Supporting Information for

Collective Property Rights Lead to Secondary Forest Growth in the Brazilian Amazon

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SI References

Other supporting materials for this manuscript include the following:

Dataset S1

Supporting Information Text

Here, we provide more in-depth discussion of several aspects of the paper. The supplement consists of 3 sections: (1) link to the accompanying Policy Brief, (2) background information on the demarcation process in Brazil and (3) an in depth explanation of our Regression Discontinuity methods, including a subsection on the random aspect of the timing of homologation, a subsection on balance of our covariates and robustness tests. The contents of the SI are largely the same as the SI in Baragwanath and Bayi (2020)(1).

Policy Brief

We have written a Policy Brief where we summarize the results from Baragwanath and Bayi (2020) and this paper.

The Demarcation Process

The main governmental agency responsible for the protection and management of indigenous territories is the Fundação Nacional do Índio, the National Indian Foundation (FUNAI). FUNAI was founded in 1967 under the jurisdiction of the Ministry of Justice. It replaced the Indian Protection Service (SPI) charged for genocide, rape, torture and enslavement of indigenous tribes. Indigenous peoples were placed under the "tutorship" of FUNAI by the Indian Statute, promulgated in 1973. This statute is still in force today but is a source of controversy as it is in clear contradiction with the progressive and non-assimilative provisions of the 1988 Constitution (2).

Assimilation was the official policy towards indigenous peoples in all Latin American states until the 1980"s. Assimilation policies posed a huge challenge to indigenous peoples as they aimed to assimilate them with the nation, forcing them to abandon their collective identity by "dismantling their social institutions and cultural values in order to incorporate them into an acceptable subordinate position in the dominant society" (3). The Indian Statute embodies this approach as Article 1 states, "this law rules on the legal situation of Indians and indigenous communities, with the purpose of preserving (their) culture and of integrating them, progressively and smoothly, to the national communion" (4).

After the foundation of FUNAI in 1967 and the promulgation of the Indian Statute in 1973, the demarcation process by which indigenous tribes would receive lands was set forth in 1976 by Decree 76999 (Instituto Socioambiental 2018a)* The demarcation of indigenous territories consists of a four-step process involving (1) an anthropological study to identify the physical boundaries of the territory, (2) the approval of FUNAI, (3) the approval of the Minister of Justice and (4) the homologation by Presidential decree and registration in the national land registry. This process further holds that, prior to the presidential homologation, any third party can contest the demarcation of a territory and non-indigenous parties living on said territory will be resettled and financially compensated. Our paper relies strongly on the fact that territories are still open to dispute before homologation, giving third parties incentives to contest, invade and make use of these lands in order to prove in courts of law that they would be significantly harmed by the demarcation of the land.

There are three other types of legal land tenure an indigenous territory can hold, although these are much less common than homologated indigenous territories. Indigenous territories can hold the title of (1) "reserve" - if the land was donated by a third party, purchased or expropriated by the Union, (2) "dominion" - when a territory is fully owned by indigenous communities, and (3) "restrictions on usage" - when a territory is comprised of isolated indigenous peoples and FUNAI deems it necessary to establish restrictions on entry for their protection. Reserves make up 8% of the territories analyzed, while domains and restrictions on usage lands represent 0.85% each.

The Federal Union remains the proprietor of homologated and "restrictions on usage" territories which distinguishes them from their counterparts. For purposes of this study, we consider reserves, dominions and restrictions on usage territories as having completed the step of homologation which grants collective property rights to indigenous peoples and gives them the rights over the land. We further consider territories that have yet to be homologated as territories with no property rights.

Once homologated, indigenous territories gain their full property rights as enumerated in the 1988 Brazilian Constitution. The Constitution states that indigenous peoples' socio-political rights and original right to land is incumbent upon the Union's demarcation of these territories (Article 231) and recognizes these homologated territories as "those indispensable for the preservation of environmental resources necessary for their well-being" (5). Article 231 poses that indigenous peoples have "the exclusive usufruct of the riches of the soil, rivers and lakes existing thereon" (158) while exploitation rights of the subsoil remain vested in the State. Additionally, the Union has the constitutional "responsibility to delineate these lands and to protect and ensure respect for all their property" (5). Thus, without homologation, indigenous territories do not have the legal rights needed to protect their territories, their territorial resources are not considered their own and the government is not constitutionally responsible for protecting them from encroachment, invasion and external use of their resources. Once homologated, a territory becomes the permanent possession of its indigenous peoples (5), no third party can contest its existence and extractive activities carried out by external actors can only occur after consulting the communities and the National Congress.

Methods

We use NASA's Making Earth System Data Records for Use in Research Environments (MEaSUREs) Vegetation Continuous Fields (VCF) Version 1 data product (VCF5KYR) which provides remote-sensing validated historical fractional vegetation cover (FVC) data at a 0.05° resolution between 1982 and 2016 to measure deforestation at yearly intervals (6). This is a new

*The demarcation process was then altered by Decree 88118 (1983), Decree 94945 (1987), Decree 22 (1991) and Decree 1775 (1996) (Instituto Socioambiental 2018a).

dataset which has been used in (7) and allows us to cover over 30 years of deforestation. While the spatial resolution of this dataset is significantly lower than the Hansen Global Forest Change data, the temporal resolution is much longer. Most other papers in this literature are analyzing short time periods due to limited temporal resolution of older datasets, however, the long time coverage provided by VCF5KYR allows us to compare deforestation before and after the homologation of most of the indigenous territories in Brazil.

We create a panel data set between 1982 and 2016 which includes forest cover in each year. Summary statistics can be seen in Table S1. We create the deforestation variable which is equal to the difference in forest cover between year t and t-1. If the difference is higher than 0, deforestation is equal to 0. Since years 1994 and 2000 are missing in the Hansen data, we impute forest in those years as the average forest in the years before and after.

