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# Working Paper A Reproduction of "Formal Designation of Brazilian Indigenous Lands Linked to Small but Consistent Reductions in Deforestation"

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# A Reproduction of "Formal Designation of Brazilian Indigenous Lands Linked to Small but Consistent Reductions in Deforestation"

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#### Abstract

We reproduced West (2024) "Formal designation of Brazilian indigenous lands linked to small but consistent reductions in deforestation," which investigates the impact of formally recognizing Indigenous Lands (ILs) on deforestation rates in Brazil from 1986 to 2021. The original study uses a quasi-experimental design, employing temporal and sectional matching methods to compare deforestation rates before and after IL designation, concluding an average reduction of -0.05% in deforestation. To verify these findings, we conducted three main tests: a logit analysis, the consideration of negative deforestation values in the Atlantic Forest, and the synthetic control method. The logit analysis assessed the relationship between IL designation and covariates like land size, elevation, slope, and proximity to urban centers, confirming that these factors significantly influence IL designation, consistent with the original study. We also examined the treatment of negative deforestation values in the Atlantic Forest, originally treated as zero. By retaining these values, we found no significant impact on the study's overall results, indicating that the original methodological choice did not affect the main conclusions. Finally, the synthetic control method was used to replicate the counterfactual analysis of IL-designated areas, demonstrating that these areas consistently exhibited

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lower deforestation rates compared to the synthetic control post-2011. These tests confirmed the original study's findings, demonstrating that the formal designation of ILs contributes to small but significant reductions in deforestation, supporting the effectiveness of ILs as a strategy for environmental conservation and indigenous rights protection. The reproducibility of these results reinforces the study's conclusions.

Keywords: Land tenure, Governance, Impact evaluation, Matching, Leakage.

### 1 Introduction

The article titled "Formal designation of Brazilian indigenous lands linked to small but consistent reductions in deforestation" investigates the impact of the formal recognition of Indigenous Lands (ILs) on deforestation rates in Brazil from 1986 to 2021. Using a quasi-experimental design, the authors employ temporal and sectional matching methods to compare deforestation rates before and after the designation of ILs. The study concludes that, on average, the designation of ILs is associated with a -0.05% reduction in deforestation, with the Cerrado biome showing the largest average impact of -0.12%. The article highlights that the formal designation of ILs plays a significant role in reducing deforestation, contributing to the preservation of natural resources and indigenous rights, with no evidence of deforestation leakage.

To verify the reproducibility of the original article's findings, we conducted three main tests that also aimed to assess computational reproducibility. First, we executed a logistic regression analysis to understand the relationships between the designation of an indigenous land and the covariates considered in the study, such as land size, elevation, slope, and proximity to urban centers. Our analysis revealed that these covariates significantly influence the likelihood of a land being designated as an IL, corroborating the factors considered in the original article for IL designation.

Second, we addressed the issue of negative deforestation values in the Atlantic Forest, which the original article treated as zero. We retained these actual negative values to check for any modifications in the propensity score matching (PSM) results and conclusions. The analysis showed that when considering the negative values, the propensity score matching was not significantly altered, and the results remained consistent. This suggests that the original article's decision to treat negative deforestation as zero did not substantially affect the main findings. Finally, we applied the synthetic control method to create a control unit that combines characteristics of non-designated units to replicate the deforestation trajectory of ILs before the intervention. The analysis confirmed that, after 2011, areas designated as ILs consistently exhibited lower deforestation rates compared to the synthetic control. This result aligns with the original study's conclusions that the formal designation of ILs is associated with a reduction in deforestation.

Overall, the computational replication efforts successfully reproduced the original results, confirming the robustness and validity of the study's conclusions. The strong reproducibility observed across different methods reinforces the importance of formal IL designation as an effective strategy for environmental conservation and the protection of indigenous rights in Brazil.

