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Land Restitution and Deforestation in Colombia

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We examine the environmental impacts of legal provisions to restore land rights for populations displaced by armed conflict, focusing on Colombia's Land Restitution Law. Leveraging annual satellite data on forest cover loss, detailed records of the timing and location of restitution claims, and a staggered difference-in-differences strategy, we find that land restitution is associated with increased tree cover loss. Importantly, this effect is not driven by deforestation in primary forests, but rather by forest loss in areas formerly used for agriculture. These findings highlight the environmental trade-offs inherent in post-conflict land reforms. While restoring land rights is critical for transitional justice and economic recovery, attention to environ- mental outcomes is essential to ensure sustainable and equitable reconstruction.

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KEYWORDS

Deforestation | Land rights | Internal conflict | Colombia

Executive summary

At the end of 2024, the number of people internally displaced by conflict and violence was estimated at 73.5 million, which is likely to increase with global warming. When conflict subsides and displaced individuals return to their places of origin, they may find their land occupied by others or reclaimed by the forest. These conditions pose significant challenges to post-conflict recovery and raise pressing questions regarding land governance and environmental sustainability. This paper examines the impact of a national land restitution program, designed to facilitate the return of displaced persons, on changes in forest cover in resettlement areas. Specifically, we ask: how does formal land restitution reshape deforestation patterns in areas previously abandoned due to conflict?

This paper provides the first empirical evidence on the environmental consequences of Colombia's Land Restitution Law, a large-scale post-conflict property rights program designed to sup- port the reintegration of displaced populations. Using satellite-based measures of forest cover and a staggered difference-in-differences design, we examine how efforts to restore land rights of displaced populations have shaped deforestation patterns.

We find that land restitution activities led to a measurable increase in tree cover loss. This increase was not driven by the conversion of primary humid tropical forests but by the reoccupation of previously cultivated land abandoned during displacement. These results highlight a fundamental policy trade-off: while land restitution advances transitional justice and reintegration, it can also accelerate forest loss if not paired with adequate safeguards.

1 Introduction

At the end of 2024, the number of people internally displaced by conflict and violence was estimated at 73.5 million, representing a 33 million increase from a decade earlier (IDMC, 2025). With global warming expected to heighten conflict risks through multiple pathways (Abel *et al.*, 2019; Bloem *et al.*, 2025; Hsiang *et al.*, 2013; Koubi, 2019; Mach *et al.*, 2019; Meriläinen *et al.*, 2022; Schleussner *et al.*, 2016), displacement is likely to grow further.

A growing body of research has examined how conflict influences land use and forest outcomes (Alix-Garcia *et al.*, 2013; Baumann *et al.*, 2015; Burgess *et al.*, 2015; Eklund *et al.*, 2016; Nackoney *et al.*, 2014; Ordway, 2015), while newer studies assess the effects of conflict resolution on forests; an important frontier given the role of forests in carbon sequestration and ecosystem services (Clerici *et al.*, 2020; Murillo-Sando val *et al.*, 2023; Murillo-Sandoval *et al.*, 2020; Prem *et al.*, 2020). However, relatively little attention has been paid to how public policies aimed at supporting the return of displaced populations shape forest dynamics (Suarez *et al.*, 2018).

When conflict subsides and displaced individuals return to their places of origin, they may find their land occupied by others or reclaimed by the forest. These conditions pose significant challenges to post-conflict recovery and raise pressing questions regarding land governance and environmental sustainability. This paper examines the impact of a national land restitution program, designed to facilitate the return of displaced persons, on changes in forest cover in resettlement areas. Specifically, we ask: how does formal land restitution reshape deforestation patterns in areas previously abandoned due to conflict?

Theoretically, land restitution may affect forest cover through two main mechanisms. First, by reducing the transaction costs of reclaiming property, it encourages return migration and the resurgence of economic activities in previously abandoned land. Whether this results in higher deforestation depends on the relative economic returns to agricultural activities. If cropland that was abandoned and subsequently reforested is cleared upon return, the loss of trees may increase. Conversely, if forest rents are higher, reforestation may persist (Angelsen, 2010). Second, restoring land to its original owners may displace secondary occupants, who may, in turn, clear nearby forested land for their activities. However, if mutually beneficial arrangements compensating good-faith secondary occupants are possible, displacement and deforestation may be mitigated. Overall, the impact of land restitution on forest cover change remains theoretically ambiguous and is context-dependent, warranting an empirical assessment.