Maps containing the geolocation of the indigenous territories were obtained from FUNAI, and maps of Brazil's administrative units (states, and municipalities) and roads were obtained from the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatisticas - IBGE). Indigenous territories in the first step of the demarcation process do not have their boundaries geocoded thereby reducing the number of territories we analyze. Additionally, we updated the data to include legal status and the year the legal status was obtained for each indigenous territory using the Instituto Socioambiental's (ISA) online indigenous land database.

We also use several other sources for our control variables. Existing literature has found that proximity to roads, rivers and mines, as well as elevation and rainfall are significant predictors of deforestation (8–14) and are readily available in the time scope we need. Additionally, poverty and population have been found to matter as well(8), however, the time frame for which these are available in a geographically explicit manner is limited. We can use nightlights to proxy for development (which can capture poverty), however these are only available from the 1990s onwards (15). Additionally, population at a spatially explicit scale is only available beginning in 2000 and in 5 year intervals through the Gridded Population of the World (16). Given these data limitations, we present our main findings using only covariates which are available for the entirety of the sample, which are mainly geological and physical characteristics. Robustness checks including nightlights and Gridded Population of the World (GPW) indicate that our results regarding property rights are somewhat smaller, but remain statistically significant.

When the resolution of a control variable is different to that of our grids, we calculate the average value for each grid cell. We use the Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010) dataset provided by the U.S. Geological Survey (USGS) containing elevation data for the globe measured in meters at a 7.5 arc seconds resolution. Mean elevation is computed for each grid. The precipitation dataset (CHIRPS Pentad: Climate Hazards Group Infrared Precipitation with Station DATA 2.0) is provided by UCSB/CHG. This dataset consists of a gridded rainfall time series for trend analysis and seasonal drought monitoring. Precipitation is measured in mm/pentad at a 0.05 arc degrees resolution; mean precipitation is computed for each grid from 1982 to 2016. Data on the main rivers in Brazil was obtained through Esri software provided by the Brazilian National Agency for Water (ANA). We also use NASA's USGS Earth's Resources Observation and Science (EROS) Center water mask data which provides a map of surface water at 250m resolution from 2000. We compute the sum of water mask for each grid and eliminate grids that are more than 60% water.

Our final dataset is a panel dataset with 35 year observations of 30,699 pixels, coming to 1,074,465 observations. The level of analysis is at the pixel level. Below we describe the key features of our design, namely the orthogonality of the timing of homologation which provides us with temporal identification and the regression discontinuity design from which our estimates are derived.

By only using observations close to the borders, we are able to isolate many of the confounding effects that arise from the fact that indigenous territories might be located in systematically different lands. Observations right inside the territory are expected to be similar to observations right outside the territory, as seen in S1. Another way we try to alleviate these concerns is by comparing the results in homologated territories to the results in territories that have not been homologated. Many territories are demarcated, which means that their boundaries are drawn, identified as indigenous lands and put on maps, however they never reach the step of homologation, when actual property rights are granted to the indigenous communities. These territories serve as a useful control group. If the effect on deforestation is coming from property rights, then these territories which have been identified as indigenous lands but have not yet received the rights should show no effects.

Additionally, we exploit the orthogonality in the timing of homologation to identify the effect of property rights. The number of homologated territories per year varies greatly, from 0 to 70 territories homologated in any given year, and seems to follow no clear pattern. Article 67 of the Temporary Provisions in the 1988 Constitution required the Union to demarcate 532 territories by 1993 (9). However, by 1993, less than 50% of these territories had started the demarcation process (Hutchison et al. 2006), let alone received full property rights as was required by the Article. The large number of indigenous territories homologated in 1991 under President Collor de Mello might reflect the government's attempt to follow the demarcation requirement set out by the 1988 Constitution, however this requirement was not met and many of the territories had to wait years in order for their property rights to be granted. While some years have witnessed more homologations than others, figure S2 illustrate the randomness of timing of the demarcation process. Additionally, apart from the two most recent governments, every President has signed over property rights during their tenure, regardless of party or ideology. Election years are not more likely to have more homologations. The demarcation process has no set timeline or duration pattern, with no guarantees of how long it might take for an indigenous territory to obtain its full property rights or even advance in the process.

As such, we take the exact year of homologation as a treatment that is as orthogonal to our dependent variable, so we can recover the causal effect of Collective property rights on deforestation. We look at the deforestation levels right inside and right outside a territory's borders, right before and right after the property rights were finally granted.

