and potentially benefit from its continued existence. We call them "passive cooperators", as no incentive is needed to induce them to curb their deforestation activities. The second group is composed of households with high cattle to land ratios, or high household size to land ratios, or little chance of accessing future benefits from the forest (e.g., they may not be *ejidatarios*). They are better off cutting down more trees than not. For this reason, we label them "unrestrained encroachers".

The last group is composed of "cooperators." Cooperation gains are equal to the difference between a cooperator's benefits when he is part of the group that does not encroach on the forest (or clears at a lower level), and the benefits he would receive if cooperation broke down and all members of the group were to cut forest at their optimal individual level. These households have access to current and future benefits, with high costs to encroaching. While the structure of benefits makes these households prefer a cooperative solution, it is not sufficient to prevent individual defaulting at the margin on the group's decision. This is the usual incentive that leads to a non-cooperative equilibrium, even in the case of recognized benefits from cooperation. Sustainability of the coalition requires, as in most cooperation cases, an enforcement mechanism. The coalition of cooperators is thus composed of households that have voluntarily given themselves a mechanism of enforcement and punishment that prevents the unraveling of their collective choice. They typically commit to the cooperative encroachment level by a show of hands in the assembly. This type of mechanism is not unusual in agrarian communities (see Baland & Platteau (1996) for similar examples).

Using the commons does not necessarily mean that users are deforesting, nor does non-use equal cooperation, which would involve farmers using commons land at a lower level than they would in a non-cooperative solution. We can, however, make some educated guesses about who might be more likely to use the commons more intensively (and therefore convert forest). If we make the assumption that those with smaller parcels are more likely to need more land from the commons then we can divide these *ejidatarios* into four groups along a continuum of likelihood to deforest. This division is described in table 15, along with labels which we described above. Encroachers are those with the most incentive to convert forest because they have a very small land endowment per household member. "Possible cooperators" have large land endowments, but use the commons anyways. "Passive cooperators" need not be passive, but are labeled in this way because they have large amounts of land and do not farm or put cattle in the commons. One might think of them as the potential cooperation leaders, as their main benefits come from using the standing forest. Finally "cooperators" are labeled as such because they seem to have a strong incentive to encroach (small land endowment), but do not do so.

See Table 14.

Table 15 summarizes some other information we have on people in these categories. Here we see that encroachers are the poorest members of the *ejido*, as measured by their participation in Progresa, an educational subsidy program. The possible cooperators are not nearly as poor, with high migration to the United States and large cattle herds. This latter fact gives them countervailing incentives: first, to manage the common pasture well because they have the highest stake in it, and second, to abuse the pasture more since they have the biggest need for it. Leaders are more likely to come from the "possible cooperator" group, though the differences across this variable are not very large. "Cooperators" are the most likely to have someone in their household working off-farm, have very small cattle herds and are the least likely to be receiving the maize subsidy program Procampo.

See Table 15.

In order to create a proxy for cooperation, we must use the predicted values of commons use rather than the actual ones, which we extract from our reduced form equation of commons use detailed in table 12. We combine these predicted probabilities with the categorization of members according to land class. Taking the mean of this calculation gives us the proportion of members that we expect to see in each group. In order to find the number of group members in the cooperation categories, we simply multiply this by the number of members in 1990. The next question is how these proxies affect deforestation.

Table 16 shows the correlation coefficient, regression coefficients and bootstrapped confidence intervals of the effect of cooperation group size on deforestation. These coefficients come from adding our proxy for the number of cooperators in each community to the deforestation regression of table 9. We create an upper bound for the encroacher group as explained above. The lower bound is composed of just those who do not encroach and have no incentive to do so, the "passive cooperators". We also include a possible upper bound on the non-cooperative group, which is the "encroachers" category plus the number of non-members in the community. We show only the coefficients of interest here, given that we have already examined the larger table. We find that the simple correlations all have the expected sign - negative for the lower and upper bounds on the size of the cooperation group and positive for the upper bound on non-cooperators. Once we put these into the regression, however, we find that a possible lower bound on cooperation has no significant effect on overall deforestation, although the point estimate is negative. The upper bound, however, has quite a large and significant effect–a one standard deviation increase in group cooperation size (189 members) would lead to an 142 hectare decrease in forest loss over the period. Finally, the upper bound on non-cooperation shows a positive though insignificant effect on deforestation.