Colombia offers a unique setting for such an empirical assessment. With 7.3 million internally displaced persons (IDPs) as of 2024, it ranks as the third most affected country after Sudan and Syria (IDMC, 2025). In response to decades of internal armed conflict, the Colombian government enacted Law 1448, the Land Restitution Law (LRL), in 2011. The law guarantees land claims for individuals displaced between 1991 and 2011, while also providing compensation mechanisms for good-faith secondary occupants (Counter, 2019; Mora-Godoy and Cruz-Gutierrez, 2023; Wiig and García-Reyes, 2020). Given Colombia's exceptional biodiversity (WWF, 2017), understanding the intersection of restorative land justice and forest dynamics is of global interest.

In 2016, the Colombian government and the Revolutionary Armed Forces of Colombia (FARC) signed a peace accord, ending a key phase of the armed conflict. Prior research shows this transition was associated with increased forest loss in former FARC territories (Clerici *et al.*, 2020; Murillo-Sando val *et al.*, 2023; Murillo-Sandoval *et al.*, 2020; Prem *et al.*, 2020). However, few studies isolate the role of specific public policies, like land restitution, in shaping post-conflict land-use decisions.

To identify the effect of the LRL, we restrict the analysis to the pre-2016 period and leverage the staggered timing of land restitution claims across municipalities. Specifically, we compare annual tree cover loss before and after the first claim in each municipality relative to those where claims were filed later, using a *dynamic difference-in-differences* approach (de Chaisemartin and D'Haultfœuille, 2024), with robustness checks using alternative estimators (Callaway and Sant'Anna, 2021).

We find that land restitution is associated with a 22% increase in annual tree cover loss in municipalities with early claims, compared to trends observed in municipalities where claims were filed later. This effect grows gradually over time and coincides with a 24% rise in fire-related forest loss, a common technique for clearing forested areas ahead of agricultural activities (Armenteras *et al.*, 2019). However, we find no evidence of increased tree cover loss in primary humid tropical forests. Instead, the increase is concentrated in areas used as cropland before displacement, suggesting that *agricultural reversion* – the resumption of agricultural use on formerly abandoned land – drives these losses, rather than *forest conversion* – the expansion of agricultural activities in primary forest.

These results contribute to several strands of literature. First, they suggest that land restitution may inadvertently exacerbate deforestation, adding to our understanding of post-conflict land dynamics in Colombia (Clerici *et al.*, 2020; Murillo-Sando val *et al.*, 2023; Murillo-Sandoval *et al.*, 2020; Prem *et al.*, 2020). Second, they underscore the importance of distinguishing between primary and secondary forest loss (Wolfersberger *et al.*, 2022) and of accounting for short-term regrowth when analysing deforestation dynamics. Third, they highlight a trade-off in restorative justice: while supporting returnees and asserting property rights, land restitution can generate unintended environmental costs.

The rest of the paper proceeds as follows. Section 2 reviews the historical and legal background of displacement and land restitution in Colombia. Section 3 describes our data and identification strategy. Section 4 presents the main results. Section 5 explores the mechanisms. Section 6 concludes.

2 Context

2.1 An armed conflict in a world's biodiversity hotspot

Colombia has endured one of the longest-running internal armed conflicts in modern history, spanning over five decades and involving multiple armed actors, including the Revolutionary Armed Forces of Colombia (FARC), paramilitary groups, and state forces. What made the Colombian conflict distinct was its deep roots in concerns over unequal access to land and resources. Armed actors often sought control over valuable territories, resulting in the expulsion of vulnerable populations and the consolidation of political and economic power (Marulanda, 1973; Álvaro Delgado *et al.*, 2016).