# 2 Robustness Reproducibility

### 2.1 Results for Logit Method

In general, the literature associates the designation of indigenous lands with political and institutional factors, considering that the demarcation of these lands does not occur randomly. (Mueller, 2022) highlights that the demarcation process involves complex stages, such as anthropological studies, delimitation, and official recognition, making it lengthy and susceptible to political interference. Macklem (2008) argue that institutions are responsible for creating laws that recognize indigenous territorial rights, with the existence and enforcement of adequate laws being essential to ensure the security of Indigenous Lands (TIs). However, could there be underlying factors that influence the designation of these lands? This is the question we seek to explore.

To deepen the understanding of the designation of Indigenous Lands in Brazil, we employed a Mixed-Effects Logistic Regression Model:

$$logit(P(Y_{ij} = 1)) = X_{ij}Q + Z_{ij}b_j$$
(1)

where  $X_{ij}$  are the fixed effects covariates and  $Z_{ij}$  represent the random effects covariates (Hansen, 2022). This method, widely known in the literature, provides us with the necessary

tools to capture the impact of covariates over time on the formal designation of Indigenous Lands (ILs). The model will provide us with an estimate of the probabilistic impact for each variable.

Table 1 summarizes the results of the Mixed-Effects Logistic Regression Model, used to analyze how the variables probabilistically impact the legal designation of Indigenous Lands. The model includes fixed variables (deforestation in the current and previous periods, deforestation in the buffer zone in the current and previous periods, distance from ports, soil quality, terrain slope, temperature in August and September) and random variables with a random intercept for the year variable.

Variable	Coefficient	Standard Error	P-value
Deforestation (%)	-0.383	0.062	0.000***
Lagged Deforestation $(\%)$	-0.345	0.059	0.000***
Buffer Zone Deforestation $(\%)$	0.302	0.064	0.000***
Lagged Buffer Zone Deforestation $(\%)$	0.293	0.063	0.000***
Ports	0.001	0.001	0.000***
Soil Quality	-0.065	0.019	0.001***
Slope	0.037	0.006	0.000***
Temperature (Aug-Sep)	0.079	0.006	0.000***

 Table 1: Summary of Mixed Effects Logistic Regression

Note: Own elaboration based on the dataset. \*\*\*, \*\*, and \* indicate that the marginal effect is significant at 1%, 5%, and 10%, respectively.

All variables showed statistical significance at the 1% level, indicating a high probability that the results are not due to chance. Deforestation in the current and past periods presented a negative sign, indicating that as deforestation increases, there is an inverse influence on the legal designation of Indigenous Lands (ILs). However, as deforestation in buffer zones increases, we observe a positive effect on the probability of legal designation. Additionally, the farther from ports, the steeper the terrain, and the higher the temperature between August and September, the greater the likelihood of the land being designated. Finally, the higher the soil quality, the lower the probability of designation.

In summary, this implies that higher incidence of deforestation within undesignated indigenous territories is associated with a lower probability of designation compared to those that have not suffered as much from deforestation. However, as deforestation on the borders of indigenous lands increases, there is a higher probability of these lands being designated. The distance from ports and its positive correlation with land designation indicates that ILs farther from ports are more likely to be designated. The negative coefficient for soil quality implies that the higher the soil quality, the lower the likelihood of the land being designated, thus leaving indigenous peoples with lower-quality lands. The positive relationship with slope implies that the steeper the terrain, the greater the probability of it being designated. Finally, the higher the temperature between August and September, the greater the likelihood of designation, indicating that hotter lands are more likely to be designated.

Table 2 summarizes the Average Marginal Effect (AME) for the variables analyzed, complementing the findings in Table 1. Although some marginal effects are small in magnitude, all of them are statistically significant, reinforcing the conclusions of the Mixed-Effects Logistic Regression Model.

Variable	AME	Standard Error	$\mathbf{Z}$
Deforestation (%)	-0.060	0.010	-5.925
Lagged Deforestation $(\%)$	-0.054	0.009	-5.652
Buffer Zone Deforestation $(\%)$	0.047	0.010	4.593
Lagged Buffer Zone Deforestation $(\%)$	0.046	0.010	4.545
Ports	0.000	0.000	10.807
Soil Quality	-0.010	0.003	-3.329
Slope	0.006	0.001	5.647
Temperature (Aug-Sep)	0.012	0.001	11.160

Table 2: Summary of Marginal Effects

Note: Own elaboration based on the dataset. \*\*\*, \*\*, and \* indicate that the marginal effect is significant at 1%, 5%, and 10%, respectively.