See Table 16.

This section gives us some evidence that increases in the size of a sub-coalition of cooperators, even in the presence of non-cooperators within the community, can positively impact forest conservation.

## 8 Conclusions

We have presented a theory of the deforestation of common property forest over space. In contrast to previous deforestation theories, ours 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 upon its characteristics relative to those of other plots of land within the same community and on that community's demand for forest conversion. Simultaneously, total deforestation depends, through the marginal value of the converted land, on the characteristics of the most profitable parcels and on community features affecting the collective action problem.

We tested this theory using data from 318 Mexican ejidos and found support for these hypotheses. Specifically, we see that within a given ejido, parcels of forest that are relatively closer, of lower slope and altitude in a particular community are at higher risk of deforestation. Given that the Mexican government is currently designing programs of payments in exchange for forest conservation, one implication is that these payments should be higher for land within an ejido with these types of characteristics. Similarly, between ejidos, targeting should focus on those with large tracts of accessible forests on land of good quality for agriculture or pasture. With regards to community variables, we find the encouraging result that 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. 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. Using individual data, we see some evidence that inequality operates through constraints on those with smaller endowments, though it is also possible that it works through the formation of sub-coalitions to manage the commons more efficiently.

We analyzed the characteristics of the community members that use the commons, finding that older individuals who have been leaders, have migrants from their household to the U.S., have household members with secondary education, and larger families are more likely to use the commons. We also see that education and migration affect commons use through the number of cattle held by a household, a finding that corroborates field observations of the use of cattle as a savings and insurance mechanism. This suggests that policies to support alternative forms of savings in rural areas could reduce deforestation.

In order to test the hypothesis that groups of cooperators may exist even in the presence of non-cooperators in the same community, we divided community members into groups with potential to deforest according to their use characteristics and their land endowment. We find that those that are most likely to cooperate are the least likely to have been leaders, have the smallest cattle herds, do not receive subsidies for farming and are the most likely to have off-farm employment. Those most likely to convert forest to pasture or agriculture have medium sized cattle herds, are the least likely to have off-farm employment and are the poorest sub-group. Using a proxy for cooperation constructed from this information, we find empirically that larger cooperation groups are associated with considerably lower deforestion.

## References


Alix-Garcia, J., de Janvry, A. & Sadoulet, E. (2004), 'Payments for Environmental Services: To Whom, For What, and How Much?'. Working Paper, Department of Agricultural and Resource Economics, University of California, Berkeley.

Alix-Garcia, J., de Janvry, A. & Sadoulet, E. (forthcoming), 'A Tale of Two Communities: Explaining Deforestation in Mexico', *World Development* .

Anselin, L. (1999), 'Spatial Econometrics'. Working Paper, Bruton Center, School of Social Sciences, University of Texas as Dallas.

Baland, J.-M. & Platteau, J.-P. (1996), *Halting Degradation of Natural Resources: Is There a Role for Rural Communities?*, Oxford University Press.

Baland, J.-M. & Platteau, J.-P. (1997), 'Wealth Inequality and Efficiency in the Commons. Part I: The Unregulated Case', *Oxford Economic Papers* **49**(4), 451–482.

Cardenas, J.-C. (2003), 'Real Wealth and Experimental Cooperation: experiments in the field lab', *Journal of Development Economics* **70**, 263–289.

Chomitz, K. & Gray, D. (1996), 'Roads, Land Use and Deforestation:a spatial model applied to Belize', *World Bank Economic Review* **10**, 487–512.

Chomitz, K. & Thomas, T. (2003), 'Determinants of Land Use in Amazonia: A Fine Scale Spatial Analysis', *American Journal of Agricultural Economics* **85**(4), 1016–1028.

Conley, T. (1999), 'GMM Estimation with Cross Sectional Dependence', *Journal of Econometrics* **92**, 1–45.

