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Abstract

Almost a third of world's forest area is under communal management. In principle, this arrangement could lead to a "tragedy of the commons" and therefore more deforestation. But monitoring outsider's deforestation may be easier if the owner is a community rather than an individual. We study the effect of communal titling on deforestation in Colombia using a difference-in-discontinuities strategy that compares areas just outside and inside a title, before and after titling. We find that deforestation decreased in communal areas after titling. Interestingly, we find evidence of positive spillovers of reduced deforestation in nearby areas.

Keywords: Deforestation; Communal Land; Tragedy of the Commons
JEL Codes: P32, Q23

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1 Introduction

Deforestation carbon dioxide emissions are a major contributor to climate change. For example, emissions from tropical deforestation are larger than those of the entire European Union (Seymour & Busch, 2016). Although almost a third of world's forest area is under communal management (Gilmour, 2016), little is known about the effect of communal property rights on land use and deforestation. Under standard economic assumptions, communal property is subject to the tragedy of the commons. However, it may also induce conservation under certain conditions (Ostrom, 1998). For example, a community may have an easier time than an individual protecting a forest from outsiders due to economies of scale (Janvry & Sadoulet, 2001). Hence the effect of communal rights on land use is an empirical question.

We study the effect of communal titling on deforestation in Colombia using a natural experiment: In 1993 certain regions of the country became eligible for communal land titling among Afro-Colombian communities. The first titles were allocated in 1996. By 2017 communal lands encompassed 5.3 million hectares of land distributed across 168 titles. We use a differences-in-discontinuities strategy that compares the forest cover of land just inside and outside the communal title (the discontinuity) before and after the title is granted (the difference). Estimates of the effect of titling on deforestation might be affected by site selection bias and spatial spillovers (Andam, Ferraro, Pfaff, Sanchez-Azofeifa, & Robalino, 2008; Robalino & Pfaff, 2012). To address the first concern, we use location fixed effects to control for time-invariant observable and unobserbable sources of bias (Jones & Lewis, 2015). To address spatial spillovers, we study the sensitive of our estimates to excluding pixels close to the border (more likely to receive spillovers).

We find that deforestation is lower after titling, with heterogeneity by the number of inhabitants of the communal land. The probability that a 90 mts $\times$ 90 mts plot is deforested decreases by 0.33 percentage points from a base of 4.95% (a 6.7% decrease). In small communities, this probability decreases by 0.49 percentage points, a decrease of around 10%. In large communities, this probability decreases by 0.28 percentage points.[1] This could be explained because smaller groups induce higher levels of trust and cooperation (Poteete & Ostrom, 2004).

We present a simple theoretical framework to understand how communal land titling affects the use of forest resources. The model highlights the non-monotonic relationship between the size of the communal title and deforestation. The intuition is straightforward: Each individual owner is able to lower his monitoring effort when there are more members since he benefits from his co-owners' monitoring. This behavior causes total monitoring effort to increase at first (when the number of owners is small), but eventually total monitoring declines as the number of owners grows.

Community forest management has been mostly studied in the case of *ejidos* in Mexico. Barsimantov and Kendall (2012) find that "ejidos" reduce deforestation because of better governance. However, Rueda (2010) suggests the opposite due to agriculture expansion. Both studies rely on cross-sectional correlations and are unable to tease out causality (i.e., whether communal titling caused an increase/decrease in deforestation). A recent meta-analysis of deforestation drivers recommended rigorous impact evaluation methods to study the effects of community forest management on deforestation, given the lack of consistent results across studies Busch and Ferretti-Gallon (2017). Our paper contributes to fill this gap using panel data (as opposed to a cross-section) and quasi-experimental methods to asses causality. Since *ejidos* were established at the beginning of the twentieth century, there are no forest measurement before they were created. By contrast we

[1] We define small and large communities based on the median number of inhabitants.

have satellite data before and after the creation of communal lands in Colombia. Finally, we study a country outside the six that dominate the literature surveyed on the meta-analysis.

Our results speak to two other strands of the literature. First, to the literature on the effects of different institutional arrangements on deforestation. Regarding indigenous communities, similar to this paper some studies also find a reduction in deforestation after titling (Blackman & Veit, 2018; Blackman, Corral, Lima, & Asner, 2017) while others find no effect (BenYishay, Heuser, Runfola, & Trichler, 2017; Pfaff, Robalino, Lima, Sandoval, & Herrera, 2014). In the case of environmental land registration, Alix-Garcia, Rausch, L'Roe, Gibbs, and Munger (2018) find it decreases deforestation by 10% in deforestation in Brazil. The communal lands in Colombia studied here provide a different setting, because the main goal of their creation was titling, not environmental conservation.

Second, we contribute to the literature on well-identified impact evaluations of communal lands. Peña, Vélez, Cárdenas, Perdomo, and Matajira (2017) — the only previous research that focus on the effects of communal titling on individuals — show that collective titling increases per capita income, housing investment, and school attendance. In this paper we focus on the environmental impact of communal titling. A closely related paper by Bonilla-MejÃa and Higuera-Mendieta (2019) studies deforestation in all protected areas in Colombia, including communal lands. Our paper differs in several aspects. First, while Bonilla-MejÃa and Higuera-Mendieta (2019) use only spatial variation, we use a difference-in-discontinuities identification strategy that exploits both spatial and temporal variation. In addition, we provide a theoretical framework to interpret the results. Finally, they use pixels with a resolution $1,000mts \times 1,000mts$, and hence miss small communal titles, which represent half of all communal titles. We use a finer resolution ($90mts \times 90mts$) and analyze heterogeneity by title size.

2 Theoretical Framework

We present a simple model of how communal land titling affects the use of forest resources. The main goal of the model is to highlight the non-monotonic relationship between the size of the title (proxy by the number of inhabitants) and deforestation. The model is similar to the one developed by Dasgupta and Heal (1979).

