

Pixel Patterns of Deforestation in Mexico 1993-2000 ¹

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Pixel Patterns of Deforestation in Mexico: 1993-2000

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1. Introduction

This paper uses a pixel approach to explain deforestation in Mexico between 1993/1994 and 2000, in both private and common forests. The data is generated from the comparison of the last two forest inventories, national censuses of private and community owners and, which makes it possible to identify most of the physical characteristics of the plots, and some of the basic characteristics of the decision makers. We follow an empirical approach, seeking to identify, among the variables that have been pointed out in the literature as important in explaining deforestation, those that have a significant effect in Mexico for the period studied. The information about the dependent variable at the pixel level is whether it was degraded, deforested or if the forest still stands, so the estimation is carried out with qualitative dependent variable estimation methods: probit, ordered probit, multinomial logit.

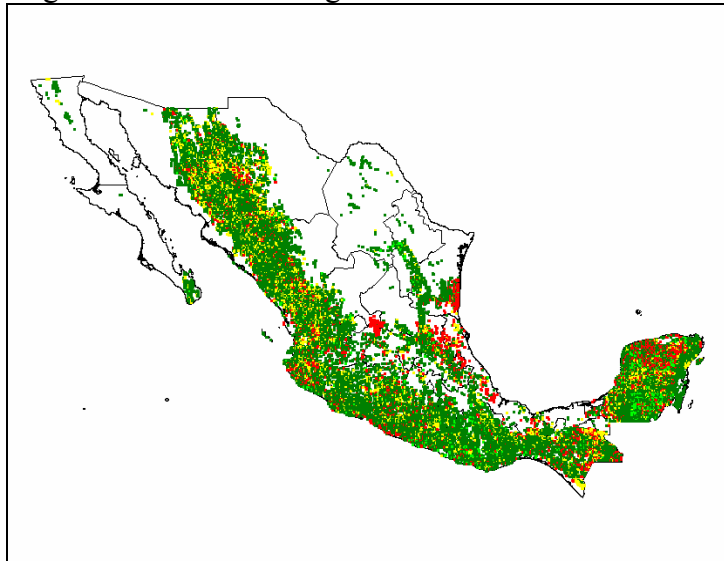
2. Data

The sources of the data are the National Forest Inventories of 1993 & 2000, the Ejido census of 1990, and the private property registry database of 1990-1992. The National Forest Inventory interpretation by INE² is used to identify the land use changes in Mexico. The data have a scale of 1:250,000, and distinguishes among 15 categories of forests, which are grouped here into two types of tropical forests: (1) rainforests and (2) dry tropical forests; and three types of temperate forests (3) coniferous, (4) pine/oak and cloudforests, and (5) oak and dry temperate forests.

A pixel grid of 23,402 points was obtained from the area under either primary or degraded forests in 1993. These points are located 0.05 degrees (≈ 5 km) apart from each other neighbor in the directions North-South and East-West. The relatively large distances between the points in the grid respond to two different needs. The first one is to reduce the computer time needed to calculate the travel cost related variables. The second reason is to reduce the effect of any spatially correlated error term. The incorporation of spatial dependence is indeed an important issue, but outside the scope of the analysis at this phase of the project.

² Alejandro Velázquez, Jean F. Mas y José Luis Palacio, “Análisis del Cambio de Uso del Suelo”, INE-IGg (UNAM), January 2002.

Figure 1. Land use change in Mexico



The yellow and red points indicate degradation and deforestation, while lighter green indicates regeneration.

The 5 potential outcomes that generate for each pixel a qualitative, but ordered, type of land use change are these:

- 1) Complete deforestation
- 2) Degradation, from primary forest to degraded forest
- 3) No change in primary forest
- 4) No change in secondary (degraded) forest
- 5) Regeneration, from degraded forest to primary forest

Explanatory variables:

The market signal for deforestation of a particular plot is the difference between the net present value of the rents it would generate as pasture or agriculture, and the positive rents that the forest would provide as a sustainable forestry operation and/or local source of materials and food. This latter value could be zero if the plot has no use. These potential rents depend on the physical characteristics of a particular plot, and the relative prices of the different outputs and inputs. However, similar market signals would have very different results depending on the institutions that frame the land use decisions. In Mexico, this framework has two basic formats: private and community property rights, with the added level of the formality and precision of land title held. Also part of the framework, Mexico has several regulations that set limits to the type of activities allowed in a particular forest, foremost among them those linked to the status of Natural Protected Area³ (ANP).

There are two variables that are important for the land use outcome: the undertaking of legal forestry operations, and the level of poverty of the forest owners. At least in the same time period they are endogenous to the fundamental characteristics of the plot and the forest owner. Incorporating them with a lag could solve the endogeneity problem, as would the use of instrumental variables. It is important to understand how precisely

³ *Área Natural Protegida* or ANP.

they would affect the deforestation decision. Regarding the decision of the forest owners to undertake legal timber operations, these would signal that the owners are expecting positive rents to be made from a particular forest, and, in the case of community owned forests, that at least a basic organization has emerged to manage common property resources under the restrictions of costly cooperation. Being legally sanctioned operations also means the forest owners have the (imperfectly enforced) regulatory requirement of undertaking reforestation and having a long term management plan for their forest. The indicator we have is imperfect, because it does not refer to the decision to undertake forestry by the owner(s) of the plot where the pixel is, but to anyone in the census tract undertaking legal forestry activities.

In a different perspective, the poverty levels of the land owners and other inhabitants of the villages in close proximity to the forest can influence the land use decisions in several ways, either as a liquidity constraint for timber, cattle or commercial agriculture operations, or as a high discount rate. As a liquidity constraint it is expected that timber would face more restrictions than the other activities given the long term maturation of the investments. In order to use these variables to explain land use changes, we seek to obtain their values for the immediate period before the initial forest cover observation, so at least the decision or outcome is exogenous to the period where deforestation is measured.

The potential explanatory variables are thus classified in three main groups: The first one are those that relate to the physical characteristics of the pixel that have an influence on the relative productivity of the land in generating timber or other forest products on the one hand, and agricultural or cattle ranching outputs on the other. The second group of variables refers to the transaction costs of bringing inputs from and sending outputs to the market, creating a divergence of local net prices from the national level price. The third group refers to the institutional framework that constrains this decision, including the type of property, and the characteristics of the owners. In what follows these are discussed in more detail, presenting their descriptive statistics. The second section of the paper presents the results of the econometric work, and the third section discusses the results to draw conclusions.