Table S1. Summary Statistics and Balance: Full Sample

Variable	Mean control	SD control	Mean treat	SD treat	Difference	P-Val
Panel A: Non Homologated Territories						
Elevation (m)	193.803	(144.950)	169.510	(112.115)	4.976	(0.053)
Distance to Mines (km)	159.430	(149.492)	185.867	(138.176)	2.619	(0.457)
Distance to Rivers (km)	29.066	(26.050)	33.540	(27.361)	1.749	(0.253)
Distance to Roads (km)	70.626	(61.964)	79.327	(66.805)	1.297	(0.584)
Rainfall	30.582	(7.620)	33.816	(7.097)	0.217	(0.001)**
Population	24.290	(218.006)	4.346	(15.584)	-4.009	(0.152)
Nightlights	0.444	(0.751)	0.431	(0.707)	-0.006	(0.036)**
Observations	*76,300*		*39,270*		*115,570*	
Panel B: Before Homologation						
Elevation (m)	189.486	(125.802)	229.390	(166.449)	15.706	(0.073)
Distance to Mines (km)	201.173	(194.167)	225.200	(200.082)	2.339	(0.555)
Distance to Rivers (km)	39.864	(38.674)	46.874	(39.531)	2.574	(0.028)*
Distance to Roads (km)	66.312	(61.238)	69.851	(55.216)	4.792	(0.062)
Rainfall	30.227	(6.418)	30.598	(6.927)	-0.182	(0.057)
Population	30.532	(329.072)	6.135	(27.578)	-19.265	(0.002)***
Nightlights	0.149	(1.042)	0.076	(0.261)	-0.021	(0.001)***
Observations	*236,713*		*167,661*		*404,374*	
Panel C: After Homologation						
Elevation (m)	213.331	(138.190)	249.734	(174.577)	21.898	(0.146)
Distance to Mines (km)	194.067	(183.500)	198.495	(177.549)	-1.739	(0.763)
Distance to Rivers (km)	44.651	(43.547)	47.886	(42.308)	0.908	(0.393)
Distance to Roads (km)	55.356	(56.551)	66.510	(55.344)	7.827	(0.040)*
Rainfall	28.671	(6.372)	30.120	(6.988)	-0.120	(0.226)
Population	86.428	(1,162.048)	8.082	(45.685)	-40.034	(0.000)***
Nightlights	0.684	(1.731)	0.562	(0.772)	-0.070	(0.000)***
Observations	*328,607*		*225,914*		*554,521*	

Table S2. Timing of Homologation is Orthogonal to Deforestation

	Years Between Declared and Homologated	Probability of Homologation
Deforestation Year Declared	-0.055	0.001
	(0.528)	*(0.916)*
Deforestation Year Before Homologated	0.022	-0.001
	(0.077	*(0.964)*

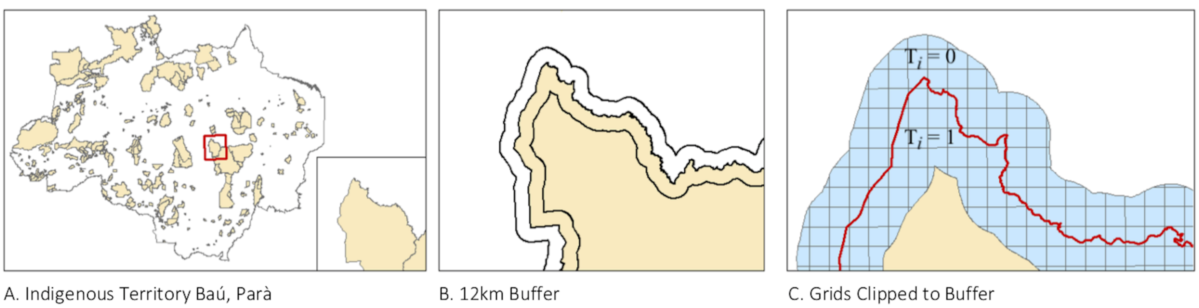

Fig. S1. RDD Method illustrated by the indigenous territory Baú in the state of Pará (A). Prior to the creation of 12km buffer on either side of a territory's border (B), we generate a tessellation of grids covering the region of the Legal Amazon. We then use the buffer to identify which units (grids) fall within 12km of a territorial border, on either side of it (C). The border defines whether our units are part of our control or treated groups.