Assume there are n agents, each choosing how much to produce in an activity that consumes some of the forest around them. The total endowment of forest in the community is F. Each agent derives utility from consuming forest goods (f_i), and from the amount of remaining standing forest ($F - \sum_{i=1}^{n} f_i$) via natural services. Extracting forest goods has a cost ($c(f_i)$). The utility of agent i is equal to:

$$u(f_i, f_{-i}) = g(f_i) + h(F - \sum_{i=1}^{n} f_i) - c(f_i) \tag{1}$$

In the case of a pure communal resource, this framework is typically used to explain the tragedy of the "commons." The first-order conditions are:

$$g'(f_i) - h'(F - \sum_{i=1}^{n} f_i) - c'(f_i) = 0, \tag{2}$$

for all i. In a symmetric Nash equilibrium, we know that $f_i = f^*$ for all i. Hence,

$$g'(f^*) = h'(F - nf^*) + c'(f^*) \tag{3}$$

While the social optimal is:

$$g'(f^*) = nh'(F - nf^*) + c'(f^*) \tag{4}$$

2.1 Common Resource Titling

Now assume that the forest is owned by the first n_1 agents in the economy. For ease of exposition we assume that only the owners get utility from standing forest and that the other agents get utility only from the forest they consume privately. If we allow standing forest to produce benefits for non-owners the qualitative conclusions of the model are unchanged, but the overall level of deforestation is lower. The key is that owners obtain higher benefits from standing forest than non-forest owners. For example, non-owners receive water and air filtering, while owners can also enjoy fruit gathering and eco-tourism.

The forest owners can exert some effort (e_i) to keep the other $n - n_1$ agents away from the forest since those agents have no incentives to preserve any of it. The monitoring implies that although outsiders spend f_i deforesting, their return is lower ($f_i/(1+E)$, where $E = \sum_{j=1}^{n_1} e_j$).

The utility for one of the forest owners would be:

$$u_1(f_i, f_{-i}, e_i, e_{-i}) = g(f_i) + h\left(F - \sum_{j=1}^{n_1} f_j - \frac{1}{1+\sum_{j=1}^{n_1} e_j} \sum_{j=n_1+1}^{n} f_j\right) - c(f_i, e_i) \quad (5)$$

and the utility for one of the other $n - n_1$ agents would be:

$$u_2(f_i, e) = g\left(\frac{f_i}{1+\sum_{j=1}^{n_1} e_j}\right) - c(f_i, 0) \quad (6)$$

The first-order conditions for the forest owners are:

$$g'(f_i) - h'\left(F - \sum_{j=1}^{n_1} f_j - \frac{1}{1+\sum_{j=1}^{n_1} e_j} \sum_{j=n_1+1}^{n} f_j\right) = c'_f(f_i, e_i) \tag{7}$$

$$\frac{\sum_{j=n_1+1}^{n} f_j}{\left(1+\sum_{j=1}^{n_1} e_j\right)^2} h'\left(F - \sum_{j=1}^{n_1} f_j - \frac{1}{1+\sum_{j=1}^{n_1} e_j} \sum_{j=n_1+1}^{n} f_j\right) = c'_e(f_i, e_i) \tag{8}$$

and for the non-owners (the other $n - n_1$ agents):

$$\left(\frac{1}{1+\sum_{i=1}^{n_1} e_i}\right) g'\left(\frac{f_i}{1+\sum_{i=1}^{n_1} e_i}\right) = c'_f(f_i, 0) \tag{9}$$

In a symmetric equilibrium, where f^* is the optimal quantity of forest consumed by the forest owners and f^{**} is the optimal quantity of forest consumed by the other $n - n_1$ agents, we have:

$$\underbrace{c'_f(f^*, e^*) + h'\left(F - n_1 f^* - \frac{(n-n_1)f^{**}}{1+n_1 e^*}\right)}_{\text{mg cost private consumption}} = \underbrace{g'(f^*)}_{\text{mg benefit private consumption}} \tag{10}$$

$$\underbrace{\frac{(n-n_1)f^{**}}{(1+n_1 e^*)^2} h'\left(F - n_1 f^* - \frac{(n-n_1)f^{**}}{1+n_1 e^*}\right)}_{\text{mg benefit keeping outsiders out}} = \underbrace{c'_e(f^*, e^*)}_{\text{mg cost keeping outsiders out}} \tag{11}$$

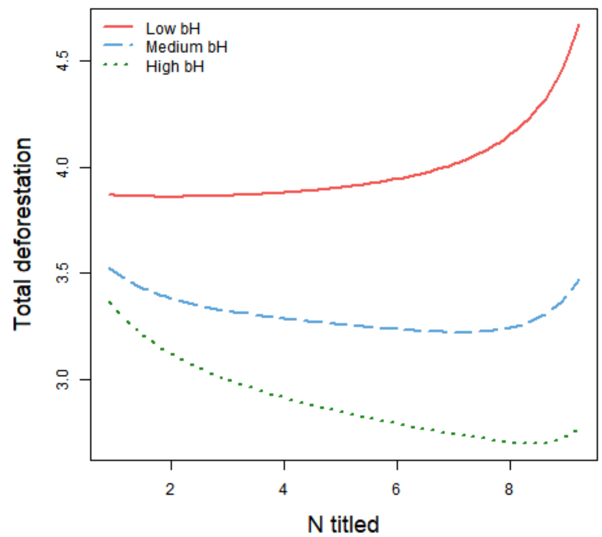
$$\underbrace{\left(\frac{1}{1+n_1 e^*}\right) g'\left(\frac{f^{**}}{1+n_1 e^*}\right)}_{\text{outsiders' mg benefit private consumption}} = \underbrace{c'_f(f^{**}, 0)}_{\text{outsiders' mg cost private consumption}} \tag{12}$$

2.2 Comparative Statics

We solve numerically, assuming $g(f) = f^{\alpha_g}$, $h(f) = b_h f^{\alpha_h}$ and $c(f,e) = b_c(f + b_e e)^{\alpha_c}$, and show how the resulting equilibria vary as we vary the valuation of standing forest (b_h).