Dayton-Johnson, J. (2000), 'Determinants of Collective Action on the Local Commons: a model with evidence from Mexico', *Journal of Development Economics* **62**, 181–208.

Deininger, K. & Minten, B. (1999), 'Poverty, Policies, and Deforestation: The Case of Mexico', *Economic Development and Cultural Change* **47**(2), 313–325.

Godoy, R. & Contreras, M. (2001), 'A Comparative Study of Education and Tropical Deforestation among Lowland Bolivian Amerindians: Forest Values, Environmental Externality, and School Subsidies', *Economic Development and Cultural Change* **49**(3), 555–574.

Goetz, R. & Zilberman, D. (2003), The Economics of Land-Use Regulation in the Presence of an Externality: A Dynamic Approach. Working paper, Department of Agricultural and Resource Economics, University of California, Berkeley.

McCarthy, N., de Janvry, A. & Sadoulet, E. (2001), 'Common Pool Resource Appropriation Under Costly Cooperation', *Journal of Environmental Economics and Management* **42**(3), 297–309.

Molnar, A., Scherr, S. & Khare, A. (2004), *Who Conserves the World's Forests?*, Forest Trends.

Monroe, D., Southworth, J. & Tucker, C. (2002), 'The Dynamics of Land-cover Change in Western Honduras: Exploring Spatial and Temporal Complexity', *Agricultural Economics* **27**, 355–369.

Munoz-Pina, C. (2001), 'Structural Reforms and the Individual Appropriation of the Commons in the Mexican Ejido'. Ph.D. Dissertation, Department of Agricultural and Resource Economics, University of California, Berkeley.

Pfaff, A. (1999), 'What Drives Deforestation in the Brazilian Amazon?', *Journal of Environmental Economics and Management* **37**, 26–43.

Pinkse, J. & Slade, M. (1998), 'Contracting in Space: An Application of Spatial Statistics to Discrete Choice Models', *Journal of Econometrics* **85**, 125–154.

Puri, M. C. J. & Griffiths, C. (2001), 'Predicting the Location of Deforestation: The Role of Roads and Protected Areas in North Thailand', *Land Economics* **77**(2), 172–186.

Segura, G. (2000), Mexico's Forest Sector and Policies: A General Perspective. Presented at "Constituting the Commons: Crafting Sustainable Commons in the New Millenium," the Eight Conference of the International Association for the Study of Common Property, Bloomington, Indiana, USA.

Vance, C. & Geoghegan, J. (2002), 'Temporal and Spatial Modeling of Tropical Deforestation: A Survival Analysis Linking Satellite and Household Survey Data', *Agricultural Economics* **27**, 317–332.

Velasquez, A., Mas, J. F. & Palacio, J. L. (2002), Análisis del Cambio de Uso del Suelo. Convenio INE-IGg (UNAM).

Xabadia, A., Goetz, R. & Zilberman, D. (2003), 'Control of Accumulating Stock Pollution by Heterogeneous Polluters'. Working paper, Department of Agricultural and Resource Economics, University of California, Berkeley.

# 9 Tables

Table 1: Summary Statistics on Deforestation, 1994-2000

| Characteristic | Mean | SD |
|---|---|---|
| Number of *ejidos* | 318 | |
| Hectare increase in pasture/ag land, 1994-2000 | 234 | 562 |
| Total hectares in pasture, 1994 | 998 | 1,701 |
| Total *ejido* area in hectares | 3,888 | 5,956 |
| Percentage of *ejidos* with deforestation | 59 | |

Table 2: Percent positive responses to the question: "Why was this area deforested?"

| Reason | |
|---|---|
| For agriculture | 50 |
| For pasture | 51 |
| For wood | 4 |
| Forest fire | 9 |