3. Descriptive Statistics

The mean, variance, and minimum and maximum values of the variables for the entire grid are presented in table 1. In table 2 we have the mean and variance for the exogenous variables divided according to whether the pixel was deforested, degraded, regenerated or experienced no change.

Deforestation and Degradation

The grid was constructed over the existing forests in 1994, which included two options of the initial state: 1) primary forests -those that have the species composition, and structure of a well preserved forest- and 2) secondary forests -where some degradation has been experienced-. The primary forests represent 70% of the grid. The entire grid has 25% of the pixels degraded or deforested, which corresponds roughly to the rate observed over the 7 year period using the entire forest inventory. It was 11% of the total number of pixels in the grid that experienced deforestation, while 14% were

degraded. The econometric analysis was carried out noting the differences of the original state.

Table 1
Descriptive Statistics for the Pixel Grid

Variable	Obs	Mean	Std. Dev.	Min	Max
pixel is deforested	23402	0.111		0	1
pixel is deforested or degraded	23402	0.253		0	1
Altitude (m. a.s.l)	23402	1148.5	873.77	0.0	3900.0
Slope (%)	23402	18.4	18.50	0.0	154.0
Avg. maize yield in census tract (tons per hectare)	20605	0.91140	0.64598	0.0	8.1
Distance to nearest population center (grouped within 15 minutes intervals)	23402	113.6	85.27	15.0	1155.0
Distance to nearest urban center (>15,000 inhabitants) (grouped within 15 minutes intervals)	23402	297.4	186.02	15.0	1695.0
Tenure					
No data on tenure	23402	0.12		0.0	1.0
pixel is inside private property	20484	0.31		0.0	1.0
pixel is inside <i>Ejido</i> or <i>Comunidad</i> property	20484	0.69		0.0	1.0
<i>If Ejido or Comunidad...</i>					
<i>With PROCEDE title</i>	14069	0.54		0.0	1.0
<i>If PROCEDE, years with title</i>	14069	2.14	2.44	0.0	7.0
<i>Number of members</i>	12719	533.8	1491.05	6.0	15000.0
<i>Hectares of agricultural land per member</i>	12719	11.7	25.01	0.0	556.7
<i>Comunidad</i>	14069	0.27		0.0	1.0
pixel is inside a Natural Protected Area (ANP)	23402	0.04		0.0	1.0
Conapo marginality index for 1995	23393	3.3	1.22	1.0	5.0
Legal forestry activities registered in census tract in 1990	19539	0.61		0	1
Type of forest					
Coniferous forests	23402	0.11		0.0	1.0
Pine/Oak forest and cloud forest	23402	0.21		0.0	1.0
Oak forest and dry temperate forest	23402	0.18		0.0	1.0
Tropical rainforest	23402	0.15		0.0	1.0
Tropical dry forest	23402	0.35		0.0	1.0

Land productivity and its proxies

The set of variables related to the physical characteristics of the pixel are its altitude, average annual precipitation and its slope. While cultivation might be a problem at very high altitudes, there is a range where it would not make any difference. Higher slopes, on the other hand, are expected to always have an influence in reducing the profitability of agriculture through higher cultivation costs and long run soil erosion, while reducing also the range of animals that can graze.

Indeed we can observe in table 2 that there are large differences between the average slope of the deforested pixels (10.5%) and those that had no change in forest cover (19.6%). Graph 1 shows an interesting pattern when pixels are grouped in several slope categories: lower slopes are associated with an initial lower frequency of primary forests and a higher frequency of deforestation and degradation.

Expecting higher agricultural yields in a particular area would provide direct incentives for privately optimal deforestation. A proxy for the productivity of land available for most of the grid points is the average yield of maize per hectare registered in 1990 for the census tract⁴ where the pixel is located. It is not an perfect measure of agricultural productivity because observed yields not only depend on the suitability of land for maize production, but on input decisions, which in turn depend on their local relative prices, and any liquidity constraints that producers might have. Table 2 shows little difference in maize yields among pixels with different outcomes. The effect of these yields will only emerge in the regression analysis.

The **type of forest** that existed in a particular pixel in 1993 is important for two reasons. On the one hand it represents the potential rents that the timber could generate under a predatory or a sustainable harvest. On the other hand, the types of soil and microclimate conditions are also important to determine how much could be obtained from an agricultural plot or a pasture that substitute the forest. In a sense, the original forest cover can summarize all the physical characteristics of the pixel under a single indicator. The National Forest Inventory distinguishes between 15 categories of forests, which we group into 5, first divided in temperate and tropical forests, ordered within their division according to what is believed to be their ranking in terms of income per hectare under sustainable forestry.

Temperate Forests:

1. Coniferous Forests
2. Pine-Oak Forest and Cloudforests.
3. Oak Forest and Dry Temperate Forest

Tropical Forests:

4. Rainforest
5. Dry Tropical Forest

⁴ These are called in Mexico the *Áreas Geoestadísticas Básicas* or AGEBs.

Table 2a
Descriptive Statistics for the Pixel Grid, by vegetation change

Variable	Deforested N=2,230		Degraded N=2,913		Deforested or degraded N=5,143		No change N=13,663	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Avg. annual rainfall (mm)	1110.28	539.65	1078.94	643.98	1092.66	600.69	1046.06	547.20
Avg. temperature (C°)	22.00	4.65	19.96	4.63	20.85	4.75	20.25	4.87
Altitude (m. a.s.l)	819.71	865.41	1200.68	806.89	1033.71	854.16	1206.95	872.22
Slope (%)	10.52	15.13	19.77	19.11	15.71	18.07	19.59	18.55
Avg. maize yield in census tract (tons per hectare)	0.88	0.62	0.94	0.68	0.91	0.65	0.92	0.65
Distance to nearest population center (minutes)	76.08	48.66	112.12	72.40	96.32	65.59	118.86	88.18
Distance to nearest urban center (>15,000 inhabitants) (minutes)	221.73	155.40	322.91	193.74	278.57	184.89	305.59	186.63
Tenure								
No data on tenure	0.11		0.12		0.12		0.13	
pixel is inside private property	0.34		0.32		0.33		0.31	
pixel is inside <i>Ejido</i> or <i>Comunidad</i> property	0.66		0.68		0.67		0.69	
<i>If Ejido or Comunidad...</i>								
<i>With PROCEDE title</i>	0.61	0.49	0.52	0.50	0.56	0.50	0.53	0.50
<i>If PROCEDE, years with title</i>	2.52	2.54	2.15	2.48	2.31	2.51	2.07	2.41
<i>Number of members</i>	416.89	1310.49	551.35	1710.65	492.34	1549.02	555.47	1503.40
<i>Hectares of agricultural land per member</i>	10.90	18.89	12.35	33.67	11.71	28.16	11.77	24.30
<i>Comunidad</i>	0.15	0.35	0.26	0.44	0.21	0.41	0.30	0.46