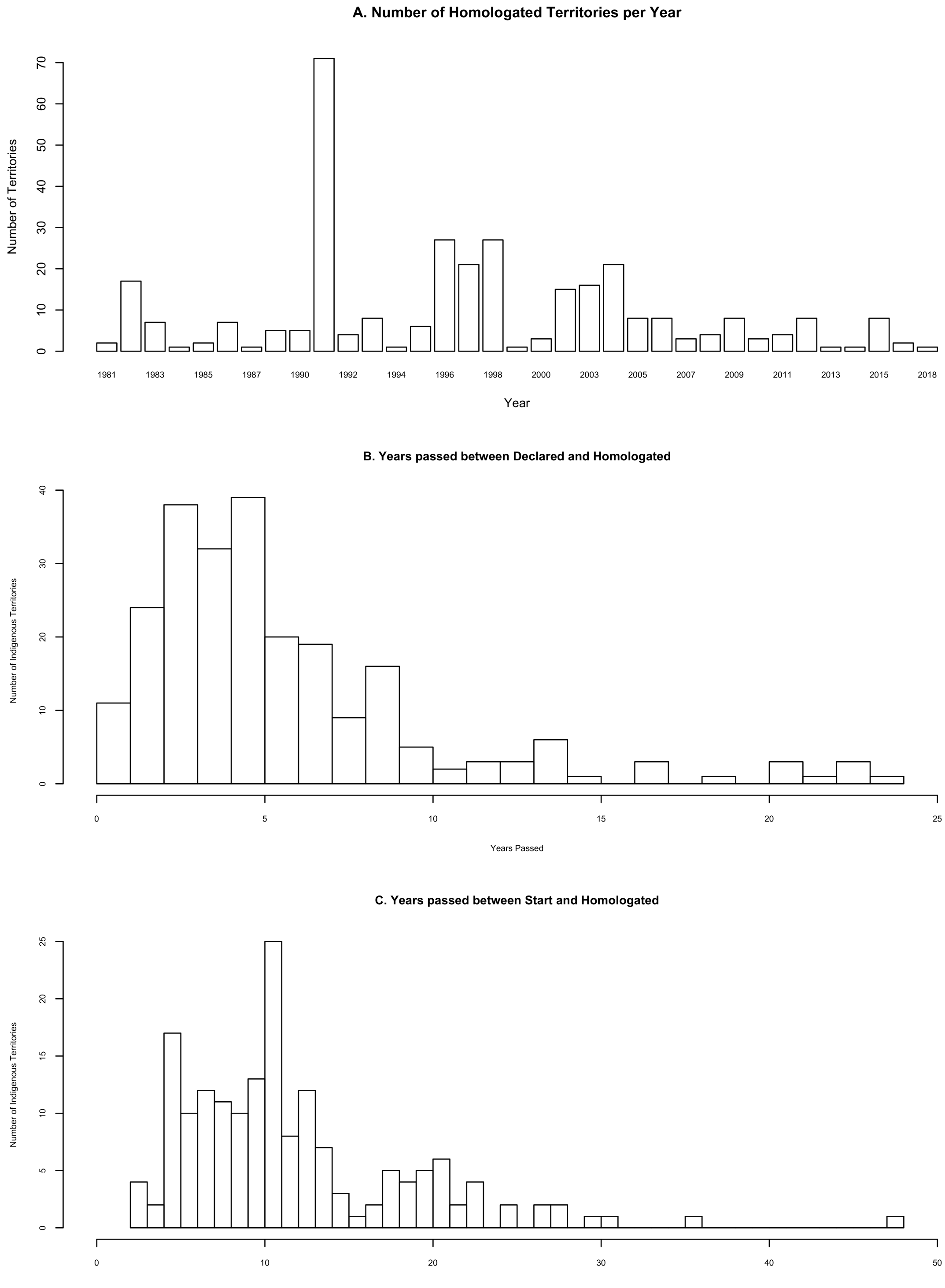

Fig. S2. Number of territories gaining full property rights since 1981 (A), the amount of years passed between homologation and when a territory started the demarcation process (B) and its previous declared status (C). These figures demonstrate that there is no clear pattern in the timing of homologation.

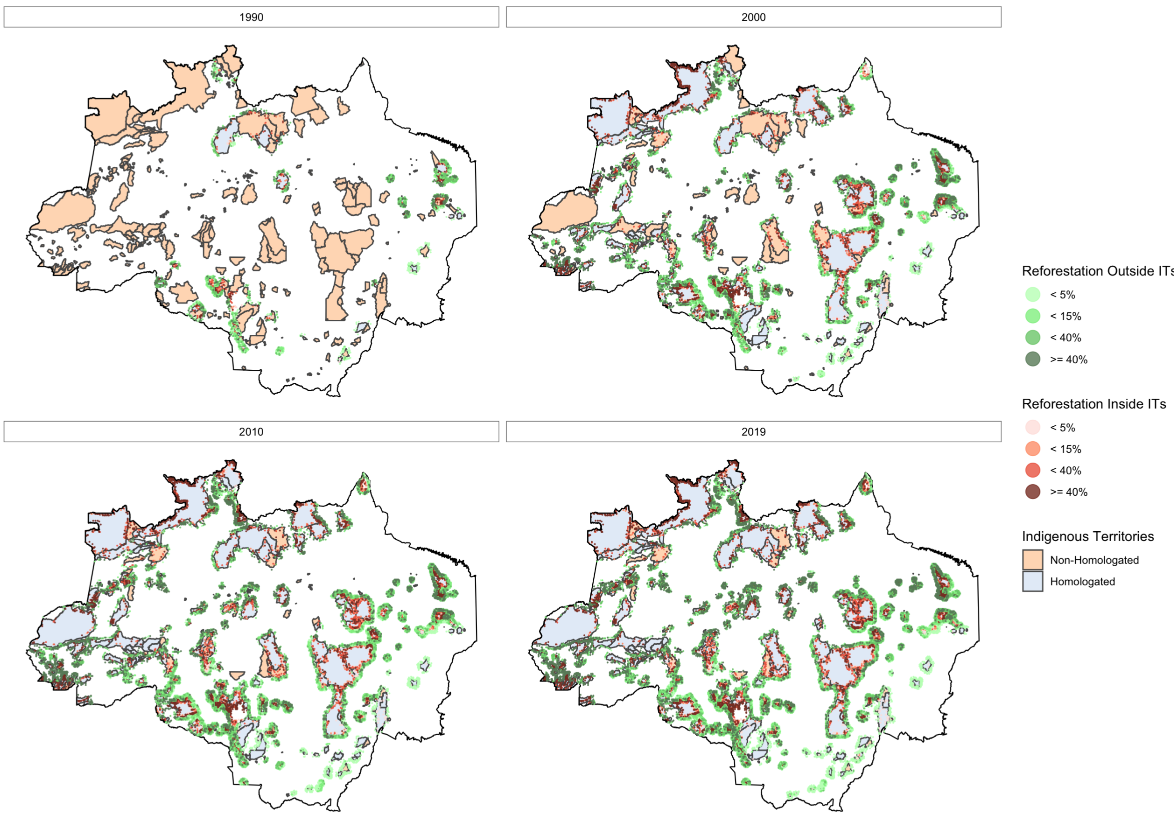

Fig. S3. Reforestation and Indigenous Territories in the Brazilian Amazon in 1990 (top left), 2000 (top right), 2010 (bottom left) and 2019 (bottom right). Green dots represent reforestation outside of ITs. Red dots represent reforestation inside of ITs. Orange Polygons Represent Non Homologated ITs while blue polygons represent homologated ITs.