Table 3: Percent 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 |

Table 4: Pixel characteristics by deforestation

| Characteristic | Not deforested | Deforested between 1994-2000 |
|---|---|---|
| Distance rank within *ejido* | 5,949 | 2,987 |
| | (8,187) | (6,324) |
| Slope rank within *ejido* | 5,224 | 2,102 |
| | (7,934) | (5,261) |
| Altitude rank within *ejido* | 5,467 | 2,509 |
| | (8,235) | (5,967) |
| Distance to houses (km) | 8.3 | 7.8 |
| | (3.7) | (4.0) |
| Slope (degrees) | 11.7 | 6.5 |
| | (9.6) | (7.5) |
| Altitude (meters) | 754 | 580 |
| | (746) | 810 |
| Observations | 821,426 | 111,407 |

Table 5: Fixed-effect OLS pixel regressions comparing absolute and relative characteristics

Dependent variable = 1 if hectare deforested between 1994-2000

| Characteristic | (1) Deforestation on absolute value of characteristics | (2) Deforestation on relative characteristic values | (3) Residuals of (1) on relative characteristic values |
|---|---|---|---|
| Distance | -.011 | $-4.4\ 10^{-6}$ | $-2.7\ 10^{-6}$ |
| | (.0002)*** | ()*** | $(8.6\ 10^{-9})$*** |
| Slope | -.005 | $-4.5\ 10^{-6}$ | $-3.4\ 10^{-6}$ |
| | (.0001)*** | $(1.1\ 10^{-7})$*** | $(7.7\ 10^{-9})$*** |
| Altitude | -.06 | $-3.1\ 10^{-6}$ | $-1.8\ 10^{-6}$ |
| | (.003)*** | $(1.0\ 10^{-7})$*** | $(7.1\ 10^{-9})$*** |
| Distance*slope | -.0002 | $2.1\ 10^{-10}$ | $1.5\ 10^{-10}$ |
| | (.00001)*** | $(5.2\ 10^{-12})$*** | $(3.6\ 10^{-}13)$*** |
| Distance* altitude | .003 | $1.4\ 10^{-10}$ | $3.1\ 10^{-11}$ |
| | (.0002)*** | $(4.7\ 10^{-}12)$*** | $(3.2\ 10^{-13})$*** |
| No. parcels of lower slope and distance | | $-3.1\ 10^{-6}$ | $-4.0\ 10^{-6}$ |
| | | $(1.8\ 10^{-7})$*** | $(1.2\ 10^{-8})$*** |
| Constant | .27 | .17 | .16 |
| | (.002)*** | (.0007)*** | (.00005)*** |
| Observations | 952,356 | 952,356 | 952,356 |
| R-squared | .026 | .038 | .04 |

Robust standard errors in parentheses. *,**,*** represent significance at the 10, 5 and 1% levels.

Table 6: Reduced Form of Equation (6), Spatial Deforestation Decision

Dependent variable = 1 if pixel deforested between 1994-2000

| Characteristic | Variable | Marginal Effect |
|---|---|---|
| Pixel distance rank (/10000) | $d$ | -0.04 |
| | | (0.02)** |
| Pixel slope rank (/10000) | $q$ | -0.07 |
| | | (-0.02)*** |
| Pixel altitude rank (/10000) | | -0.05 |
| | | (0.03) |
| Distance*slope rank (/1000000) | | 0.0004 |
| | | (0.0001)*** |
| Distance*altitude rank (/1000000) | | 0.0001 |
| | | (0.0001) |
| Parcels with lower slope and distance (/10000) | | -0.09 |
| | | (0.03)*** |
| Average distance to forested area in km | | -0.005 |
| | | (0.002)*** |
| Average slope of forested area in degrees | | -0.007 |
| | | (0.002)*** |
| Average altitude of forested area in meters | | -0.005 |
| | | (0.01) |
| Hectares of forest, 1994 (1000s ha) | $T^f$ | 0.002 |
| | | (0.001) |
| Agricultural/pasture land, 1994 | $T^p$ | 0.001 |
| | | (0.02) |
| Average private parcel | $X$ | -0.0007 |
| | | (0.0002)*** |
| Proportion of households with secondary education | | -0.06 |
| | | (.03)** |
| Number of *ejidatarios*, 1990 | $Z$ | 0.00003 |
| | | (0.00002) |
| Gini coefficient of private parcels | | -0.11 |
| | | (0.04)*** |
| Chile prices, 1993 (1000s pesos) | $p^p$ | 0.004 |
| | | (0.008) |
| Bean prices, 1993 (1000s pesos) | | -0.02 |
| | | (0.01) |
| % growth bean prices 1993-2000 | | 0.008 |
| | | (0.05) |
| Observations | | 931,812 |
| Pseudo R-squared | | 0.13 |
| Log-likelihood | | -297,653 |