Table 2b
Descriptive Statistics for the Pixel Grid, by vegetation change

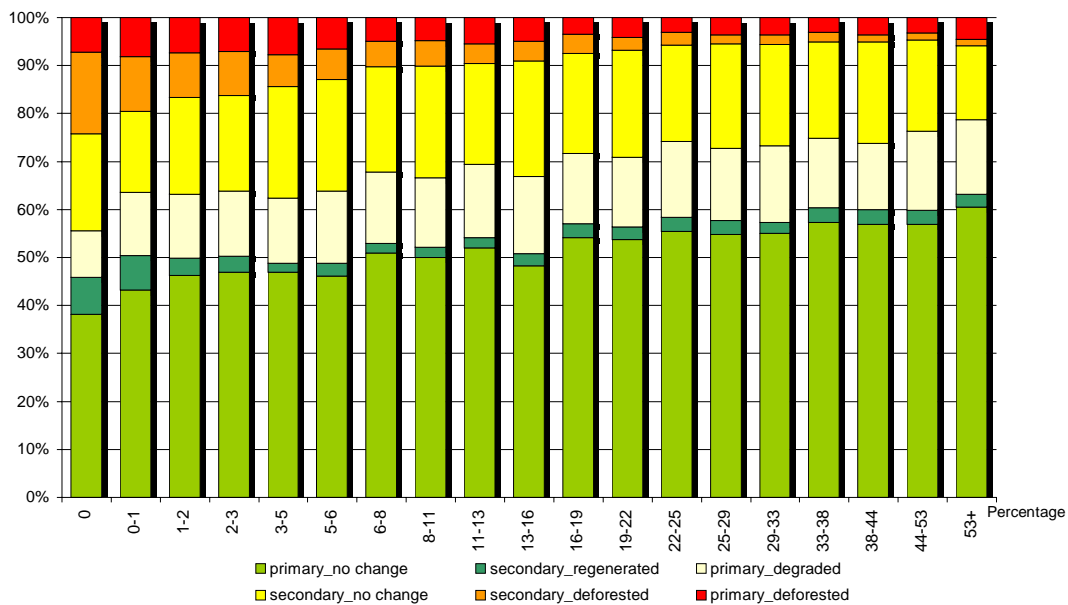
Variable	Deforested N=2,230		Degraded N=2,913		Deforested or degraded N=5,143		No change N=13,663	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
pixel is inside a Natural Protected Area (ANP)	0.02	0.13	0.02	0.15	0.02	0.14	0.05	0.22
Conapo marginality index for 1995	3.39	1.11	3.28	1.26	3.33	1.20	3.26	1.23
Legal forestry activities registered in census tract in 1990	0.63	0.48	0.64	0.48	0.63	0.48	0.60	0.49
Type of forest								
Coniferous forests	0.05		0.03		0.03		0.14	
Pine/Oak forest and cloud forest	0.13		0.29		0.22		0.21	
Oak forest and dry temperate forest	0.15		0.29		0.23		0.17	
Tropical rainforest	0.19		0.16		0.17		0.13	
Tropical dry forest	0.49		0.24		0.35		0.35	

Despite this ranking with respect to the value of the sustainable timber that could be obtained per hectare, we cannot suggest *a priori* what could the net effect for each of types of forest be. It is the relative profitability between forestry and the alternative land uses (cultivation and pastures) what matters for the final effect.

It is interesting to note in table 2 the coniferous forests have a larger representation in the group of pixels that kept their forests than among the deforested ones, while the opposite is true for the rainforests.

Graph 1:

Land use changes and slope*



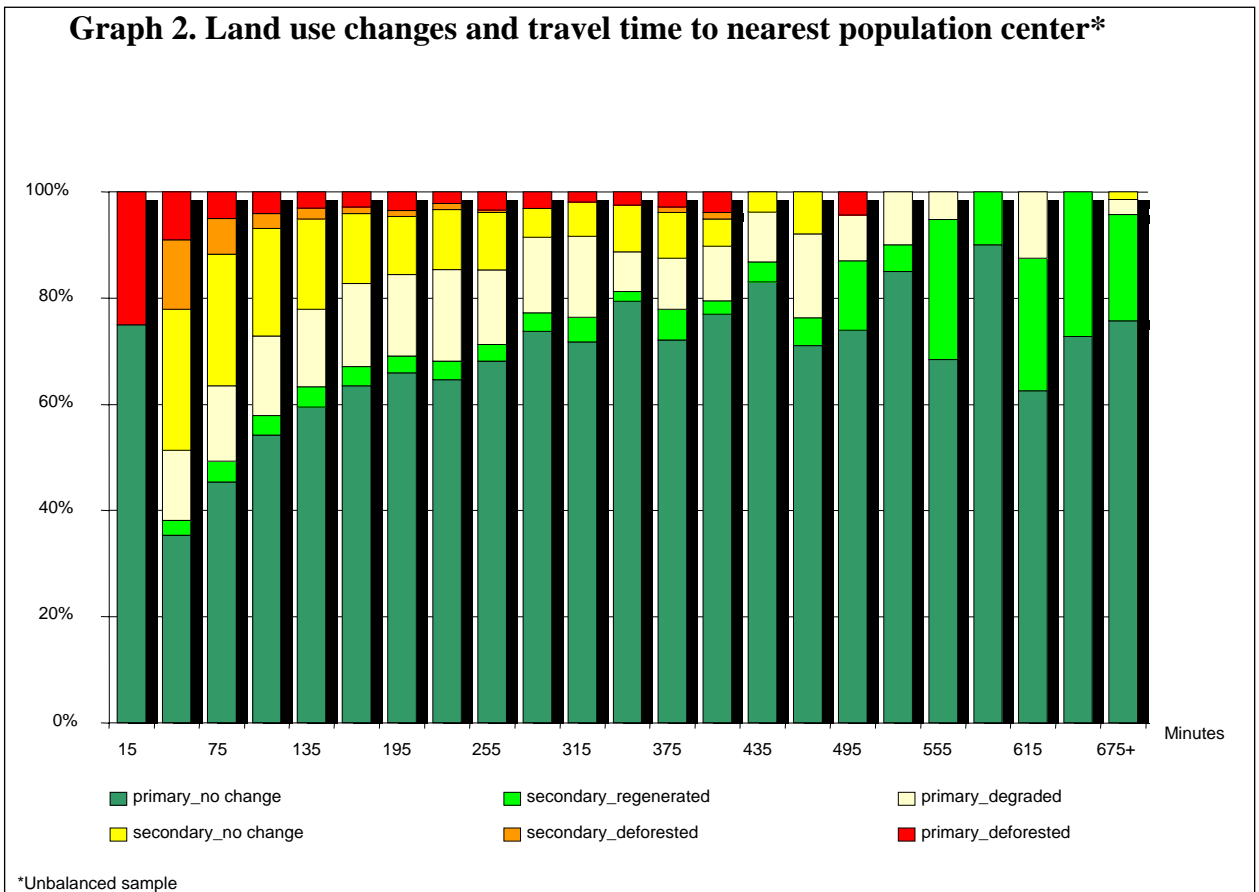
*Slope is measured in percentages.

Price spatial variations and transportation costs

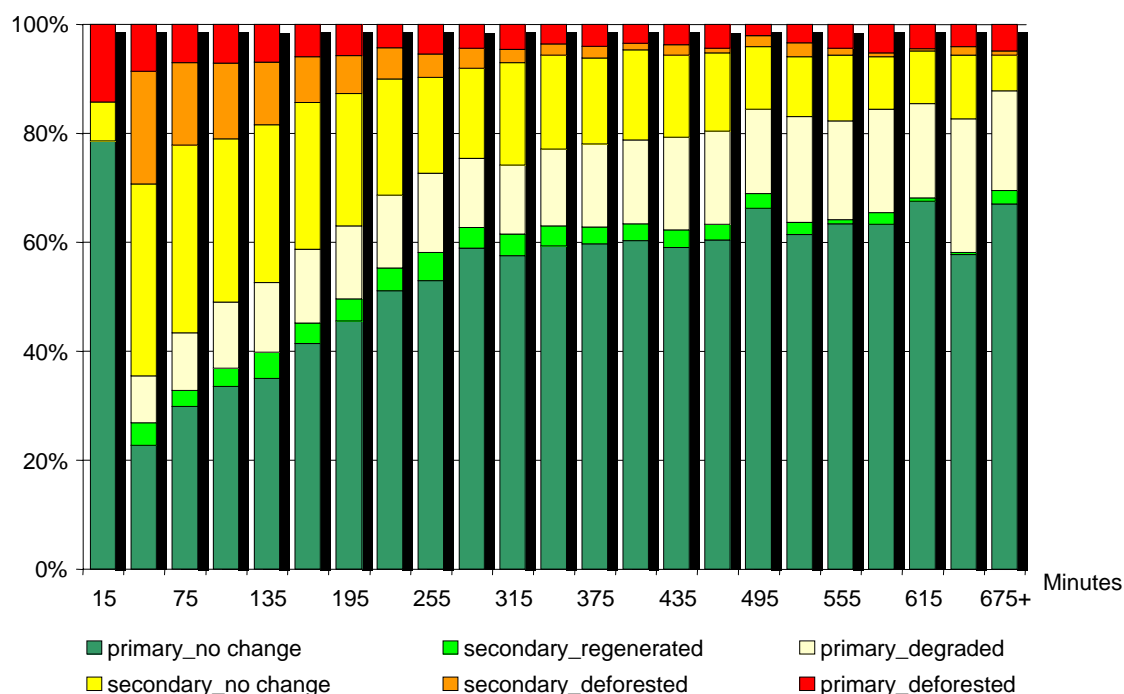
Given that the data is a cross-section of the observed land use changes, it is not possible to attribute differences in rates of deforestation to change in the national relative prices of outputs and inputs. These changes in prices would be the same for all observations. However, we can find a spatial source of variation in prices, if we consider them as net of transportation costs. Therefore, two measures of costs of transportation are included. One of them is the time of travel from the pixel to the nearest population center, defined as any location in the 2000 census has more than 50 inhabitants. The other one is the time of travel from the pixel to the nearest urban center with more than 15,000 inhabitants. The former would capture the cost of transporting labor for agricultural and animal husbandry activities, and products for self-consumption or local sales. The latter would capture the effect of the transportation cost of the different products for regional market sales, including those to access the urban labor markets.

Travel cost to nearest location and urban center: using the road network data and introducing weights for off-road travel costs based on digital models of elevation and the type of vegetation, we estimated a travel time from the pixel to the nearest location and urban center, measured in minutes.

The average distance from a pixel to any population center for the grid is 113 minutes. The difference of 43 minutes between the pixels that were deforested and those that remained under forest appears to be important. The difference between deforested and no-change pixels is also large for the case of the distance to any urban center greater than 15 thousand inhabitants: 84 minutes on average for the grid. Both of these differences are not so large when comparing degraded pixels and the ones that experienced no-change. In graphs 2 and 3 we can observe an interesting pattern where the percentage of degraded and deforested pixels falls with distance both to the nearest population center and to the nearest urban center (except for the initial point, which might have problems of selection bias).



Graph 3: Land use changes and travel time to urban centers



*Unbalanced sample

Property rights

The market signals for or against deforestation are interpreted under the property rights structure governing the use of the forest. The main two types of property rights over land in Mexico are the fully private ones, and the community rights of the *Ejidotes* and *Comunidades*, which combine individual rights with restrictions over sales for cultivated plots and commons rights for the rest of the property.