The forced displacement of rural populations led to widespread disruption of agricultural activities (Centro Nacional de Memoria Histórica, 2013), with significant consequences for Colombia's biodiversity-rich ecosystems (Clerici *et al.*, 2019; WWF, 2017). In some regions, land abandonment allowed for natural regeneration and passive reforestation (Sánchez-Cuervo *et al.*, 2012). In others, especially those under FARC control, restrictions on access and informal environmental norms enforced by the group limited deforestation (Baptiste *et al.*, 2017; Camacho and Rodriguez, 2013; Dávalos, 2001; Prem *et al.*, 2020). However, where governance collapsed or state presence was weak, contested areas became hotspots for informal occupation by armed actors, illicit crop cultivators, and other opportunistic users (Ballvé, 2013; Engel and Ibáñez, 2007; Ibanez, 2009; Ibáñez and Vélez, 2008). These dynamics accelerated deforestation through the expansion of coca cultivation, illegal mining, and extensive cattle ranching (Fergusson *et al.*, 2014; Negret *et al.*, 2019).

The interplay between displacement, land abandonment, and illicit activity had varied and regionally specific impacts on forest cover. As a result, measuring the net effect of the conflict on deforestation remains an active area of research (Christiansen *et al.*, 2022; Landholm *et al.*, 2019; Prem *et al.*, 2020). With the signing of the historic peace accords in 2016, hostilities largely subsided, but, paradoxically, tree cover loss increased in several former conflict zones (Prem *et al.*, 2020), driven by a combination of legal and illegal activities (Murillo-Sando val *et al.*, 2023). This trend raises concerns about the post-conflict policies needed to balance reconstruction, justice, and environmental sustainability (Suarez *et al.*, 2018).

Given the central role that land dispossession and rural displacement played in the conflict, a widespread and increasing demand for land restitution has been building from those who were forcibly displaced. However, implementing a public policy response to this demand also raises important questions about how reactivating land use in previously abandoned areas might impact forest dynamics, especially in fragile ecosystems where institutional governance is still limited.

2.2 Land restitution law and post-conflict restorative justice

In response to intense social and legal demands for land restitution after conflict, both to restore victims' rights and to promote lasting peace, the Colombian government enacted Law 1448 in 2011, known as the Victims and Land Restitution Law (LRL). This law is a crucial component of Colombia's transitional justice system, designed to restore land rights to those *displaced by violence between 1991 and 2011* (Unruh, 2019). Initially set for 10 years, the law was extended for an additional decade, now assisting in resettling until 2031 all displaced populations who lost land due to violence between 1991 and 2011 (Congreso de Colombia, 2021).

The LRL established the Land Restitution Unit (*Unidad de Restitución de Tierras*, URT), which is responsible for identifying, documenting, and managing land claims. Claimants initiate the process by submitting petitions to the URT, which conducts a comprehensive administrative investigation. This includes collecting documentary and testimonial evidence, analysing cadastral and land-use records, performing site visits, and reconstructing local conflict histories. A defining innovation of the LRL is the reversal of the burden of proof: claimants are presumed to have been dispossessed unless proven otherwise, thus removing a key procedural barrier for displaced individuals who often lack formal documentation (Esquirol, 2021; García-Godos and Wiig, 2014).

Once a claim is validated, it is referred to one of the specialized land restitution courts, which have the authority to issue binding rulings. These courts can order the return of property, resolve competing claims, and mandate complementary reparations such as land titling, technical assistance, and protection measures for vulnerable populations. In order to acknowledge the rights of good-faith occupants or secondary occupants, many of whom may themselves be vulnerable, courts had to weigh restitution against competing social claims (Counter, 2019; Wiig and García-Reyes, 2020).

To prevent harm to returnees, the LRL established a two-tiered territorial certification system known as macro- and micro-focalization. Macro-focalization designates municipalities or larger regions deemed secure for restitution, based on assessments by the National Security Council and the Ministry of Defense, in consultation with the URT, although the precise criteria remain undisclosed (García-Godos and Wiig, 2014). Micro-focalization occurs within these pre-approved macro zones and identifies the specific territories where claims can be processed. While some microzones are defined narrowly at the neighborhood level, in most cases, they align with municipal boundaries, effectively making municipalities the operational unit of restitution.

The rollout of microzones was highly staggered. This sequencing reflected not only the limited administrative resources of the URT, which prevented the simultaneous certification of all eligible areas, but also the intensity of local demand for restitution. As a result, claims were sometimes filed before the corresponding microzone was formally certified (García-Godos and Wiig, 2014), and the observed variation in timing across municipalities reflects administrative capacity and claimant pressure more than ongoing conflict dynamics (Peralta, 2022; Unruh, 2019).