In Figures 1-3 we assume $\alpha_g = 0.5$, $\alpha_h = 0.5$ (i.e., concave returns from forest consumption) and $\alpha_c = 2$ (i.e., convex costs). We show total deforestation for different values of the forest services valuation parameter: low ($b_h = 1$), medium ($b_h = 2$), and high ($b_h = 3$). For any number of agents, deforestation increases when valuation is lower, as would be expected. When the forest services valuation is low, deforestation increases with the number of agents titled. Intuitively, the private value of cutting trees is higher than keeping them standing. On the other hand, when the forest services valuation is high, deforestation decreases when there are more owners. Intuitively, the forest is very valuable: The gains from ecosystem services outweigh the private benefits from cutting down trees. For the intermediate case, there is a decrease in deforestation for small N but for larger values deforestation increases. Intuitively, at first more owners share the cost of keeping outsiders from logging the forest, which allows them to protect more of the forest. Eventually, however, as the number of owners grows the tragedy of the commons "effect" becomes more prevalent and deforestation increases.

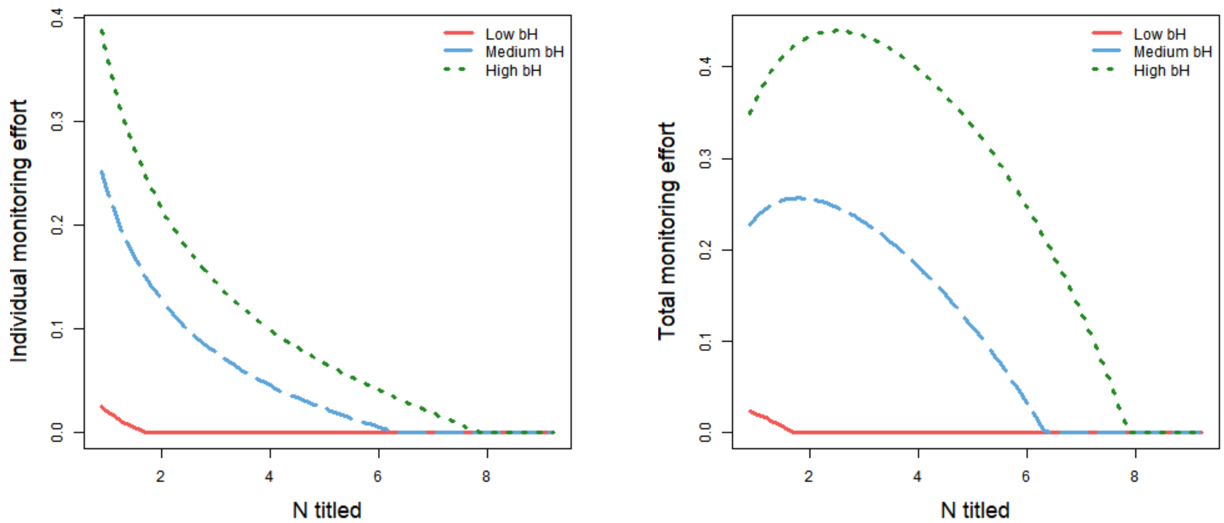
Figure 1: Deforestation and number of owners of communal title



Notes: The x-axis plots the number of owners and the y-axis total deforestation. The curves differ on the level of forest services valuation (b_h). The higher curve indicates greater deforestation because of lower forest valuation.

To understand the mechanisms behind these results, we show the monitoring effort and individual deforestation in Figures 2 and 3. The higher the forest valuation, the more monitoring effort that individuals exert (see Figure 2a). But each individual monitors for less time when there are more members since he benefits from his co-owners' monitoring. This individual behavior causes total monitoring effort to increase with N for low values of N, but it eventually declines as N becomes large (Figure 2b).

Figure 2: Monitoring effort and number of owners of communal title

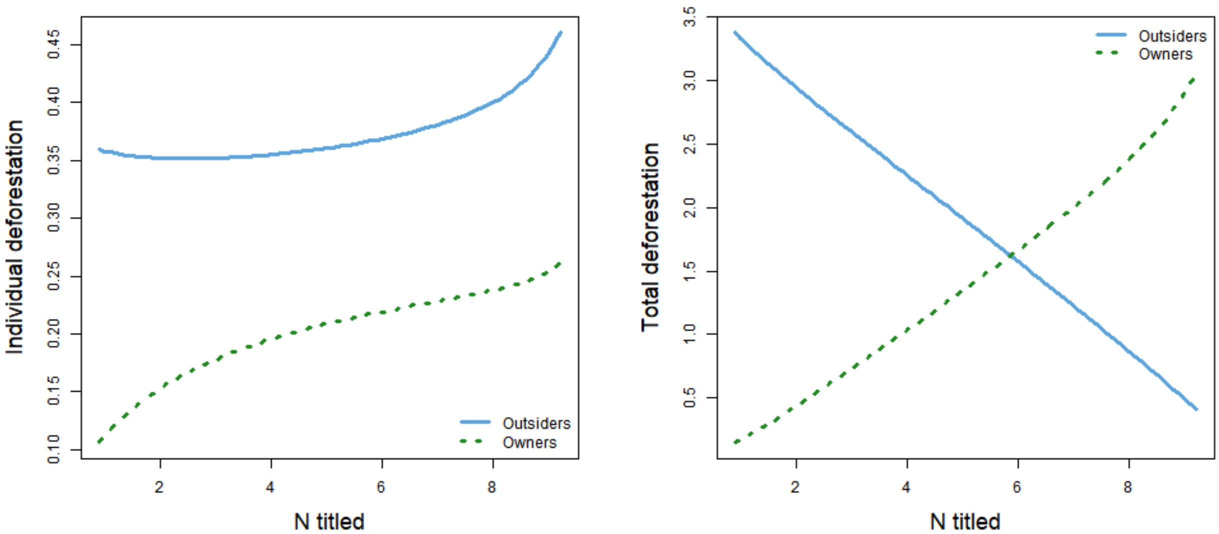


(a) Individual monitoring effort (b) Total monitoring effort

Notes: The x-axis indicates the number of owners and the y-axis indicates effort. The left panel plots individual monitoring and the right panel total monitoring. The curves differ on the level of forest services valuation (b_h). Effort is higher for higher levels of forest valuation.