For the entire grid, we can identify 60% of the pixels as part of community property (44% are inside *ejidos* and 16% are inside *comunidades*), while 27% are in private property. For the remaining 13% of the pixels we have no tenure data. This figures fall short of the often quoted (but not yet supported by a published result) estimate of 80% of the forests under community property. However, we acknowledge the fact that our layer of information about tenure is more complete for private properties than for their community counterpart, so the figure might still be true. It is also important to note that our database does not allow us to identify if a pixel inside an ejido falls inside the commons area or in an individual ejidatario's plot. The latter would have institutional constraints closer to private property than to common property.

Among common property regimes, one of the basic explanatory variables for their departure from the behavior of single individual or single firm ownership is the size of their membership. This is a variable available at the census level, and it is thus used as a measure of the cost of cooperation. An interesting result from the INE-UCB survey of

2002 is that managed forestry is an activity always undertaken as a group, while agriculture, even if carried out in the commons, is always an individual activity, and animal production is observed with a combination of individual herds in either common or private pastures. This is why we would expect to find an increase in the probability of deforestation as the number of members and their costs of cooperating increase, controlling for the rest of the opportunity cost variables. In table 2, we can observe that the mean number of *ejidatarios* for the deforested pixels is actually smaller than for those pixels that had no change⁵. As will be seen, this result carries over to some of the econometrics results, contradicting our expectations.

Among the community owned forests there are differences in the degree of certainty and definition of the property rights. The *ejidos* and *comunidades* have undergone an intense process of land titling since 1994, when the program PROCEDA started to provide a new, more precise, type of titles to both the individual households and at the *ejido* or *comunidad* level. These titles provide both the owners and the land registry with detailed, georeferenced maps, showing their internal and external boundaries, and actually come from a community exercise of delimitation with signed consent and mutual recognition of neighbors. This voluntary program advanced gradually over the decade and is still underway. By the year 2000 it had titled approximately 70% of the properties.

It is expected that better defined property rights would provide incentives for long term investment in land. How this favors sustainable forestry in relative terms to its agricultural or pasture alternatives is not clear cut, but as the former have longer term investments one would expect the net effect to be to reduce deforestation. However, one must consider an associated phenomenon. The work by Muñoz, De Janvry and Sadoulet (2003) finds evidence that after the 1992 reforms, the *ejidos* began to individually title some of the land they held in commons. ProcEDA was the mechanism to formalize these new individual plots. Because of the economies of scale in managed forestry one would expect that a single household would receive a higher income from converting a small plot of forest into agricultural fields or pastures, when that would not occur if held as a large tract of managed forest.

To capture the effect of a better definition of property rights, and the potential effect of the division of the commons, we introduce two additional property right variables for the pixels falling inside *ejidos* and *comunidades*: 1) whether or not their members had received their ProcEDA titles, and 2) for long had they held them at the time when the 2000 forest inventory was taken. In table 1 we can see that 54% of the pixels inside *ejidos* or *comunidades* fell in those that had ProcEDA titles, with an average of 2.1 years of having received them. There is indeed a large difference between the overall ProcEDA advance and the relatively smaller share of titling observed in the sample, perhaps due to the lower titling rates among *ejidos* in forested areas.

Unfortunately we have to leave out other variables known to increase or decrease the costs of cooperation in community property forests because of their unavailability at the census level. Among the most important ones left out are the distribution of assets

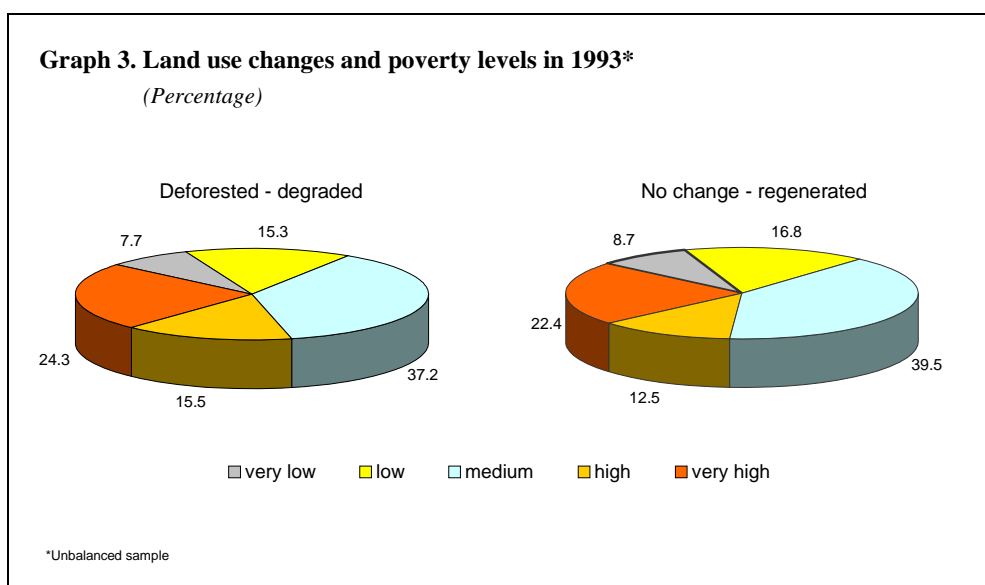
⁵ It is important to note here that because of the way the grid was constructed there is the probability that several pixels fall in the same *ejido*. This is taken into account in the econometric analysis by correcting the error term for the cluster nature of the data.

within the community, and the number of non-member households that have access to forest resources or the possibility of encroaching.

Poverty

The effect of the poverty of the owners and neighbors of the forest in the deforestation process has long been discussed in the literature, though few empirical studies have been able to deal with the inherent endogeneity of the problem. One of the arguments is that poor households with liquidity constraints cannot invest in maintaining the fertility in their land; hence they exert pressure for the conversion of available forest lands to agricultural uses either with rights or through encroachment. Another hypothesis is that the remaining forests in poor areas are the result of a “natural protection” derived from a lack of sufficient resources of poor households for clearing this forest. Without addressing the endogeneity of the poverty levels through instruments, the option taken in this paper is to use the marginality index calculated for the beginning of the period. We use the closest one: the 1995 CONAPO⁶ index, associating each pixel to the marginality index value of the nearest rural population center.