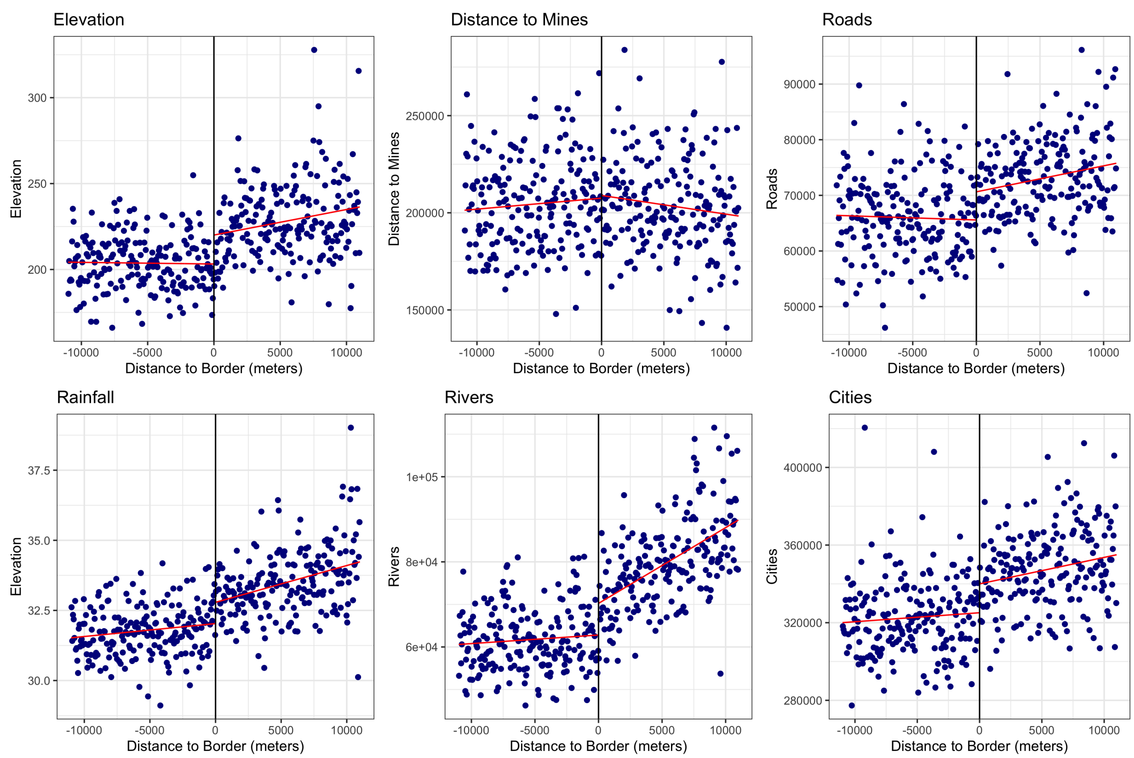

Fig. S4. Covariate Balance: After Homologation, P=1

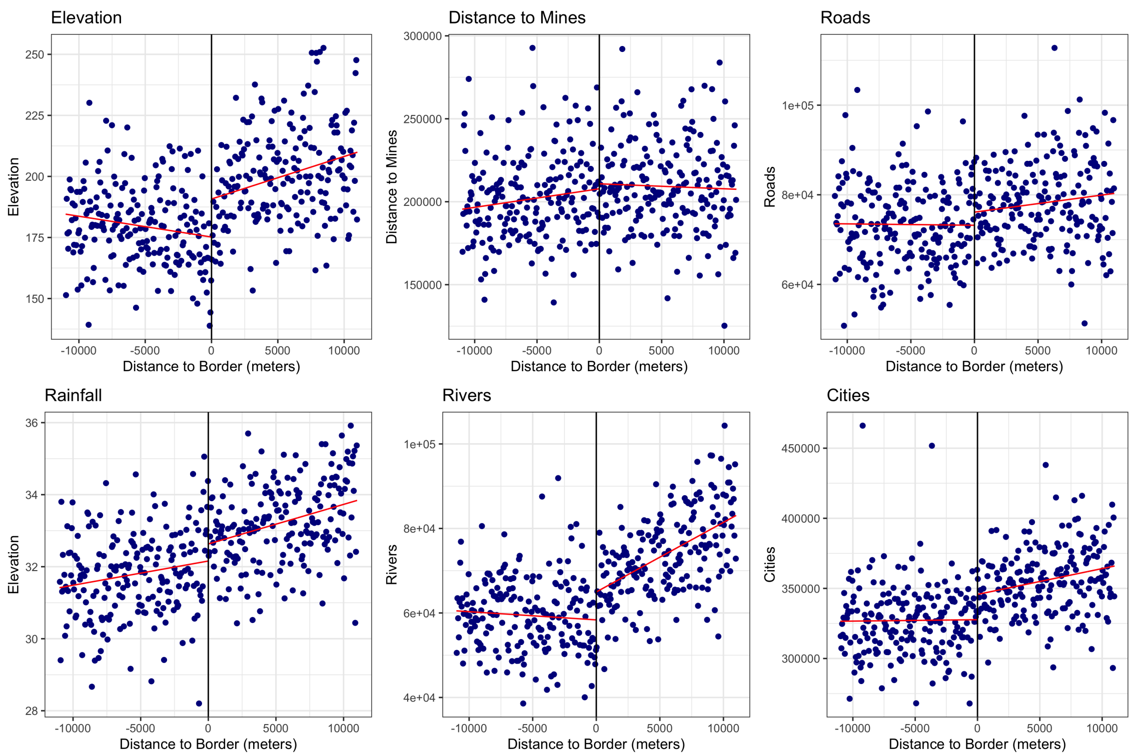

Fig. S5. Covariate Balance: Before Homologation, P=1

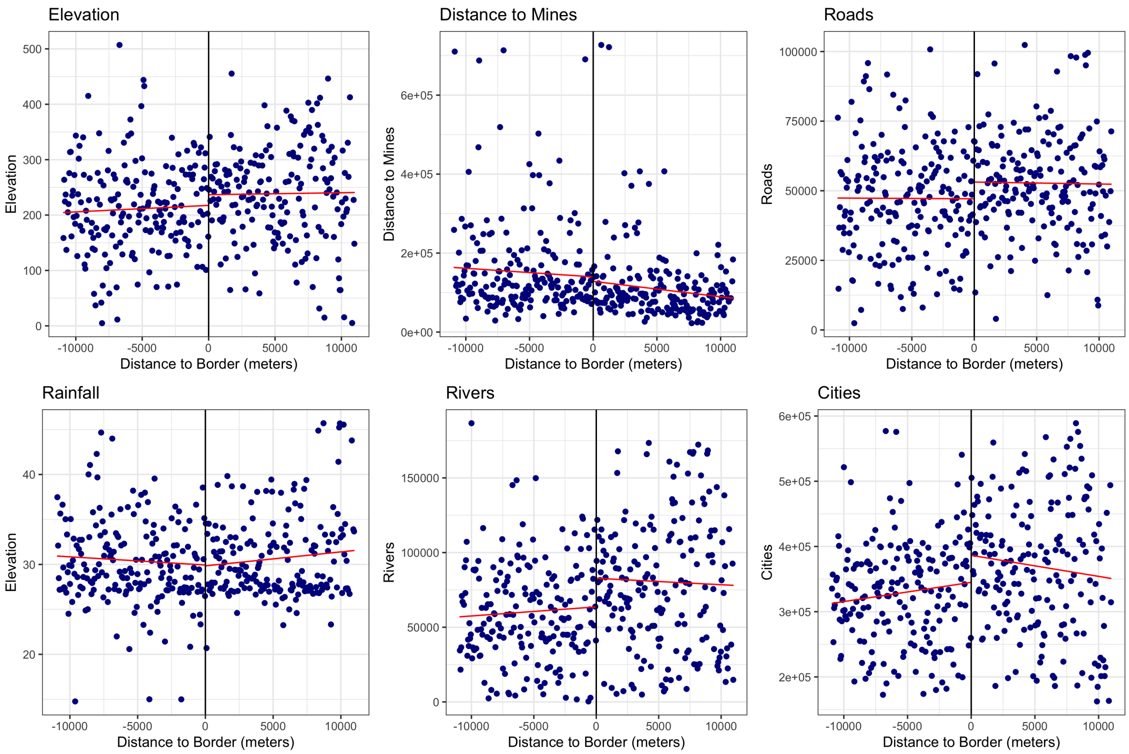

Fig. S6. Covariate Balance: Non Homologated, P=1

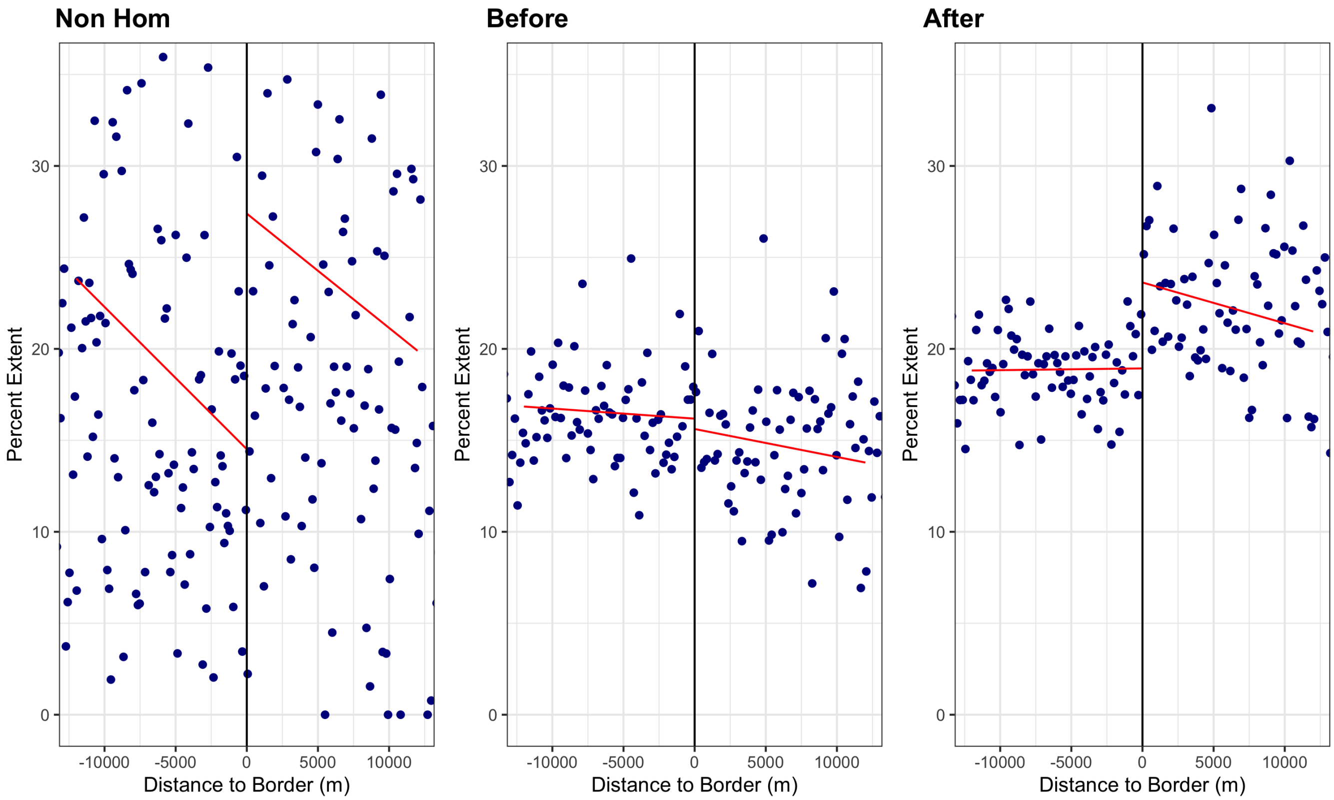

Fig. S7. Regression Discontinuity Plot for Proportion of Secondary Forest Extent

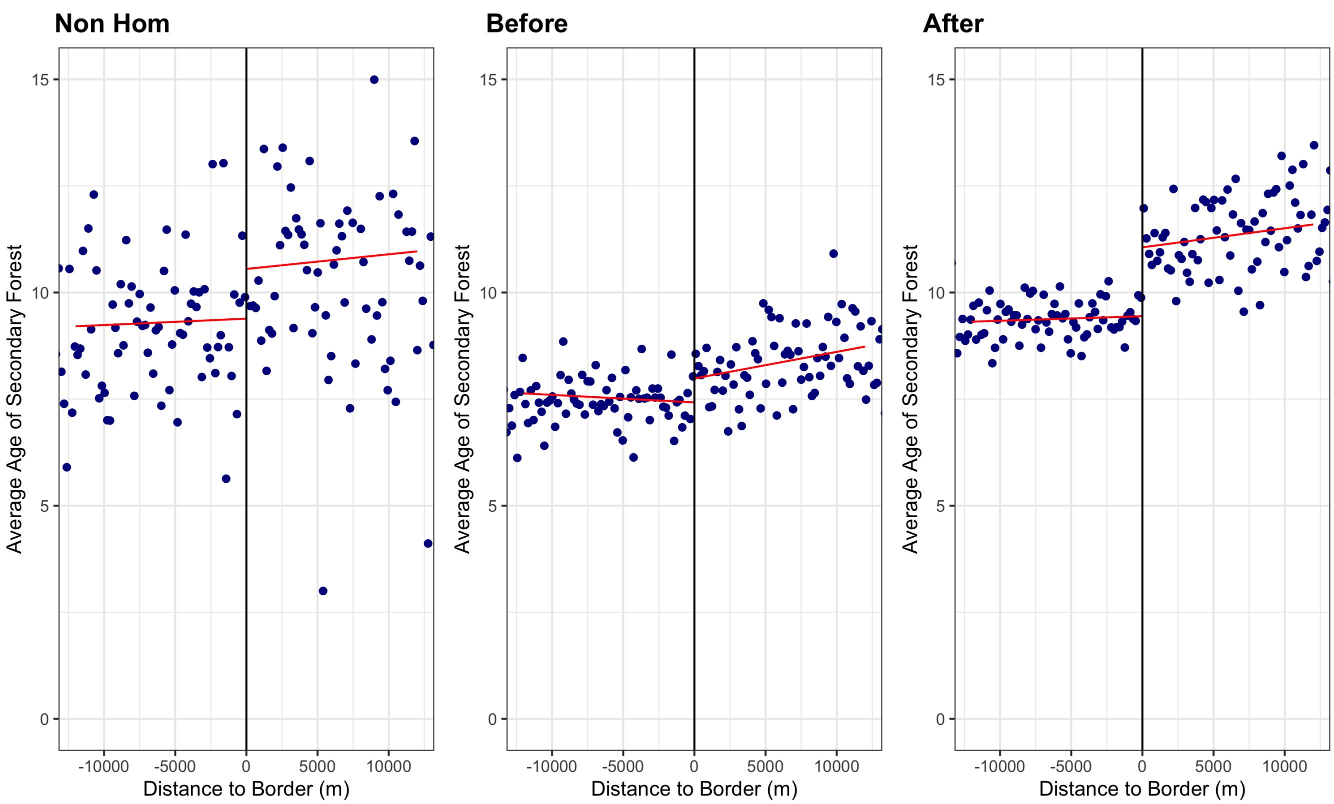

Fig. S8. Regression Discontinuity Plot for Proportion of Secondary Forest Age

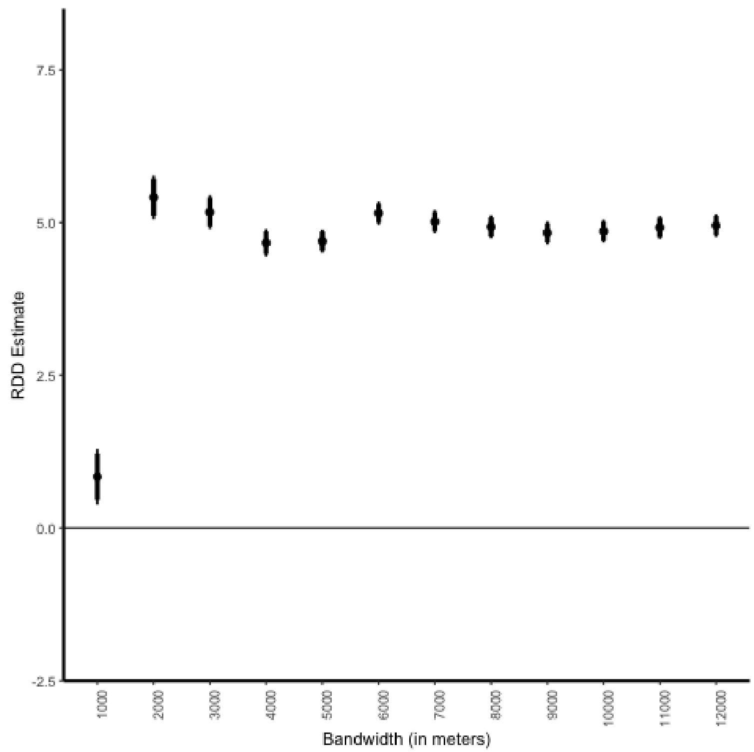

Fig. S9. BW Sensitivity: After Homologation, P=1

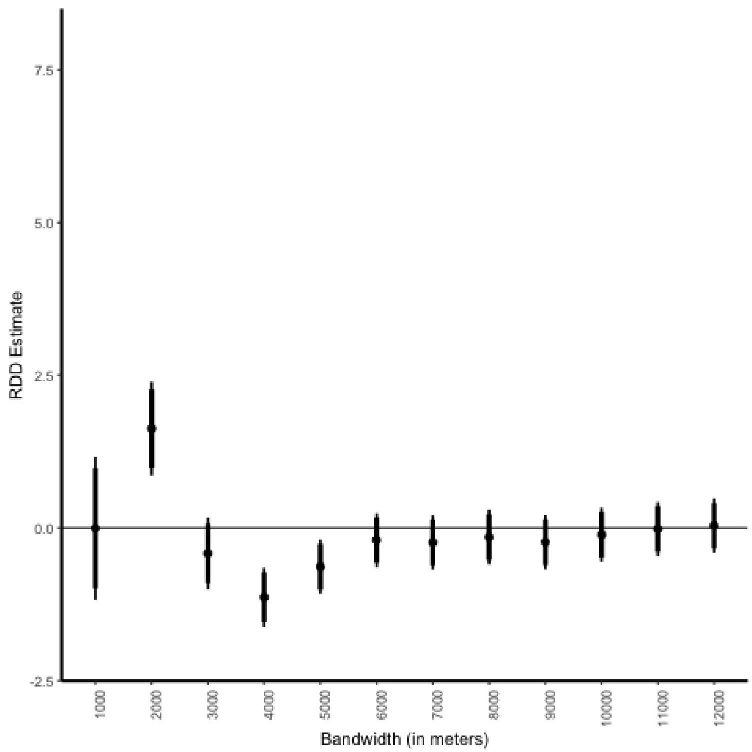

Fig. S10. BW Sensitivity: Before Homologation, P=1

1. Robustness