Despite operational challenges, Colombia's land restitution program remains one of the most ambitious and legally advanced restorative justice initiatives worldwide. Its emphasis on restoring territorial rights is key to broader efforts in peacebuilding, reconciliation, and strengthening institutional legitimacy in rural areas long ignored by the government (Unruh, 2019; Wiig and García-Reyes, 2020).

3 Data and Methods

To assess how land restitution affected deforestation in Colombia, we constructed a municipality-year panel dataset that tracks annual forest cover and tree cover loss over time. The dataset also includes characteristics of each municipality, such as the year when the first land restitution claim was filed. However, estimating the causal effect of land restitution on deforestation presents three key challenges.

First, the peace agreement signed on June 23, 2016, significantly altered conflict dynamics, with potentially heterogeneous effects on deforestation depending on the FARC's presence in a given municipality. To isolate the impact of land restitution from broader post-conflict dynamics, we focus our analysis on the period between the enactment of the land restitution law in 2011 and 2015, before the signing of the peace accord.

Second, land restitution claims can only be processed in eligible municipalities deemed secure for returnees. As a result, these municipalities may already differ in terms of governance or security conditions from other municipalities without claims, potentially confounding the observed effects of restitution. To mitigate this concern, we compare municipalities where land restitution began before 2015 with those where it started later, and provide supporting evidence that this strategy addresses potential bias from differential security dynamics.

Third, isolating the effect of land restitution from other time-varying and location-specific factors remains a core identification challenge. Furthermore, municipalities differ in when restitution claims were initiated, and the impact may evolve as the number of claims increases. To address this, we use a dynamic difference-in-differences strategy that accounts for staggered treatment timing and heterogeneous treatment effects over time (Callaway and Sant'Anna, 2021; de Chaisemartin and D'Haultfœuille, 2024).

3.1 Data

Our study combines data on land cover, deforestation, forest cover, primary forest distribution, cultivated land area, municipal characteristics, and land restitution claims. Information on land cover, forest cover, deforestation, and the distribution of primary forests is derived from remote sensing data based on Earth observation from various satellites. Data on municipal characteristics come from the municipality-level panel dataset developed and maintained by the Center for Studies on Economic Development (CEDE – *Centro de Estudios sobre Desarrollo Económico*), which includes a broad set of social, economic, and demographic indicators for all Colombian municipalities and is widely used in academic and policy research. Finally, data on land restitution activities are obtained from the Land Restitution Unit.

3.1.1 Land cover in 1992

Because land eligible for restitution must have been lost between 1991 and 2011, we sought spatial data on land cover and land use dating back to January 1991. However, such data are not available. The earliest detailed dataset is the 1992 global land cover map produced by the Climate Change Initiative of the European Space Agency (European Space Agency, 2017). This dataset, which includes annual land cover maps from 1992 to 2015 at a 300-meter spatial resolution, helps classify the territory into eight categories: built-up areas (settlements), cropland, tree cover, grassland, shrubland, sparse vegetation, wetlands, and water bodies. We used the 1992 map to establish a baseline land use before displacement and combined it with satellite-derived data on forest cover loss to identify tree cover loss in areas classified as cropland, tree cover, or grassland.

3.1.2 Forest loss

We measure forest loss using the global forest cover change dataset from Hansen *et al.* (2013). The dataset is derived from the analyses of Earth observation by the satellite Landsat and divides the Earth's surface into 30×30 meter pixels. For each pixel, the global forest cover change dataset provides the percentage of area covered by tree canopy in the year 2000, as well as the specific year when the pixel experienced the clearing of at least half of its tree cover. Although regrowth may occur later, pixels that lost more than half of their tree cover are considered irreversibly deforested, reflecting the permanence of habitat loss for local biodiversity.

Using these data, we compute the total forested area in 2000 at the municipal level by summing all pixel areas within each municipality, weighted by their tree canopy coverage. We then measure annual forest loss (deforestation) from 2001 to 2024 as the weighted sum of pixel areas that lost all tree cover in each corresponding year.