The CONAPO marginality index has a range from 1, representing the lowest marginality, to 5, the highest marginality. Those communities classified as levels 4 or 5 were the target of the poverty reduction program *Progresa*, now called *Oportunidades*. The average index for the entire grid is 3.28. Table 2 shows small differences between deforested, degraded and no-change pixels overall. In graph 4 we can see the characteristics of the pixels that fall under each level.



Legal Forestry Activities in the Census Tract

This variable is endogenous to the characteristics of the forests inside the census tract. Its main limitation, as mentioned before, is that we are not observing the decision following the tenure boundaries, so a particular community could have decided not to undertake forestry activities, while they neighbors did. Commercial forestry use would increase the value of a standing forest, and thus provide the incentives to maintain this

⁶ “Índice de marginación a nivel de localidad, 1995” CONAPO-PROGRESA, 1998.

type of land use in the medium or long run. In this context the endogeneity would become a problem because the particular characteristics of a plot of land simultaneously determine the existence of a forestry regime and where deforestation occurs. We seek to avoid endogeneity by using the variable that corresponds to the Rural Census of 1990, the closest one before the period studied. In table 1 we can see that 61% of the pixels falling in census tracts that had legal timber activities in 1990.

Natural Protected Areas

Another institution that frames the forest owners' decisions is the regulation and enforcement of prohibitions against land use change. In the environmental and forestry legislation that was valid during the period land use change was prohibited, but enforcement was extremely weak. Perhaps the only relevant regulation, plus one that has regional variations that can be studied in a cross section analysis such as this, is the *Natural Protected Area* (ANP) status. Land use is regulated by a special decree over those areas of key biodiversity importance. Restrictions have two levels: the core or nucleus part of the reserves where no economic activity is allowed, and the buffer zone, where "lower intensity" and sustainable activities that do not change land use are permitted. It is in the ANPs that government efforts are channeled to monitor and enforce regulations, and to support the development of sustainable activities. In table 1 we can observe that the grid has 4% of the forests inside Natural Protected Areas

Table 5
Explanatory variables for deforestation and their anticipated effects

Variable	Expected effect over Deforestation/Degradation
Physical Characteristics:	
Altitude	-
Average rainfall	+
Slope	-
Type of Forest	+/-
Agricultural yields observed in area	+
Cost of access (price modifier)	
Travel time to nearest population center	-
Travel time to nearest urban center	-
Institutional Framework	
Common Property (vs. Private Property)	?
# of members	+
PROCEDE land title	-
Years since PROCEDE titling	-
Natural Protected Area status	-
Poverty	
Marginality index	?
Forestry	
Legal timber extraction in census tract	-

ECONOMETRIC ANALYSIS

The decision to study the land use decision at the pixel level drives us to use a qualitative dependent variable approach. As mentioned in the introduction, there are two different initial states which can each become three different states in the second period, making in total six transitions. A primary forest can remain as such, or become a degraded (secondary) forest, or be completely deforested. A secondary forest, on the other hand, can recover to become a primary forest again, can remain degraded, or can be completely deforested. What we have is a continuous unobservable variable measuring forest degradation, which the satellite image interpretation converts into these 3 discrete outcomes: primary forest, secondary forest, no forest, using a threshold which is not made explicit in the forest inventory.

For the econometric analysis the sample is split in two, dividing the observations depending on the 1994 state of the forest, either primary or secondary. We use three different types of models; (1) a dichotomous probit model analyzing only the difference between deforestation and no deforestation, (2) an ordered probit model where degradation is an intermediate before deforestation, and regeneration is also a possible

outcome resulting from having “negative net pressure” over the forest, this is, having the natural growth rate of the forest be greater than the extraction or disruption, and (3), a multinomial logit where the decision to degrade and deforest are not necessarily driven in the same direction by the exogenous variables. Because the information on tenure is patchy, the type of specifications that includes tenure variables sacrifices some observations. Finally, there are some very large communities and ejidos which include more than one point from the grid, so it was necessary in the econometric analysis to account for the clustering effect of pixels falling under the same owner.

Table 6

Probit, ordered probit and multinomial logit estimates for the pixel grid
Primary forests

Variable	Probit 0= degraded or no change 1: deforested	Ordered Probit 0: no change 1: degraded 2: deforested	Multinomial Logit	
			Base category: no change	
			Degraded (1)	Deforested (2)
	Marginal effects (P>z values)	Coefficients (P>z values)	Coefficients (P>z values)	Coefficients (P>z values)
Slope (%)	-0.00111 (0.003)	-0.00390 (0.000)	-0.00346 (0.088)	-0.01539 (0.000)
Maize yield (tons x ha)	0.03256 (0.009)	0.07070 (0.040)	0.21241 (0.002)	0.03923 (0.688)
Distance to nearest population center (min)	-0.00101 (0.000)	-0.00321 (0.008)	-0.00401 (0.000)	-0.01028 (0.000)
Square of distance to nearest population center	0.0000005 (0.011)	0.000002 (0.008)	0.000001 (0.255)	0.00001 (0.001)
Distance to nearest urban center (min)	-0.00027 (0.027)	-0.00104 (0.002)	-0.00041 (0.331)	-0.00388 (0.000)
Square of distance to nearest urban center	0.0000003 (0.006)	0.000001 (0.000)	0.000001 (0.348)	0.000004 (0.000)
Pixel is inside <i>Ejido</i> or <i>Comunidad</i> property...	Dropped	dropped	dropped	dropped
Inside a <i>Comunidad</i> (0,1) *	-0.209019 (0.012)	-0.31008 (0.000)	-0.53626 (0.000)	-0.66065 (0.001)
<i>PROCEDE</i> title (0,1)*	-0.02220 (0.390)	-0.04937 (0.522)	-0.13907 (0.315)	-0.07288 (0.733)
If <i>Procede</i> , years with title	0.00598 (0.203)	0.01500 (0.287)	0.03424 (0.188)	0.02633 (0.494)
Number of members of <i>Ejido</i> or <i>Comunidad</i>	-0.000000 (0.772)	-0.00000 (0.732)	0.000000 (0.976)	-0.00001 (0.738)
Inside a Natural Protected Area (ANP)*	-0.11103 (0.007)	-0.32275 (0.015)	-0.54564 (0.087)	-1.11038 (0.048)
CONAPO Marginality index 1995	0.01838 (0.018)	0.06005 (0.009)	0.07154 (0.086)	0.18171 (0.002)
Municipality migration rate in 1995	-0.00227 (0.810)	-0.00933 (0.735)	-0.00464 (0.928)	-0.04495 (0.585)
Forestry activities in census tract in 1991 *	0.04379 (0.004)	0.12305 (0.005)	.23202 (0.010)	0.18171 (0.111)
Coniferous forests	(base category)	(base category)	(base category)	(base category)
Pine-Oak forest and cloud forest*	0.33805 (0.000)	0.80784 (0.000)	2.18805 (0.000)	0.77635 (0.000)
Oak forest and dry temperate forest*	0.41787 (0.000)	0.98719 (0.000)	2.46571 (0.000)	1.26651 (0.000)
Tropical rainforest*	0.32325 (0.000)	0.80355 (0.000)	1.98774 (0.000)	1.06980 (0.000)
Tropical dry forest*	0.25281 (0.000)	0.62127 (0.000)	1.73536 (0.000)	0.70845 (0.002)
Constant			-3.03191 (0.000)	-1.89649 (0.000)