This regression also includes the proportion of overall forest in secondary vegetation, hours to nearest town, municipal marginality index, 1990, index growth, 1990-2000, municipal population growth, and the number of ejidatarios x Gini, none of which were significant.

*,**,*** represent significance at the 10, 5 and 1% levels.

Table 7: Estimation of Equation (6)

Dependent variable = 1 if pixel deforested between 1994-2000

| Characteristic | Variable | (1) Probit Equation (6) | (2) Probit Equation (6) + slope, dist, alt | (3) Linear Probability |
|---|---|---|---|---|
| Pixel distance rank (/10000) | $d$ | -0.05 | -0.05 | -0.06 |
| | | (0.02)** | (0.02)** | (0.04)* |
| Distance to houses in km | | | -0.001 | |
| | | | (0.001) | |
| Pixel slope rank (/10000) | $q$ | -0.08 | -0.03 | -0.06 |
| | | (0.04)*** | (0.027)* | (0.04) |
| Slope in degrees | | | -0.003 | |
| | | | (0.0005)*** | |
| Pixel altitude rank (/10000) | | -0.05 | -0.06 | -0.05 |
| | | (0.04)** | (0.03)** | (0.03) |
| Altitude in meters | | | 0.001 | |
| | | | (0.01) | |
| Distance*slope rank (/1000000) | | 0.0005 | 0.0003 | 0.0003 |
| | | (0.0002)*** | (0.0001)** | (0.00002)* |
| Distance*altitude rank (/1000000) | | 0.0002 | 0.0002 | 0.0002 |
| | | (0.0002) | (0.0004) | (0.0001)* |
| Parcels with lower (/10000) slope and distance | | -0.08 | -0.06 | -0.06 |
| | | (0.04)** | (0.08) | (0.06) |
| Converted forest, 1994-2000 (1000s ha) | $C^p$ | 0.21 | 0.18 | 0.26 |
| | | (0.04)*** | (0.03)*** | (0.06)*** |
| Hectares of forest, 1994 (1000s ha) | $T^f$ | -0.07 | -0.07 | -0.09 |
| | | (0.03)** | (0.02)*** | (0.04)** |
| Observations | | 931,812 | 931,812 | 931,812 |
| R-squared | | 0.11 | 0.12 | 0.07 |
| Log-likelihood | | -302,603 | 300,001 | - |

* significant at 5% level; ** significant at 1% level. Prices are also included in this estimation but are not significant

Standard errors bootstrapped 1000 times.

Table 8: Changes in characteristics of deforested area with changes in overall deforestation

| Characteristic | Variable | Actual forest loss | 50% increase in forest loss | Doubling of forest loss | t-test between (1) & (2) | t-test between (2) & (3) |
|---|---|---|---|---|---|---|
| Distance Rank | $\overline{d}^c$ | 1,248 | 1,300 | 1,343 | 3.4 | 1.6 |
| Slope Rank | | 989 | 1,054 | 1,146 | 5.0 | 3.9 |
| Altitude Rank | $\overline{q}^c$ | 1,060 | 1,110 | 1,169 | 3.6 | 3.6 |

Table 9: First stage regression of equation (8) to determine overall pasture demand