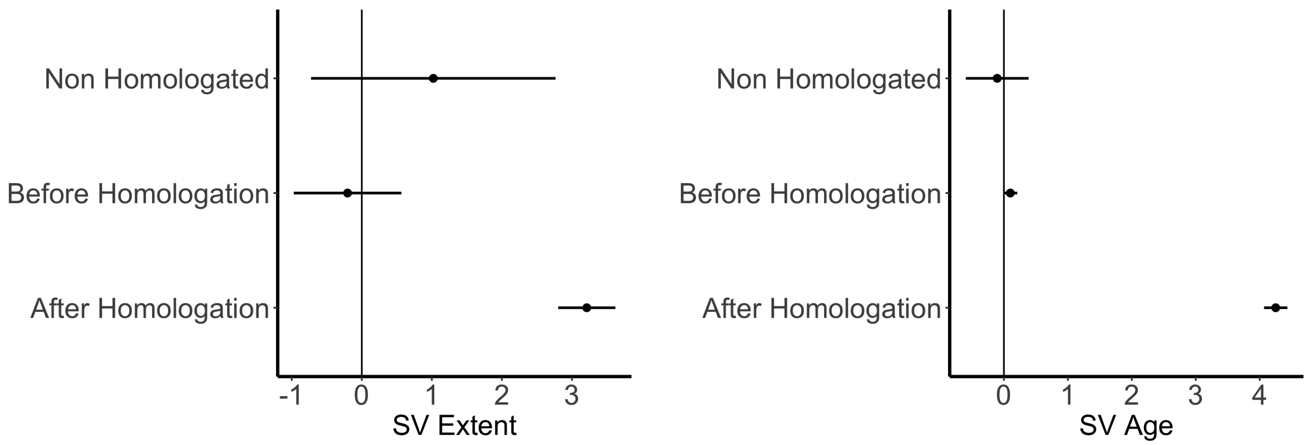

Fig. S11. Coefficients from RDD for SV Secondary Forest (left) And Age of Secondary Forest (right) for Non Homologated Territories, Territories Before Homologation and Territories After Homologation for full panel including all years before and after homologation. Points show robust coefficients from RDD and lines show 95% confidence intervals. All models use linear polynomials on either side of the cut-off, optimal bandwidth selection procedure that minimizes mean square error, triangular kernels and standard errors are clustered at the IT level.

Table S3. RDD Results for Secondary Vegetation with Full Panel Sample

	(1) Non Homologated	(2) Before Homologation	(3) After Homologation