We also measure annual forest loss in areas identified as primary forest in 2001 using the global map of humid tropical primary forests produced by the Global Land Analysis and Discovery (GLAD) laboratory at the University of Maryland (Turubanova *et al.*, 2018). This allows us to distinguish forest loss affecting mature forest ecosystems.

Finally, recognizing that forest clearing for agriculture in Colombia is frequently carried out through fire (Armenteras *et al.*, 2019), we use the global forest loss due to fire dataset from Tyukavina *et al.* (2022) to measure fire-induced forest loss. This dataset builds on Hansen *et al.* (2013) and identifies the subset of pixels where tree loss was caused by fire with high certainty. For each year, we calculate fire-related forest loss as the weighted sum of the area of these pixels by their canopy area in 2000.

3.1.3 Forest Cover

To explore broader patterns of forest cover, including forest regrowth, and to improve our understanding of how land restitution impacts forest landscape, we use the Vegetation Continuous Fields (VCF) product, derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard NASA's Terra satellite (DiMiceli *et al.*, 2017). The VCF dataset provides a continuous representation of land cover at 250-meter resolution. It reports the proportion of tree cover, non-tree vegetation, and bare ground for each pixel. By representing land cover as percentages rather than discrete categories, the VCF offers a nuanced, quantitative view that is widely used in environmental monitoring and modelling (DiMiceli *et al.*, 2022). Produced annually since 2000, it allows us to track the extent of forest cover in each municipality by calculating the weighted sum of pixel areas, using the reported tree cover percentages for each year from 2000 to 2024.

3.1.4 Social, Economic, and Demographic Indicators

We complement the data described above with municipality-level characteristics from the Panel CEDE database (Acevedo and Bornacelly, 2014). This dataset consolidates information from multiple national sources, including the National Administrative Department of Statistics (DANE), the Agustín Codazzi Geographic Institute (IGAC), the National Planning Department (DNP), the Ministry of Agriculture, AGRONET, the Ministry of Health, and the Ministry of Mines and Energy, among others.

We use this data to describe key structural features of each municipality. Specifically, we record land area and average altitude as geographic fundamentals, and average population size in the decade before the restitution law as a proxy for demographic pressure on forested land. To assess economic conditions, we include local agricultural value added and the 2005 poverty index. The panel CEDE also reports estimates of cultivated area produced by the Municipal Agricultural Assessments (EVA) of the Ministry of Agriculture, which helps measure the extent of land allocated to agricultural activities. Finally, to measure conflict-related dynamics before the restitution law, we document: (i) the average number of people displaced from each municipality per year between 1993 and 2010, (ii) the average number of displaced people arriving in each municipality annually over the same period, and (iii) the average number of attacks per year from 2000 to 2009.

3.1.5 Land restitution

We use open cartographic data on land restitution claims, provided by the Land Restitution Unit (URT), to identify each property involved in a claim (Unidad de Restitución de Tierras, 2025). This dataset is continuously updated and includes information on all claims registered by the URT's regional offices nationwide, whether the claim is still under review, has resulted in a judgment granting restitution, or has been denied. The version used for this study corresponds to the release from June 16, 2025. As of that date, a total of 16,512 land restitution claims had been filed across 477 municipalities in Colombia.

Although, in principle, restitution claims are only admissible in areas certified through the micro-focalization process, the URT has, in practice, registered claims from across the country, regardless of whether the area had been formally macro- or micro-focalized (García-Godos and Wiig, 2014). To evaluate the effect of land restitution on forest use, we define a municipality as *treated* once a restitution claim has been filed for a property within its boundaries. Since filing a claim marks the beginning of potential access to institutional support for return and recovery, we argue that the land restitution law becomes relevant for the municipality starting from the moment of the first claim submission.

3.2 Descriptive Statistics

We combined the datasets described above for all 1,122 local administrative units in Colombia. Figure 1 displays the spatial distribution of land restitution claims across municipalities as of June 3, 2025. Municipalities that filed their first restitution claim by December 31, 2015, are shown in blue; those that initiated claims later are shown in red; municipalities with no claims appear in gray.