Dependent variable = hectares in *ejido* deforested between 1994-2000

| Characteristic | Variable | Coefficient | Mean |
|---|---|---|---|
| Total forest land, 1994 (1000s ha) | $T$ | 49.7 | 3.9 |
| | | (13.9)** | (5.9) |
| Total ag/pasture land, 1994 (1000s ha) | $T^p$ | -12.4 | 1.0 |
| | | (26.3) | (1.7) |
| Mean distance to pixels with predicted deforestation | $h^c(\cdot), g^c(\cdot)$ | -29.5 | 8.3 |
| | | (15.8)* | (3.8) |
| Mean slope of pixels with predicted deforestation | | -18.7 | 9.3 |
| | | (10.6) | (6.4) |
| Mean altitude of pixels with predicted deforestation | | -166.3 | .75 |
| | | (57.4)** | (.85) |
| Distance*slope | | 0.26 | 73.3 |
| | | (1.1) | (59.0) |
| Distance*altitude | | 17.7 | 6.1 |
| | | (7.4)** | (8.3) |
| Proportion of forested land in secondary forest | $X^f, X^p$ | 44.3 | .24 |
| | | (117.3) | (.27) |
| Hours to pueblo by bus | | -30.7 | 1.1 |
| | | (24.8) | (1.0) |
| Average private parcel size | | -1.6 | 12.6 |
| | | (1.8) | (23.3) |
| Proportion of households with secondary education | | -235.4 | .53 |
| | | (83.7)** | (.26) |
| Municipal population change, | | -168.5 | .015 |
| 1990-2000 | | (1,951) | (.013) |
| Marginality index, 1990 | | -41.0 | -.13 |
| | | (24.7) | (.93) |
| Change in index, 1990-1995 | | -72.8 | .09 |
| | | (132.7) | (.24) |
| Number of *ejidatarios*, 1990 | $Z$ | 0.28 | 153 |
| | | (.22) | (275) |
| Gini coefficient of parcels | | -491.2 | .25 |
| | | (170.4)** | (.18) |
| *Ejidatarios**Gini | | -.84 | 41.8 |
| | | (.72) | (101.3) |
| Bean prices, 1993 (1000s) | $p^p$ | -32.1 | 2.5 |
| | | (60.2) | (.54) |
| Chile prices, 1993 (1000s) | | 35.1 | 2.7 |
| | | ( 36.5) | (1.1) |
| % growth in bean prices,1993-2000 | | 434.1 | 41.8 |
| | | (278.5) | (101.3) |
| Constant | | 1,031.7 | |
| | | (411.1)** | |
| Observations | | 318 | |
| R-squared | | 0.27 | |
| Dependent Variable | | | 234 |

Standard are bootstrapped 1000 times. *,** indicate significance at 10 and 5%, respectively

Table 10: Use of the commons in highest and lowest quintiles of landholding by inequality categories

| Inequality | | Do not use the commons at all | Have an agricultural parcel in the commons | Keep cattle in the commons | Have a parcel AND keep cattle in the commons |
|---|---|---|---|---|---|
| Low $\leq .24$ | Lowest 20% of landholders | .24 | .10 | .14 | .09 |
| n=82 | Highest 20% of landholders | .23 | .08 | .15 | .13 |
| | Chi-squared test for difference | 1.1 | .91 | .31 | 1.6 |
| High $> .24$ | Lowest 20% of landholders | .28 | .16 | .11 | .06 |
| n=139 | Highest 20% of landholders | .25 | .11 | .16 | .13 |
| | Chi-squared test for difference | 2.0 | 3.4 | 3.0 | 4.6 |

Standard errors in parentheses

Table 11: Measures of participation by inequality levels

| Variable | Low inequality | High inequality (Gini $> .24$) | Test for difference |
|---|---|---|---|
| *Ejido* membership in 1990 | 118 | 188 | 2.3 |
| Proportion of *ejidatarios* who always participate in meetings | .77 | .66 | 3.5 |
| Proportion of *ejidatarios* or their family who have been in leadership positions | .49 | .41 | 3.0 |
| Percent attendance at last assembly | 81 | 76 | 1.1 |
| Number of observations | 160 | 160 | |

Table 12: Likelihood of using the commons
Dependent variable = 1 if use the commons for agriculture or pasture
Conditional fixed effects logit.