A. Dependent Variable is Secondary Vegetation Proportion (in %)			
RDD Estimate	1.021	-0.203	3.212***
	(0.891)	(0.392)	(0.208)
Mean.Control	13.317	17.671	20.303
Kernel	Triangular	Triangular	Triangular
Bandwidth	mserd	mserd	mserd
BW	1333.490	1572.713	587.839
N	3325	20352	23479
B. Dependent Variable is Secondary Vegetation Age (in years)			
RDD Estimate	-0.105	0.101+	4.250***
	(0.251)	(0.055)	(0.093)
Mean.Control	1.624	1.636	3.181
Kernel	Triangular	Triangular	Triangular
Bandwidth	mserd	mserd	mserd
BW	1558.832	1408.369	1229.543
N	3644	18440	47399

NOTE: Significance levels: *10%, **5%, ***1% and Std. Errors in brackets. The Table shows robust coefficients from a RDD where the cut-off is the border of the IT. Panel A shows results for secondary vegetation proportion (in %) as the dependent variable. Panel B shows results for secondary vegetation age (in years) as the dependent variable. Column (1) shows the results of running the RDD on non homologated ITs, while column (2) shows the results for homologated territories before homologation and column (3) after homologation. All models use linear polynomials on either side of the cut-off, optimal bandwidth selection procedure that minimizes mean square error, triangular kernels, covariates, time fixed effects and time trends. Standard errors are clustered at the IT level.

SI Dataset S1 (data)

Data can be accessed in the Harvard Dataverse.

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