* For these variables, dy/dx is for a discrete change of dummy variable from 0 to 1.

**All estimations correct for the clustering effect of more than one pixel falling in the same property, a problem only emerging in the largest ejidos or comunidades.

Table 7

**Probit, ordered probit and multinomial logit estimates for the pixel grid
Secondary forests**

Variables	Probit	Ordered Probit	Multinomial Logit (base category=regenerated)	
	1= deforested, 0= no change or regenerated	2= deforested, 1= no change, 0=regenerated	No change (1)	Deforested (2)
Slope	-0.0164524 (0.000)	-0.0051568 (0.001)	0.0047911 (0.331)	-0.0334191 (0.000)
Maize yield	-0.0948145 (0.152)	0.0651959 (0.131)	0.7346833 (0.000)	0.4526117 (0.017)
Distance to nearest population center	-0.0052891 (0.000)	-0.0051152 (0.000)	-0.0098719 (0.009)	-0.0179862 (0.000)
Square of distance to nearest population center	0.0000589 (0.044)	0.0000582 (0.052)	0.0000113 (0.353)	0.0000191 (0.141)
Distance to nearest urban center	-0.00274 (0.001)	-0.0034033 (0.000)	-0.0075657 (0.001)	-0.0110687 (0.000)
Square of distance to nearest urban center	0.0000037 (0.001)	0.00000445 (0.000)	0.0000121 (0.000)	0.000017 (0.000)
Inside <i>Ejido</i> or <i>Comunidad</i> property	-	-	-	-
<i>PROCEDE</i> title	-0.0052698 (0.960)	0.0182658 (0.837)	-0.0592601 (0.797)	-0.073652 (0.777)
Years with title	-0.002488 (0.899)	-0.0034417 (0.84)	-0.006839 (0.875)	-0.0105228 (0.826)
Number of members	-0.0001083 (0.048)	-0.000032 (0.122)	0.0000553 (0.542)	-0.0001541 (0.141)
Agricultural land per member	-0.0002527 (0.924)	0.0009466 (0.616)	0.0019565 (0.684)	0.0013157 (0.832)
<i>Comunidad</i> tenure	-0.3984438 (0.002)	-0.2593583 (0.000)	-0.2639764 (0.161)	-1.044052 (0.000)
Inside a Natural Protected Area (ANP)	-0.3383733 (0.247)	-0.9477621 (0.000)	-2.047468 (0.000)	-1.903051 (0.001)
Marginality index	0.1220597 (0.002)	0.1139514 (0.000)	0.1853386 (0.007)	0.387468 (0.000)
Forestry activities in 1990	0.1066273 (0.136)	0.0005214 (0.993)	0.3384692 (0.044)	0.0653861 (0.706)
Coniferous forests	(base category)	(base category)	(base category)	(base category)
Pine/Oak forest and cloud forest	0.4227731 (0.021)	0.2317327 (0.018)	1.802595 (0.000)	0.5630777 (0.226)
Oak forest and dry temperate forest	0.6043434 (0.002)	0.0859018 (0.390)	0.7589653 (0.026)	0.6619813 (0.184)
Tropical rainforest	0.5610704 (0.010)	0.0503535 (0.711)	1.1582 (0.002)	0.3369918 (0.53)
Tropical dry forest	0.6404677 (0.002)	0.1540785 (0.182)	0.7641112 (0.032)	0.7187453 (0.16)
Constant	-0.5069675 (0.127)		2.376707 (0.000)	1.389926 (0.082)

*The results are presented as follows: coefficients, robust standard errors and p-values.

**All estimations correct for the clustering effect of more than one pixel falling in the same property, a problem only emerging in the largest ejidos or comunidades.

Results:

All the variables reflecting physical characteristics of the plot are parameters of the opportunity cost of the forest as agriculture or pastures. A result that appears in all specifications is that the higher the slope of a particular pixel the less likely is the degradation and deforestation, supporting the notion that there are higher costs and lower yields of undertaking agriculture or putting animals to graze in higher slopes. Also, the potential agricultural yields, as measured by the average corn yields in the census tract, are associated with a higher probability of deforestation.

The types of forests observed in 1993, are indeed the result of the characteristics of the land. The altitude, rainfall and temperature are ecological determinants of the forest we would observe in a particular area. However, the species composition has non-linear effects. The amount and type of timber that it is possible to extract, multiplied by its market value, is a signal of the profitability of extracting it today, and the profitability of engaging in sustainable forestry for the future. However, the types of soil they have created, plus the other ecological conditions, are also a proxy of the yields that this plot could have if converted to agriculture or pastures. So, it is the relative profitability in the alternative land uses that matter for the final effect. The base category used the coniferous forests, which according to forestry experts provide the highest net rent per hectare. Compared to it, the pine-oak and cloudforests have a higher probability of degradation and deforestation, while oak and dry temperate forests have the highest risk.