Figure 3a plots the deforestation by owners and outsiders when forest valuation is high. The deforestation of an outsider individual is inversely related to total monitoring effort. In addition, outsiders always deforest more than insiders because they do not enjoy the benefits of the standing forest. Finally, owner deforestation increases when there are more owners, as in the classic tragedy of the commons. For each group, total deforestation depends mainly on the number of members of each group (see Figure 3b).

Figure 3: Outsider and owner deforestation by number of titled individuals



(a) Individual deforestation by group

(b) Total deforestation by group

Notes: The x-axis plots the number of owners and the y-axis deforestation.

3 Context and data

3.1 Background

Afro-Colombian communities have inhabited the west coast of Colombia since the nineteenth century. Yet such communities did not hold title to the land they occupied until Law 70 of 1993 established their right to communal land titles.[2] The first six titles were allocated in December 1996 in the department of Chocó. By the beginning of 2017 there were 168 titles, encompassing a total of 55,000 km^2 (see Figure 4a). According to the law, only vacant lots west of a specified line — which does not correspond to any political-administrative boundary (shown in red in Figure 4b) — are eligible for titling.

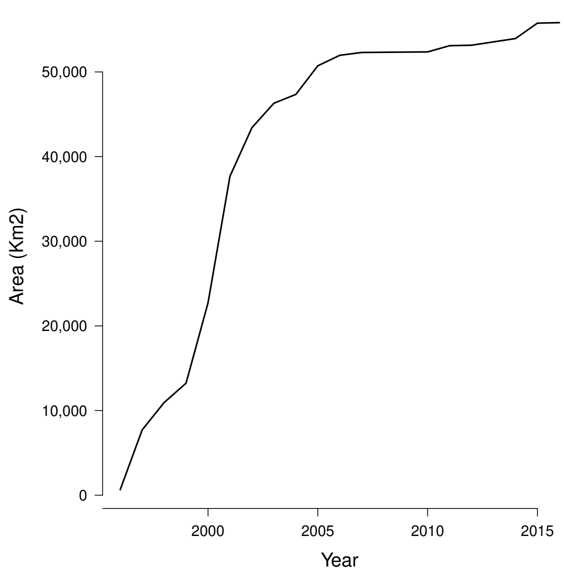
[2]In contrast to Mexican *ejidos*, there is no private property within communal titles in Colombia (Alix-Garcia, 2007).

The area that can be titled is located in mainly in the Pacific Coast of four departments (Chocó, Valle del Cauca, Cauca and Nariño). The area is geographically isolated from the rest of the country — with only two paved roads leading to the coast from the interior of the country — and has the highest poverty rate in the country.

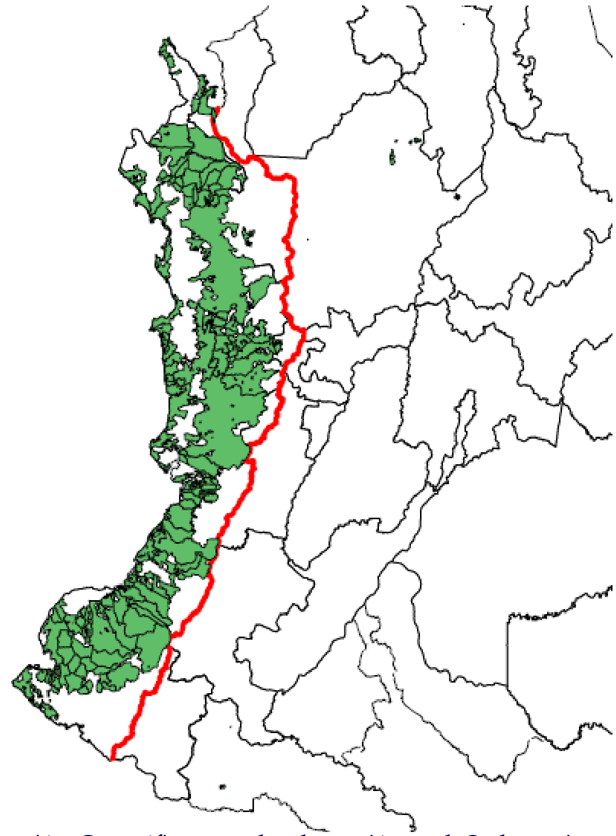
To request a communal title, community members must form a local council ("Consejo Comunitario"). This body will be in charge of "delimiting and assigning areas within the adjudicated lands; ensure the conservation and protection of the rights of collective property; ensure the preservation of cultural identity; ensure the conservation of natural resources; choose the legal representative of the respective community as a legal entity; and act as friendly constituents in the internal conflicts that may be reconciled" (Congreso de Colombia, 1993). Once the local council is formed, it must request the title from the central government by providing: A detailed description of the land to be titled; an etno-historic background of the community; a demographic description of the families within the title; and a description of the traditional means of production. After the request is received, the government has 60 days to send a delegate to verify the information. Then, the government has another 60 days to grant the title (or deny it). However, in practice the process has historically taken an average of two and a half years.