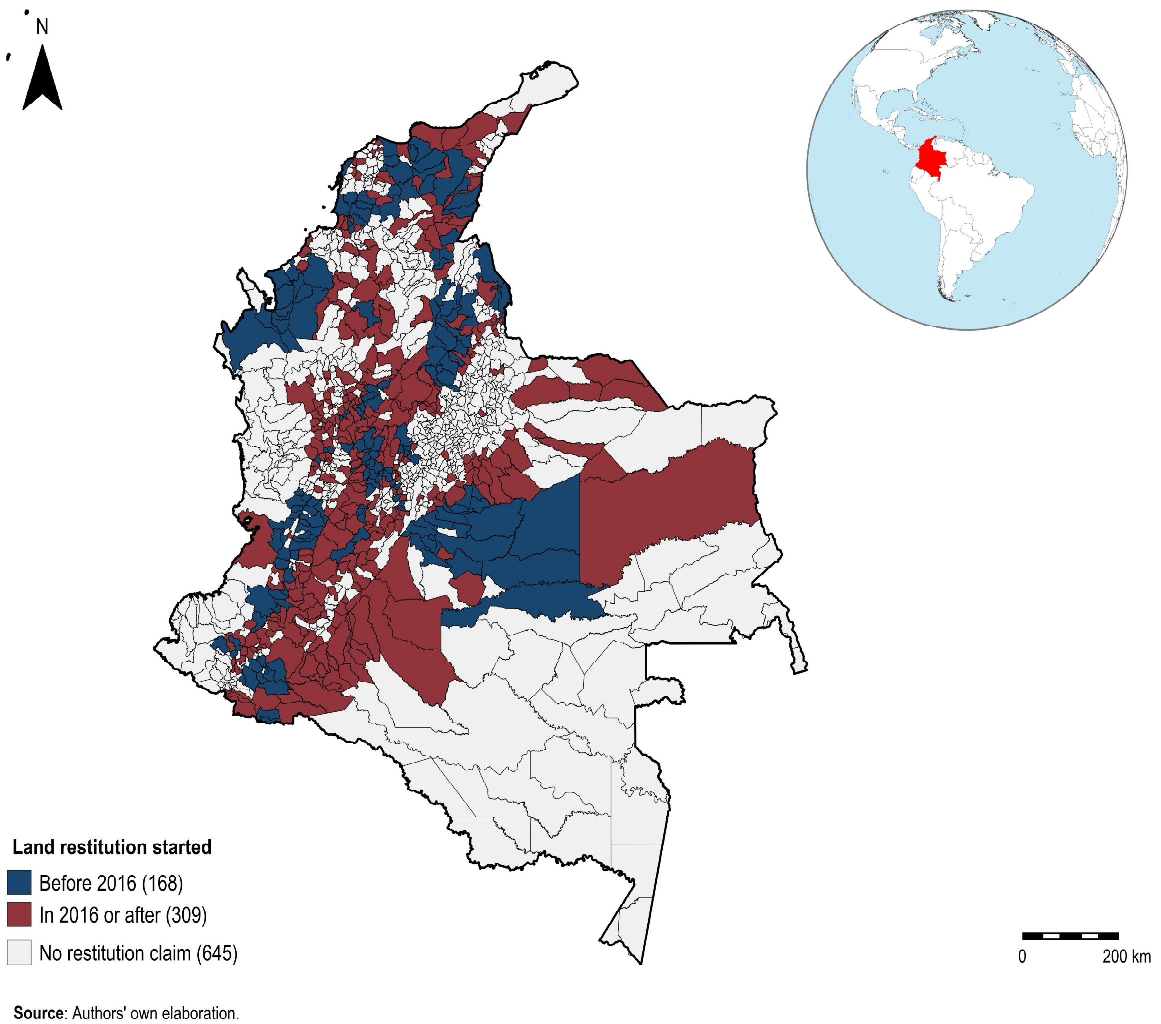


Fig. 1: Map of Municipalities by Timing of First Land Restitution Claim. This map displays the spatial distribution of municipalities based on the timing of their first land restitution claim. Municipalities in blue had a first claim submitted before 2016; those in red had their first claim filed in 2016 or later; and those in gray had no land restitution claims filed as of June 3, 2025.