To check for the presence of multicollinearity in the model, we used the Variance Inflation Factor (VIF) test, which is commonly used to assess multicollinearity in multiple regression models.

The results in Table 3 indicate that there is no presence of multicollinearity among the variables analyzed, which reinforces the robustness of the obtained results. In summary, the analysis of the Mixed-Effects Logistic Regression Model revealed that factors such as deforestation, distance from ports, terrain slope, and temperature significantly influence the probability of Indigenous Land (IL) designation. While internal deforestation within ILs is negatively associated with designation, deforestation in buffer zones increases this probability. Additionally, more isolated, steeper areas with higher temperatures tend to be more

Variable	VIF
Deforestation $(\%)$	2.1068
Lagged Deforestation $(\%)$	2.1207
Buffer Zone Deforestation $(\%)$	2.6639
Lagged Buffer Zone Deforestation (%)	2.6988
Ports	1.0014
Soil Quality	1.0105
Slope	1.4500
Temperature (Aug-Sep)	1.4782

Table 3: VIF (	Variance Inflation Factor)	)
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Note: Own elaboration based on the dataset. \*\*\*, \*\*, and \* indicate that the marginal effect is significant at 1%, 5%, and 10%, respectively.

frequently designated, while lands with higher soil quality are less likely to be designated for indigenous populations. The Average Marginal Effects confirmed these patterns, all statistically significant, and the absence of multicollinearity among the analyzed variables strengthens the robustness of the results. These findings highlight the importance of environmental and locational factors in determining the areas designated as ILs, with relevant implications for conservation policies and the protection of indigenous rights.

#### 2.2 Robustness test on codification of the outcome variable

The outcome variable "deforestation" has negative values in the raw data. Negative values would suggest reforestation, which is generally considered as unlikely, given that deforestation is calculated based on annual changes and that trees typically grow slowly. These values might be due to errors in the satellite images, or during the processing of the land cover classification The author treated these as errors and recorded this variable's negative values with zeros. This is probably a common decision in these types of analyses.

We test whether this choice affects the results. If this is a classification error that is uncorrelated with the probability that a IL gets formally designated, the coding choice should not affect the results. However, if the misclassification is systematic, for example for a specific biome, then the results might be sensitive to this decision.

We hypothesize that the negative values are not at random. For example, the Atlantic

Forest has a remarkable regenerative capacity of secondary forests (Piffer et al., 2022). Tree groups in forest clearings, borders, and spontaneous regeneration in open areas can grow over one meter in a year (Coelho et al., 2016).

Table 4 summarizes the total number of observations with negative values for the variable deforestation. Most observations are indeed in the Atlantic Forest.

Table 4: Number of observations with negative values for the variable deforestation by biome

Biome	Quantity
Amazon	13
Cerrado	32
Atlantic Forest	193
Pampa	43

Note: Most observations are indeed in the Atlantic Forest. Caatinga and Pantanal do not have negative values.

Note: Most observations are indeed in the Atlantic Forest.

Caatinga and Pantanal do not have negative values.

To estimate the impact of transforming negative numbers to zero, as performed by the author, we conducted a test with two groups: the first with negative values transformed to zero, as in the original study, and the second with negative values retained as per the primary source data. After this adjustment, we applied the same modifications to both groups. In the second stage, we filtered only the Atlantic Forest among the biomes. In the third stage, we used propensity score weighting (PSW), validated as the best method in the original study, to ensure covariate balance figure (Figura 1).

We reproduce the results for the Atlantic Forest leaving the negative values intact and compare these results with Figure 4, panel Atlantic Forest in the paper.

We find that even when the point estimates are different, the null result of an effect of the formal designation of IL on deforestation for the Atlantic Forest Biome remains true (Figure 2).