Figure 4: Communal titles under Law 70 of 1993

(a) Total area under communal titles by year



(b) Communal titles in 2016

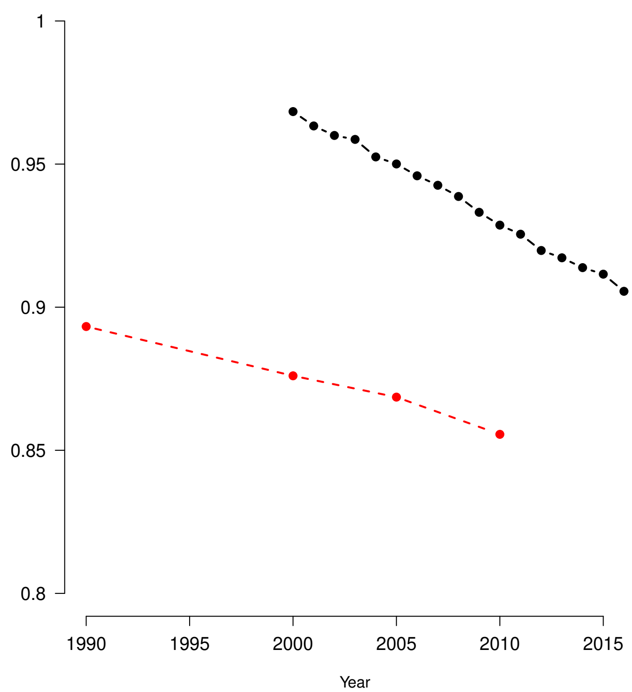


Notes: Authors' calculations based on (Sistema de Información Geográfica para la planeación y el Ordenamiento Territorial (SIGOT), 2019) data. Figure 4a shows the cumulative area under communal titles (in km^2 *from 1993 to 2016). Figure 4b shows the allocation of communal titles as of 2016. Only land to the left of the red line is eligible for communal titling.*

3.2 Data

We rely on two main data sources in our study. First, for forest coverage we use the deforestation data of Hansen et al. (2013), which quantifies areas deforested yearly from 2001 to 2016 at the $30m \times 30m$ pixel level. We aggregate to $90m \times 90m$ pixels computational purposes. We also use forest coverage information from the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM, its Spanish acronym) for 1990, 2000, 2005, and 2010 as a robustness check (Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM), 2019). The main difference between IDEAM and Hansen's data is that the former requires a minimum of 10 acres of continuous forest in order to label an area as forest, thus excluding small patches of forest (see Appendix A.1 for more details). According to the data, over 96% of the area eligible for communal titling was covered by forest in 2000; by 2016, the forest area had declined to just over 90% (see Figure 5).

Figure 5: Forest cover in area eligible for communal titling



Notes: the black dotted line represents the proportion of land in the area eligible for communal titling covered by forest according to Hansen et al. (2013). The red dashed line represents the land area within the communal titling eligible zone covered by forest according to Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM) (2019).

Second, we use information on the location of communal lands from the *Sistema de Información Geográfica para la planeación y el Ordenamiento Territorial* (SIGOT). The data include the year in which the collective title was granted, as well as its boundaries and number of inhabitants. We collect the date in which the request was first filed by coding it directly from the resolutions that granted each title. Table 1 presents summary statistics of the communal titles in our regression. The average communal title in our data was given in 2002 and encompasses 340 km^2.

Table 1: Characteristics of communal titles

	Mean	Median	Std. Dev.	Min	Max	N
Year titled	2,002	2,002	3.7	1,996	2,016	156
Year requested	1,999	2,000	2.2	1,996	2,006	142
Years request to titling	2.6	2	1.8	0	12	142
Area (km^2)	340	145	810	0	6,952	156
Population	2,145	923	4,069	0	39,360	156
Density (Population per km^2)	22	8	85	0	879	155

Notes: An observation is a communal title. Our regression does not include all 168 communities because not all of them have a control area to test the effect of titling.

3.3 Other data

We associate each pixel in our data with the closest communal title and calculate the distance between the two. We then combine spatial data from two other sources to create a data set at the pixel level: We get elevation from the ALOS Global Digital Surface Model by JAXA;[3] and roads and rivers data from DIVA-GIS (2019).

[3] Visit `http://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm` for more details

4 Empirical strategy

In order to identify the effect of communal titling on deforestation we use a differences-in-discontinuities strategy that compares areas just inside and outside the communal title (the discontinuity) before and after the title is granted (the difference). Specifically, we estimate the following model at the pixel-by-year level:

$$Y_{ict} = \beta_0 + \beta_1 After_{ct} \times Inner_i + f(Distance_i) + \alpha X_i + \gamma_{Inner_i,c} + \gamma_{ct} + \varepsilon_{ict}, \qquad (13)$$

where Y_{ict} is whether pixel i, in the vicinity of communal title c, was deforested in year t. By vicinity we mean that the pixel is close to the boundary of c, regardless of whether it is outside or inside the titled area. $After_{ct}$ is equal to one if the communal title for c has been granted by year t, and $Inner_i$ is an indicator equal to one if pixel i is inside the communal title. $Distance_i$ is the distance from pixel i to the boundary of c. Inside the communal title we set the distance as negative, and outside as positive. f is a flexible polynomial that we allow to be different on each side of the border. X_i are pixel level controls: distance to nearest road, nearest river and elevation. $\gamma_{Inner_i,c}$ and γ_{ct} are a set of communal title-inner and communal title-year fixed effects. Finally, ε_{ict} is the error term (which we cluster at the community-year level). β_1 measures the effect of collective land titling on the outcome of interest.

The strategy focuses on the land surrounding the borders of all communal titles, which usually follow natural boundaries, such as rivers. We use borders that are not adjacent to other communal titles or to the ocean.[4] The identifying assumption is that the borders

[4]An alternative identification strategy would focus on the area surrounding the arbitrary line set by Law 70 of 1993. Since the boundary of the title along the line is exogenous, the only difference between land inside and outside the title is the title itself. While the underlying identification assumption is stronger (easier to meet in practice), there are very few titles with a boundary that coincides with the line (see

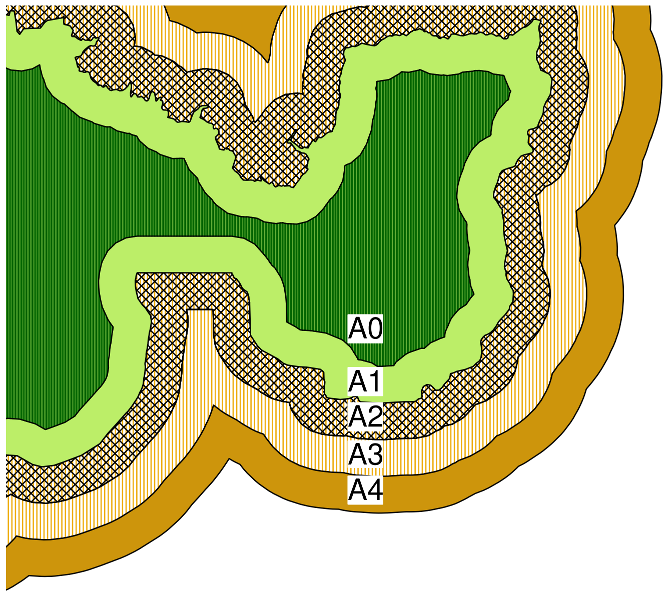
of the title are not determined by deforestation trends.