The land restitution process begins when claimants submit their applications to the nearest regional land restitution office. Thus, the absence of claims in many municipalities may partly reflect barriers to access, such as distance or remoteness. While some areas without claims might also reflect successful informal return, it is worth noting that returnees have strong incentives to formalize their return through the restitution process. Court rulings can mandate the state to deliver complementary support, including communal infrastructure, productive projects, public services, and psychosocial rehabilitation. Legal judgments may also provide security guarantees and contribute to the formalization of land rights, enabling beneficiaries to legally transfer or use their land as collateral after a minimum holding period (García-Godos and Wiig, 2014).

Comparing municipalities with and without restitution claims reveals several patterns (see Table A.1 and Peralta (2022)). Claims were more likely to be filed in municipalities with larger agricultural sectors and higher numbers of people displaced during the eligibility period (1991–2011, approximated in our data as 1993–2010). In contrast, municipalities that primarily hosted displaced populations were less likely to register claims. Similarly, there is weak (statistically non-significant) evidence that areas with higher levels of pre-law violence experienced fewer restitution claims, suggesting that claims might be slightly more common in relatively more secure municipalities. Furthermore, municipalities with restitution claims tended to have lower population density, lower multidimensional poverty, and less forest cover. This indicates that claims were more likely in moderately developed areas where land use more directly competed with forested landscapes.

These findings suggest that municipalities with and without restitution claims differ in important ways, shaped by their histories of conflict and economic activity. Such differences are correlated with the timing of treatment and may influence forest cover dynamics. To address this concern, our subsequent analysis focuses exclusively on municipalities where claims were filed during the study period. Specifically, we compare forest cover change between municipalities where land restitution began before the 2016 peace accord, a pivotal moment in Colombia's post-conflict transition, and those where claims were initiated only afterward. We find no evidence that municipalities with early restitution experienced significantly less violence before the law's passage than those with later claims, supporting the credibility of this strategy (see Table A.2).[1]

Table 1: Descriptive statistics of administrative units with land restitution claims (N = 477)

	Min	Mean	Median	Max
A. Municipality characteristics				
Land area (thousand ha)	3.7	106.1	44.5	6545.2
Altitude (km)	0.003	1.2	1.1	3.3
Total population (2000-2010, in thousands)	0.2	31.6	6.1	2036.7
Municipal Agricultural GDP (2000-2010)	33.9	33 328.3	21 936.0	349 031.8
Multidimensional Poverty Index (2005)	26.4	68.8	70.1	97.6
Refugees leaving per year (1993–2010)	3.3	543.7	236.4	7138.1
Refugees hosted per year (1993–2010)	2.3	484.0	132.3	10 638.8
Annual number of attacks (2000–2010, VIPAA)	0	6.1	2.2	134.6
B. Land restitution experience				
Year of first land restitution demand	2012	2016.6	2017	2023
First demand submitted before 2016 (0 = No, 1 = Yes)	0	0.4	0	1
Total Area under restitution claim (2012-2025, ha)	0.002	1111.3	88.8	156 851.2
C. Tree cover and loss (thousand ha)				
Tree cover in 2000	0.5	58.6	21.3	4059.2
- within primary forest areas	0	30.4	2.3	3473.1
Tree cover loss (2006–2010)	0.003	1.4	0.4	59.9
- within primary forest areas	0	0.5	0.006	48.3
- due to fire	0	0.05	0.01	2.9
Tree cover loss (2011–2015)	0.003	1.1	0.3	47.5
- within primary forest areas	0	0.4	0.004	42.8
- due to fire	0	0.04	0.008	1.3

Note: The table presents descriptive statistics of local administrative units in Colombia where at least one land restitution claim was filed by 2025. Area and tree cover variables are expressed in hectares (ha) or thousand hectares, where indicated. All monetary figures are in local currency units (LCU).

Table 1 provides additional details on the municipalities with land restitution claims. The first claims were filed in 2012, and, by June 2025, a total of 0.5 million hectares had been subject to claims, representing 1% of the land area in the 477 municipalities of interest. Of these municipalities, 40% had their first claim filed by the end of 2015.

Although municipalities with land restitution claims had, on average, less forest cover, 52% of their cover in 2000 was located in areas classified as primary humid tropical forests, an essential habitat for Colombia's rich biodiversity. Between 2006 and 2010 (before the passage of the restitution law), 2.4% of that cover was lost. Notably, only

[1]Early restitution claims, however, were more common in poorer, more rural municipalities that had experienced higher levels of forced displacement in the past.