| Characteristic | Coefficient | Standard Error | Mean |
|---|---|---|---|
| Age of *ejidatario* | .007 | (.003)*** | 52 |
| | | | (15.1) |
| Migrant in U.S. | .13 | (.09) | .29 |
| | | | (.45) |
| Has secondary education | .19 | (.08)*** | .49 |
| | | | (.50) |
| Number of children less than 15 | .07 | (.03)*** | .94 |
| | | | (1.3) |
| Private land per capita | -.002 | (.006) | 3.9 |
| | | | (10.4) |
| Has held leadership position | .57 | (.09)*** | .36 |
| | | | (.48) |
| Progresa poverty index | .26 | (.10)*** | .41 |
| | | | (.49) |
| Observations | 3,901 | | |
| Log likelihood | -1,830 | | |

Table 13: Instrumental Variables Estimation of Effect of Cattle Holdings on Commons Use
Fixed-Effect Logit IV

| Characteristic | First Stage<br>Dependent Variable =<br>Number of Cattle | IV<br>Dependent Variable =<br>1 if Use Commons |
|---|---|---|
| Migrant in U.S. | 1.8 | |
| | (.83)*** | |
| Has secondary education | 1.9 | |
| | (.76)*** | |
| Number of Cattle | | 0.08 |
| | | (0.04)** |
| Age of *ejidatario* | .03 | .004 |
| | (.02) | (.004) |
| Number of children less than 15 | .78 | .01 |
| | (.28)*** | (.06) |
| Private land per capita | .61 | -.05 |
| | (.05)*** | (.03)** |
| Has held leadership position | 1.7 | .44 |
| | (.74)*** | (.01)*** |
| Receives Progresa | -1.8 | .41 |
| | (.83)*** | (.12)*** |
| Observations | 3,901 | 3,901 |
| R-squared | 0.04 | 0.03 |
| F-statistic | 23.3 | |
| Chi-squared | | 90.1 |

Table 14: Likelihood of cooperating given commons use & land endowment

| | Increasing likelihood of cooperating $\longrightarrow$ | | | |
|---|---|---|---|---|
| Use the commons | yes | yes | no | no |
| Have > 1 ha land per capita | no | yes | yes | no |
| "Label" | Encroachers | Possible cooperators | Passive cooperators | Cooperators |

Table 15: Characteristics of cooperating continuum

| Characteristic | Encroachers | Possible cooperators | Passive cooperators | Cooperators |
|---|---|---|---|---|
| Always participate | 78.8 | 67.2 | 71.0 | 61.4 |
| in meetings | (40.8) | (46.9) | (45.3) | (48.6) |
| Have been leaders | 40.3 | 42.5 | 40.6 | 29.9 |
| (or family members have) | (49.5) | (49.3) | (49.1) | (45.8) |
| Number of cattle | 5.8 | 13.7 | 6.6 | 1.5 |
| | (12.0) | (27.8) | (24.6) | (6.2) |
| Receive Procampo | 70.0 | 78.2 | 68.8 | 47.4 |
| | (45.8) | (41.3) | (46.3) | (49.9) |
| Household member | 24.6 | 30.7 | 29.0 | 35.8 |
| has off-farm job | (43.1) | (47.5) | (45.4) | (47.9) |
| Have household | 22.7 | 34.6 | 27.6 | 22.2 |
| member in U.S. | (41.9) | (47.6) | (45.4) | (41.5) |
| Receive Progresa | 61.1 | 48.8 | 54.1 | 53.8 |
| | (48.5) | (50.1) | (49.8) | (49.8) |
| Observations | 2,448 | 2,343 | 4,262 | 1,467 |
| Obs (Progresa) | 2,098 | 1,850 | 4,373 | 1,032 |

Table 16: Cooperation proxies and deforestation

| Category | Correlation coefficient | Regression coefficient | 95% Confidence Interval |
|---|---|---|---|
| Lower bound on cooperators | -0.08 | -.34 | (-1.5, 2.0) |
| Upper bound on cooperators | -0.12 | -.75 | (-2.3, -.20) |
| Upper bound on non-cooperators | 0.04 | .004 | (-.02, .02) |

Regression coefficients are marginal effect of proxy on total hectares deforested, 1994-2000, controlling for all the variables in table 10