Specifically, $\gamma_{Inner_i c}$ absorbs any difference between land just inside and just outside the title. For example, if the border of the title is determined by a river, $\gamma_{Inner_i c}$ absorbs any difference between the two shores of the river. γ_{ct} absorbs any time variation (for each title separately). For example, if there is a new road constructed that allows easier access to a title, any change in deforestation (both inside and outside the title) is captured by these fixed effects. Thus, identification relies on two assumptions: First, the decision to title and the specific borders are not determined by deforestation. For example, if a community decides to title because deforestation is growing this would not violate the identification assumption (γ_{ct} would capture this). However, if the community decides to impose a border because deforestation is growing inside (or outside) such border, this would violate the identification assumption. Since borders usually follow natural boundaries, this seems unlikely. Second, that no other change takes place at the same time inside the title, as titling itself. It is unlikely this is a threat to identification as it would require a policy change that has both the same timing and the same geospatial attributes as titling.

Figure 6 provides a visual representation of the identification strategy using a sample communal title. The idea is to compare land just outside the title (in black-and-white crosshatch pattern) to that just inside the title (in orange horizontal lines), before and after the title is given to the community.

Figure 4b), and hence any estimates from this identification strategy are too imprecise to be informative.

Figure 6: Visual representation of differences-in-discontinuities identification strategy



Notes: Example of areas used in the regressions. The area deep inside the title is depicted in solid dark green (A0), with the portion near the title border denoted in light green (A1). The black and white cross-hatch pattern denotes land located just outside the title area (A2). The border of the title is between A1 and A2. The yellow area with vertical lines represents area farther outside the title (A3). The area in brown represents land that is even father away (A4). The main regression compares A1 and A2. Areas A0, A3 and A4 are not included in the main regression, but A3 and A4 will be to study spillovers.

Alternative we can include pixel fixed effects (γ_i) to control for observable and unobservable characteristics of each pixel that are constant through time. For example, soil quality, potential agricultural productivity and suitability for cattle ranching. We can also control for time dummies interacted with distance to nearest road, nearest river and elevation.

$$Y_{ict} = \beta_0 + \beta_1 After_{ct} \times Inner_i + \sum_t \alpha_t Year_t X_i + \gamma_i + \gamma_{ct} + \varepsilon_{ict}, \quad (14)$$

4.1 Data balance

Table 2 presents characteristics of the treatment and control pixels. Overall, our data points are far from roads and close to rivers. As expected, they are similar along several time-invariant characteristics, such as distance to the nearest road, distance to the nearest river, and slope (see Table 2; Column 4).

Table 2: Balance around the boundary of time-invariant covariates

	(1) Control	(2) Tretament	(3) Difference	(4) Discontinuity
Panel A: Half optimal bandwidth				
Distance to nearest road (km)	24.19	24.59	0.41***	0.08
	(21.24)	(21.30)	(0.14)	(0.07)
Distance to nearest river (m)	3.91	1.34	-2.57***	-0.40
	(36.07)	(23.61)	(0.79)	(0.73)
Slope(%)	0.95	0.93	-0.02	0.00
	(1.70)	(1.67)	(0.01)	(0.02)
Panel B: Optimal bandwidth				
Distance to nearest road (km)	23.88	24.57	0.69***	0.13
	(20.93)	(21.26)	(0.20)	(0.12)
Distance to nearest river (m)	5.42	0.97	-4.45***	-0.77
	(48.17)	(19.94)	(1.32)	(1.20)
Slope(%)	0.92	0.90	-0.01	-0.01
	(1.65)	(1.63)	(0.01)	(0.02)
Panel C: Double optimal bandwidth				
Distance to nearest road (km)	23.40	24.58	1.18***	0.13
	(20.52)	(21.28)	(0.32)	(0.20)
Distance to nearest river (m)	7.96	0.67	-7.28***	-1.79
	(71.48)	(16.32)	(2.14)	(1.44)
Slope(%)	0.90	0.89	-0.01	0.01
	(1.62)	(1.60)	(0.02)	(0.02)

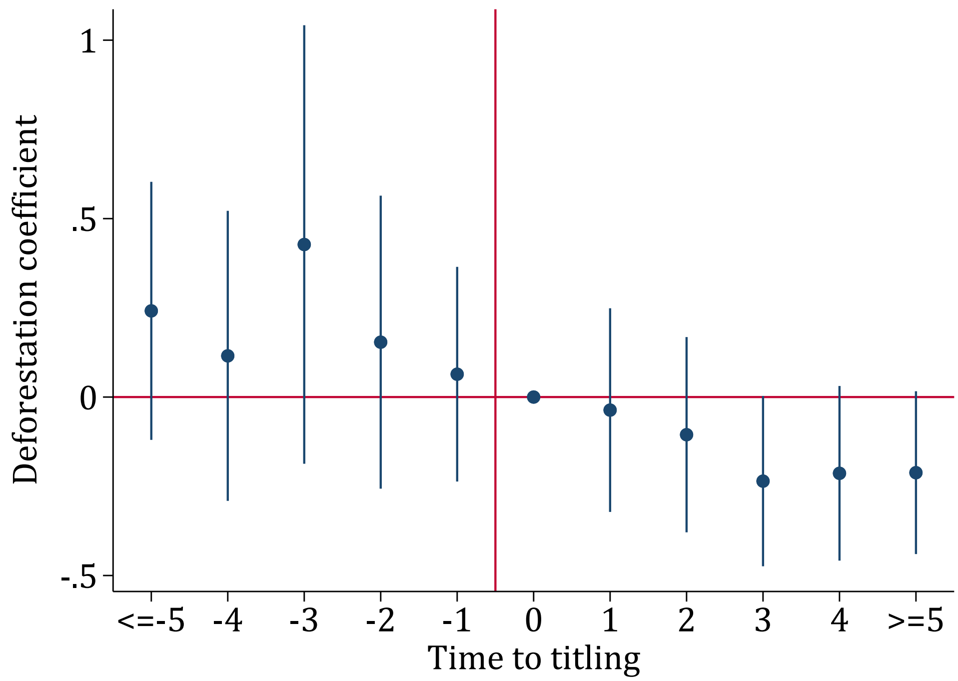
Notes: This table presents the mean and standard error of the mean (in parentheses) for the pixel just outside ("Control" Column 1) and just inside the communal titles ("Treatment", Column 2). The last columns present the difference between treatment and control (Column 3), and the discontinuity at the threshold allowing for a different linear fit inside and outside the title. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5 Empirical Results