This suggests that the results of this paper are robust to this classification choice.



Figure 1: Robustness test on the codification of the outcome variable: Covariate Balance

Notes: Comparison of Covariate Balance in the Atlantic Forest Using Propensity Score Weighting (PSW). Panel A shows the results in West (2024), which recodifies the negative values for the outcome variable. Panel B shows the results when the outcome variable includes negative values.

Figure 2: Robustness test on the codification of the outcome variable: Estimated Impacts



Note: Estimated Impacts of the Formal Designation of Brazilian Indigenous Lands on Deforestation (%) Over Time. Panel A shows the results in West (2024), which recodifies the negative values for the outcome variable. Panel B shows the results when the outcome variable includes negative values

#### 2.3 Results for Synthetic Control Method

The Figure 3 compares deforestation units in designated Indigenous Lands (ILs) (solid line) with a synthetic control unit (dashed line) over time, from 1985 to 2020. The vertical dotted line marks the year 2011, when the formal designation of ILs was halted (no further designations occurred after 2011).





Before 2011, the deforestation lines for the designated areas and the synthetic control are quite similar, indicating that the synthetic control method successfully replicated the deforestation trajectory of the ILs before the intervention. This similarity suggests that the chosen control areas are a good counterfactual approximation of the treated areas, according to the methodology established by Abadie et al. (2010).

After 2011, the lines began to diverge, with deforestation in the designated areas being consistently lower than in the synthetic control. This pattern indicates that the formal designation of ILs is associated with a reduction in deforestation compared to the counterfactual scenario where the ILs would not have been formally designated. This result corroborates the findings of the original study, which concluded that the designation of ILs contributes to forest conservation.

To calculate the average effect size of the designations from 2011 onwards, it is necessary to estimate the average difference between the solid and dashed lines in the post-2011 period. An estimate shows that the average effect size of the IL designations from 2011 onwards is approximately 10 hectares of deforestation, indicating that, on average, if the areas had not been designated by 2011, current deforestation (from that date onwards) would be 10 hectares higher.

These results are consistent with several studies highlighting the crucial role of ILs in reducing deforestation. (Nepstad et al., 2006) demonstrated that protected areas, including ILs, are effective in curbing deforestation in the Amazon. (Nolte et al., 2013) also found evidence that effective governance regimes and strategic locations increase the success of protected areas in preventing deforestation. The results obtained with the Synthetic Control Method were close to those of DiD, suggesting that the parallel trends assumption was not significantly violated, indicating the robustness of the DiD results. Previous studies comparing these methods in different contexts have also reported similar findings, corroborating the validity of the methods employed (Blackman et al. (2017); Abadie et al. (2010)). The magnitudes of the estimates between the two methods were comparable, reinforcing the conclusion that the formal designation of ILs is associated with modest but consistent reductions in deforestation, although the overall impact is relatively small (BenYishay et al. (2017); West (2024)).

The robustness of the results obtained through synthetic control is essential in impact studies of public policies because it adds credibility to the conclusions and can influence future policy decisions. The literature on impact evaluations of environmental policy interventions, such as the designation of indigenous lands, frequently suggests the importance of multiple robustness methods to ensure that the observed effects are not merely artifacts of particular methodological specifications (BenYishay et al. (2017); Baragwanath and Bayi (2020)).

Therefore, the robustness analysis demonstrates that the DiD method is suitable for this specific context, and the consistency between the methods used strengthens the conclusions that the designation of ILs contributes to reducing deforestation, albeit in a limited manner. These findings align with existing literature, which indicates that while the formalization of territorial rights can have positive impacts on forest conservation, these effects are generally small and context-dependent (BenYishay et al. (2017); Blackman et al. (2017)).

#### 2.3.1 Comparability

In the replication study, the synthetic control method was applied to assess the counterfactual scenario regarding the formal designation of Indigenous Lands (ILs) by aggregating all ILs designated before 2011 into a single group of treated units. The method aimed to answer the specific question: "What would have happened to deforestation levels if these lands had not been formally designated by 2011?" By aggregating the units in this way, the analysis focused on the overall impact of formal designation, simplifying the treatment to a single event and creating a clear pre- and post-2011 distinction.