According to experts, in the case of temperate forests, the economic rents as an alternative uses seem to move in the opposite direction as the rents derived from forestry. The best timber producing conifer areas are also the worst for agriculture. There is an interesting contrast among tropical forests. While the tropical rainforests, containing several commercial timber species, would be expected to have larger forestry rents and so a lower probability of deforestation than the dry tropical forests which basically contain no commercial species. However dry tropical forests have also lower agricultural and pasture productivity than rainforests. As we can observe in the previous two tables, the net effect results in a higher risk of deforestation for rainforests.

The distance related variables represent the transaction costs of accessing the market. In a cross-section analysis such as this, they represent the only observable variations in **net price** received for both forest and non forest outputs and inputs. In our case these are the distance to the nearest population center, and the distance to the nearest urban center with more than 15,000 inhabitants. It is important to note that the effect of former is related to the cost of access by a particular household, either someone with rights over the land or with encroaching potential, while the latter is more important to determine the net price of agricultural inputs, the selling price for labor, and the net price of timber products. Here it is important to consider that large distances from the nearest village or town have the effect of forests being preserved but not being used.

The third group of variables is composed of indicators of the institutions that frame the decisions taken by the forest owners about the land use. While the variable distinguishing between private and community property is dropped, the subcategory of *Comunidad* which implies that all the land is held in commons has a negative effect on deforestation. Of the forests in this sample which are community property, some have the most formal and precise titles that the Mexican government has provided through

the PROCEDE program. Neither the presence of titles, nor the number of members appears to have an effect.

Another important institutional layer to be considered is the government's regulation over land use and its degree of enforcement. While no forest owner has the right to change land use, in fact the restriction is more strongly monitored and enforced in those areas declared **Natural Protected Areas (NPAs)**. The results suggest that either the monitoring to inhibit land use changes or the support for forest-based activities have succeeded in slowing the deforestation process.

...aquí necesitamos más discussion de los resultados.....

Appendix

Table 10
Descriptive Statistics for the Pixel Grid, by type of forest in 1993

Variable	Primary			Secondary		
	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.
pixel is deforested	16357	0.07	0.26	7045	0.20	0.39
pixel is deforested or degraded	16357	0.28	0.45	7045	0.20	0.39
Rainfall (mm)	16307	1055.09	577.27	7021	1070.60	514.26
Temperature (C°)	16355	20.01	4.83	7044	21.61	4.67
Altitude (m. a.s.l)	16357	1209.32	867.28	7045	1007.32	872.54
Slope (%)	16357	19.77	19.04	7045	15.28	16.78
Maize yield (tons per hectare)	14154	0.91	0.64	6451	0.92	0.65
Distance to nearest population center (minutes)	16357	123.43	90.48	7045	90.73	66.33
Distance to nearest urban center (minutes)	16357	326.53	194.09	7045	229.81	144.72
Tenure						
No data on tenure	16357	0.13		7045	0.11	
Inside private property	14201	0.31		6283	0.32	
Inside <i>Ejido</i> or <i>Comunidad</i> property	14201	0.69		6283	0.68	
<i>If Ejido or Comunidad...</i>						
<i>With PROCEDE title</i>	9809	0.53	0.50	4260	0.55	0.50
<i>If PROCEDE, years with title</i>	9809	2.11	2.43	4260	2.20	2.47
<i>Number of members</i>	8864	576.79	1675.40	3855	434.96	931.31
<i>Agricultural land per member</i>	8864	12.25	28.03	3855	10.43	15.94
<i>Comunidad</i>	9809	0.29	0.45	4260	0.23	0.42
Inside a Natural Protected Area (ANP)	16357	0.05	0.22	7045	0.03	0.16
Marginality index ,1995	16348	3.25	1.23	7045	3.34	1.19
Forestry activities, 1990	14124	0.60	0.49	5415	0.62	0.49
Type of forest						
Coniferous forests	16357	0.10		7045	0.12	
Pine/Oak forest and cloud forest	16357	0.25		7045	0.11	
Oak forest and dry temperate forest	16357	0.20		7045	0.13	
Tropical rainforest	16357	0.16		7045	0.11	
Tropical dry forest	16357	0.28		7045	0.52	

Table 11
Descriptive Statistics for the Balanced Sample, by type of forest in 1993

Variable	Primary			Secondary		
	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.
pixel is deforested	779	0.15	0.35	213	0.26	0.44
pixel is deforested or degraded	779	0.58	0.49	213	0.26	0.44
Rainfall (mm)	779	1140.66	629.94	213	1345.30	620.71
Temperature (C°)	779	17.65	4.68	213	19.70	4.64
Altitude (m. a.s.l)	779	1617.37	690.99	213	1362.36	720.51
Slope (%)	779	23.34	15.56	213	22.40	12.48
Maize yield (tons per hectare)	724	0.85	0.47	196	0.85	0.44
Distance to nearest population center (minutes)	779	107.54	63.69	213	91.76	52.23
Distance to nearest urban center (minutes)	779	351.39	196.38	213	278.66	161.57
Tenure						
No data on tenure	779	0.0		213	0.0	
Inside private property	779	0.0		213	0.0	
Inside <i>Ejido</i> or <i>Comunidad</i> property	779	1.0		213	1.0	
<i>If Ejido or Comunidad...</i>						
<i>With PROCEDE title</i>	779	0.39	0.49	213	0.32	0.47
<i>If PROCEDE, years with title</i>	779	1.53	2.30	213	1.24	2.17
<i>Number of members</i>	766	408.84	648.19	207	444.03	737.49
<i>Agricultural land per member</i>	766	11.94	24.06	207	12.99	19.47
<i>Comunidad</i>	779	0.35	0.48	213	0.35	0.48
Inside a Natural Protected Area (ANP)	779	0.02	0.15	213	0.03	0.17
Marginality index , 1995	779	3.77	1.30	213	4.07	1.19
Forestry activities, 1990	703	0.67	0.47	170	0.67	0.47
Type of forest						
Coniferous forests	779	0.09		213	0.23	
Pine/Oak forest and cloud forest	779	0.45		213	0.25	
Oak forest and dry temperate forest	779	0.26		213	0.19	
Tropical rainforest	779	0.10		213	0.13	
Tropical dry forest	779	0.10		213	0.20	