In this section we explore how communal land titling affects deforestation. We find that communal titling reduces deforestation in small and large communities. The results are robust to different bandwidths, polynomial specifications, and different measures of forest coverage.

We first study the evolution of deforestation inside and outside the title before and after titling (i.e., an event stud; see Figure 7). Before titling there are no significant differences between deforestation inside and outside the titled area. However, after titling, there is less deforestation inside the area, especially after the first year. There is a slight pre-trend which could be explained by the average lag of 2.5 years between filing the request for titling and the title being granted.

Figure 7: Deforestation inside and outside communal lands, before and after titling



Note: This figure illustrates the event study of the effect of titling on deforestation. The x-axis plots years to titling, with 0 being the year of titling. The y-axis plots the coefficients of years to titling interacted with the dummy for inner in a regression explaining deforestation.

Next, we present the estimates from the difference-in-discontinuities (i.e., equation 13; see Table 3). Communal titling led to a decrease of 0.33 (p-value<0.01) percentage points from a base of 4.95% (a 6.7% decrease). There is important heterogeneity by the number of inhabitants of the communal land. Deforestation decreases in small communities (below the median size) by 0.49 percentage points, a decrease of 10% (Column 2). On the other hand, in large communities (above the median size) deforestation decreases by 0.28 percentage points. These results are consistent with medium-to-high valuation of standing forest by the community, as illustrated in the theoretical framework. The results are qualitatively similar using IDEAM data (Columns 3 and 4), and indicate a decrease in deforestation of 0.87 (p-value<0.01) percentage points from a base of 15.4%

(a 5.6% decrease). The larger coefficient can be partially explained by the periodicity of the data (5-year intervals for IDEAM vs yearly data for Hansen).

Table 3: Effect of communal titling on deforestation

Dependent Variable:	Deforested (100/0)			
	Hansen		IDEAM	
	(1)	(2)	(3)	(4)
After X Inner	-0.33***		-0.87***	
	(0.10)		(0.30)	
After X Inner X Small Pop		-0.49***		-1.20*
		(0.16)		(0.62)
After X Inner X Large Pop		-0.28**		-0.80**
		(0.12)		(0.34)
N. of obs.	15,142,393	15,142,393	2,432,789	2,432,789
Communities	156	156	156	156
Mean of Dep. Var.	4.95	4.95	15.4	15.4
R^2	0.12	0.12	0.25	0.25

Hansen yearly data (2001-2016). IDEAM is the official government data for 1990, 2000, 2005, and 2010. All regresion include communal title-inner and communal title-year fixed effects. Controls include distance to the nearest road; distance to the nearest river and slope. Standard errors, clustered by community-year, are in parentheses. Optimal bandwidth calculated for each community. Deforested=100. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The results are also robust to using pixel fixed effects (i.e., equation 14). The results using Hansen's yearly data (Table 4: Columns 1 and 2) are similar to those of Table 3. For IDEAM's data the coefficients are smaller and not statistically significant. This is partially explained by nosier estimates due to the fact that there are only four years of data and the pixel fixed effects absorbs much of the variation in the outcome variable.

Table 4: Effect of communal titling on deforestation

Dependent Variable:	Deforested (100/0)			
	Hansen		IDEAM	
	(1)	(2)	(3)	(4)
After X Inner	-0.33***		-0.40	
	(0.11)		(0.27)	
After X Inner X Small Pop		-0.49***		-0.84
		(0.16)		(0.67)
After X Inner X Large Pop		-0.28**		-0.30
		(0.13)		(0.30)
N. of obs.	15,142,393	15,142,393	2,368,548	2,368,548
Communities	156	156	156	156
Mean of Dep. Var.	4.95	4.95	15.3	15.3
R^2	0.77	0.77	0.84	0.84

Results of estimating equation 14. All regressions include pixel fixed effects and time dummies interacted with distance to nearest road, nearest river and slope. Hansen yearly data (2001-2016). IDEAM is the official government data for 1990, 2000, 2005, and 2010. Standard errors, clustered by community-year, are in parentheses. Optimal bandwidth calculated for each community. Deforested=100. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Our results are robust to a series of specification choices. First, the results do not vary qualitatively by the choice of the optimal bandwidth (see Table A.1). Since we are using a difference-in-discontinuities design, we follow the standard practice of choosing the bandwidth near the discontinuity following Calonico, Cattaneo, Farrell, and Titiunik (2017). Using a bandwidth that is twice as large or half as large yields similar results. Finally, the results are unaffected by using linear instead of quadratic polynomials (columns 4-6 of Table A.1).