In contrast, the original study employed a differences-in-differences (DiD) approach

that considered multiple treatment periods, respecting the distinct temporal assignments of each IL designation. The DiD method preserved the staggered timing of IL designations, allowing for the capture of the specific effects of each designation over time. This method provides a more granular analysis by comparing deforestation rates before and after each individual IL designation, considering that the timing of the intervention could yield different impacts on deforestation rates.

The two methods, while providing insights into the impact of IL designation, are not directly comparable due to their conceptual differences. The synthetic control approach aggregates the treated units and examines the collective effect, thus potentially masking the temporal dynamics captured by the DiD. The original DiD method, on the other hand, captures the heterogeneity in the impact of IL designation over different periods, providing a more nuanced view of the intervention's effects.

In terms of interpretability, the results from the synthetic control method represent the average impact of designating all ILs by 2011, answering a broad counterfactual question. The DiD method allows for more precise inferences regarding how the timing of IL designations affected deforestation, making it a more appropriate tool for understanding the varying impacts of policy interventions over time.

The synthetic control method has been widely used as a robustness check for DiD, particularly when concerns about the parallel trends assumption arise (Abadie et al., 2010). Although both methods may yield similar trends, the results from synthetic control tend to provide a broader, averaged estimate, while DiD delivers estimates that are specific to the timing of each treatment. This distinction is important, as the aggregation in synthetic control overlooks the staggered nature of treatment and thus cannot offer the same level of temporal detail as the DiD approach.

In conclusion, although the results from the synthetic control method and the differencesin-differences approach are not directly comparable due to the differences in how they conceptualize and apply the treatment, the synthetic control method provides a valuable general measure of the overall impact of IL designation over the period analyzed. It offers a useful summary of the broad trends in deforestation reduction post-designation, making it a good approximation for capturing the general effectiveness of IL designations when precise temporal effects are not the primary focus. This makes it a complementary tool for assessing policy interventions when considering broader, long-term impacts across multiple regions.

## 3 Conclusion

The replication of the study "Formal designation of Brazilian indigenous lands linked to small but consistent reductions in deforestation" used three distinct methods to assess the robustness and validity of the original results. First, a logit analysis was applied to understand the relationships between the designation of Indigenous Lands (ILs) and various covariates, such as land size, elevation, slope, and proximity to urban centers. This analysis revealed that these variables significantly influence the likelihood of a land being designated as an IL, confirming that the factors considered in the original study are robust and relevant to the designation of ILs.

Next, we addressed the issue of negative deforestation values in the Atlantic Forest, which were treated as zero in the original study. By maintaining the actual negative values, we found that propensity score matching (PSW) and overall results were not significantly altered. This suggests that the original article's methodological decision to treat negative deforestation as zero did not substantially impact the main conclusions, demonstrating the robustness of the findings even under different data treatments.

Finally, the synthetic control method was employed to replicate the counterfactual analysis of areas designated as ILs. The construction of an effective synthetic control unit allowed for the replication of the deforestation trajectory of the ILs before the intervention. The post-2011 results showed that the designated areas consistently exhibited lower deforestation rates compared to the synthetic control. This finding corroborates the original study's conclusions, highlighting the effectiveness of the formal designation of ILs in reducing deforestation.

The three methods applied — logit analysis, maintenance of negative deforestation values, and synthetic control — demonstrated consistency with the original study's results. The replication confirms that the formal designation of ILs contributes to forest preservation by reducing deforestation rates in a small but significant way. These methodological approaches, supported by robust literature, provide a solid foundation to assert the importance of ILs as an effective strategy for environmental conservation and the protection of indigenous rights. The reproducibility of the results reinforces the validity and credibility of the conclusions presented, highlighting the relevance of ILs in Brazilian environmental policy.

The authors declare that they have no competing interests.

The code and data used for replicating this study are available at Replication.

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