We perform additional regressions, varying the control group, to address spillovers (see Table 5). Column 1 replicates the results in Table 3: Column 1, where we compare forest just inside versus forest just outside the communal title. This is area A1 versus area A2 in Figure 6. The control group here is land that is within the optimal bandwidth from the border of the title. As we move away from the border we expect spillovers to fade-out. Column 2 compares A1 with A3. That is, land just inside the title, with land outside the title but farther away from the border (i.e., an outer ring). The control group here is land that is between the bandwidth and twice the bandwidth from the border. Column 3 performs a similar exercise but with a control group that is between two times the bandwidth and three times the bandwidth from the border (i.e., it compares A1 to A4, Figure 6). The effect of titling is larger as we use control groups that are farther from the border. We interpret this as evidence of positive spillovers. Positive spillovers are further supported by the evidence in Columns 4 and 5, where we perform placebo exercises. In Column 4 we compare land outside the border with land that is farther outside, by comparing A2 to A3. Specifically, comparing land that is twice the bandwidth from the border, with land that is near the border (at most the optimal bandwidth away). Since deforestation decreases in the land close to the title, as in Robalino and Pfaff (2012), we take this as further evidence of positive spillovers. Finally, in Column 5 we compare land outside the title that is twice the bandwidth away from the border, with land that is three times the bandwidth away from the border (i.e., comparing A3 with A4). Here we find no evidence of differential deforestation, which can be explained by positive spillovers fading-out with distance. Also, there is no reason to expect differential deforestation around this imaginary border.

6 Conclusions

In this paper we study the effect of the allocation of communal land titles on deforestation. We find that communal titling reduces deforestation. These results suggest that the tragedy of the "commons effect" does not drive an increase in deforestation, and that

Table 5: Effect of communal titling on deforestation

Dependent Variable:	Deforested (100/0)				
	(1)	(2)	(3)	(4)	(5)
After X Inner	-0.33***	-0.90***	-1.10***		
	(0.10)	(0.20)	(0.28)		
After X Placebo				-0.54***	-0.14
				(0.12)	(0.12)
Comparison	A1-A2	A1-A3	A1-A4	A2-A3	A3-A4
N. of obs.	15,142,393	13,768,419	12,665,153	13,054,266	10,577,026
Communities	156	156	156	156	156
Mean of Dep. Var.	4.95	5.01	5.18	5.42	5.80
R^2	0.12	0.13	0.13	0.14	0.15

Each column compares different regions as defined on Figure 6. Deforested=100 using Hansen's yearly data (2001-2016). Controls include distance to the nearest road; distance to the nearest river and slope. Standard errors, clustered by community-year, are in parentheses. Optimal bandwidth calculated for each community. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

communal titling can be an effective tool to protect forests. Using a theoretical framework, we show that this result depends on how highly the community values standing forest and on the size of the community.

Our results speak to the broad discussion on how best to protect forest in developing countries. Some argue that establishing national parks is an effective approach to reducing deforestation. This approach often fails to take into account existing communities as well as weak state presence in areas that might be suitable for parks. If, however, the communities obtain value from standing forest, their members might be more effective than the government at monitoring outsider deforestation. Currently, there is no data on productive projects within each community (e.g., ecotourism or fruit harvesting); future research could provide a better understanding of why certain communities place a high value on standing forest.

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A Additional tables and figures

Table A.1: Robustness effect of communal titling on deforestation

Dependent Variable:	Deforested (100/0)					
	(1)	(2)	(3)	(4)	(5)	(6)
After X Inner X Small Pop	-0.39***	-0.49***	-0.73***	-0.39***	-1.10***	-0.73***
	(0.15)	(0.16)	(0.19)	(0.15)	(0.15)	(0.19)
After X Inner X Large Pop	0.089	-0.28**	-0.53***	0.089	-0.20***	-0.53***
	(0.11)	(0.12)	(0.18)	(0.11)	(0.071)	(0.18)
Bandwith	$0.5h^*$	h^*	$2h^*$	$0.5h^*$	h^*	$2h^*$
Polynomial	Quadratic	Quadratic	Quadratic	Linear	Linear	Linear
N. of obs.	7,743,177	15,142,393	27,604,940	7,743,177	15,142,393	27,604,940
Mean of Dep. Var.	5.06	4.95	4.93	5.06	4.95	4.93
R^2	0.11	0.12	0.13	0.11	0.12	0.13

Standard errors, clustered by community-year, are in parentheses. Optimal bandwidth calculated for each community. Deforested=100. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A.1 IDEAM data

The Institute of Institute of Hydrology, Meteorology and Environmental Studies (IDEAM, in its Spanish acronym) quantifies natural forested and deforested areas in Colombia through semi-automated digital processing of remote sensor images at medium spatial resolution (one pixel is covers approximately 30 mts × 30 mts). Currently, maps are available for the years 1990, 2000, 2005, 2010, 2012 and 2013 (Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM), 2019). To be considered forest land by IDEAM, an area must meet the following minimum criteria: tree canopy density of 30%, canopy height of 5 meters, and be 10,000 m^2 in size (Galindo, Espejo, Rubiano, Vergara, & Cabrera, 2014). The images are generated by the LANDSAT satellite program and exclude forest plantation areas where palms or fruit trees are grown, for example.

By contrast, Hansen et al. (2013)'s Global Forest Change (GFC) dataset, stored at Google Earth Engine, tracked gains and losses in forested areas between 2000 and 2016 around the world. For this study, trees were defined as all vegetation higher than 5 meters in height and forest loss was defined as a disturbance of replacement of stands. These data were also generated by means of remote sensing techniques using LANDSAT images with a resolution of 30 meters per pixel. The GFC data used in this analysis include loss and gain of forest cover, derived using algorithms to detect the removal or recovery of plant biomass, with a pixel classified as “deforested” or “recovered” based on a threshold of 50%. GFC data include the percentage of tree coverage per pixel for the year 2000 and the loss of forest cover each year between 2001 and 2016.

The main differences between the two assessments are that IDEAM sets as minimums 10,000 m^2 for area and 30% of a pixel for forest cover, whereas Hansen et al. (2013) set no minimum size for area and 50% for forest cover. The differing criteria regarding area indicate that Hansen et al. (2013)’s data are a subset of IDEAM data when the forest is continuous, while the former includes small patches of forest that the latter does not. Both sources rely on the same satellite imagery.

Variable	Hansen et al.	IDEAM
Pixel resolution	30 m	30 m
Minimum canopy height	5 m	5 m
Tree density	50%	30%
Minimum area	0	10,000 m^2