36% of this loss occurred within primary forests (despite such areas representing over half of the total forest cover), indicating that primary forests were not disproportionately affected. Of total forest loss between 2006 and 2010, 3.6% was confidently attributed to fire, a signal often associated with agricultural conversion.

Following the enactment of the law, forest cover loss between 2011 and 2015 declined by 27% across all municipalities that would eventually receive land restitution claims. However, this reduction should not be interpreted as a causal effect of the land restitution law. To assess causality, we could compare trends in forest cover change between municipalities where land restitution began before the end of 2015 and those where claims started later. While the latter group was not exposed to restitution activity before 2015, the former includes municipalities that experienced claims at different times and with varying intensity between 2011 and 2015. As a result, a direct comparison of trends starting in 2011 may yield misleading conclusions. Still, before the law's passage in 2011, forest cover loss in both groups followed broadly similar patterns; even though the trends were somewhat more irregular among municipalities where land restitution began later (see Figure A.1a).

3.3 Methods

To estimate the effect of land restitution on forest cover, we leverage variation in the timing of land restitution claims across municipalities. Because claims were filed in different years, municipalities were exposed to the policy at different times, and the intensity and timing of restitution activities vary widely (see Figure A.2). We exploit this staggered adoption structure to estimate dynamic treatment effects over time (de Chaisemartin and D'Haultfœuille, 2024).

Let $\mathrm{D}_{i,t}$ denote forest cover loss in municipality i during year t. Because many municipalities experienced no loss in some years, the distribution of forest loss is highly skewed (see Figure A.1b). To address this, we apply the inverse hyperbolic sine (IHS) transformation: $\tilde{D}_{i,t} = \mathrm{IHS}(\mathrm{D}_{i,t}) = \ln\left(D_{i,t} + \sqrt{D_{i,t}^2 + 1}\right)$. This transformation accommodates zero values and yields estimates interpretable in percentage terms, much like a log specification. In what follows, we refer to $\tilde{D}_{i,t}$ simply as "forest cover loss". In this framework, differences in $\tilde{D}_{i,t}$ between municipalities exposed to land restitution and those not yet exposed can be interpreted as percentage changes in forest loss associated with restitution.

We define $\mathrm{R}_{i,t}$ as a binary indicator equal to 1 if municipality i is exposed to land restitution (i.e., a claim has been filed) at time t. We observe N municipalities over $T = 10$ years (from 2006 to 2015). Once a municipality receives its first land restitution claim in year T_i, we consider it *treated* for the remainder of the study period.

Let $\mathbf{R}_i = (\mathrm{R}_{i,1}, \cdots, \mathrm{R}_{i,T})$ be the treatment vector for municipality i, and define $\mathcal{R}$ as the set of all possible treatment paths. The potential outcome $\tilde{\mathrm{D}}_{i,t}(\mathbf{r})$ is the forest cover loss in year t if municipality i followed treatment path $\mathbf{r} \in \mathcal{R}$. For any time t, let $\mathbf{0}_t$ denote a vector of t zeros; then $\tilde{\mathrm{D}}_{i,t}(\mathbf{0}_t)$ represents the counterfactual forest loss in municipality i at time t in the absence of any land restitution exposure up to that point.

We define the *dynamic treatment effect* ℓ years after the first land restitution claim in municipality i as:

$$\delta_{i,\ell} = \mathbb{E}\left[\tilde{\mathrm{D}}_{i,\mathrm{T}_i-1+\ell} - \tilde{\mathrm{D}}_{i,\mathrm{T}_i-1+\ell}(\mathbf{0}_{\mathrm{T}_i-1+\ell})\right]. \tag{1}$$

It captures the difference between observed forest loss and the counterfactual had no restitution claim been filed by the end of that year. In other words, it represents the change in forest loss attributable to restitution exposure, relative to a scenario with no claims filed up to that year.

We estimate $\delta_{i,\ell}$ using a *difference-in-differences* estimator:

$$\mathrm{DID}_{i,\ell} = \left(\tilde{\mathrm{D}}_{i,\mathrm{T}_i-1+\ell} - \tilde{\mathrm{D}}_{i,\mathrm{T}_i-1}\right) - \frac{1}{\mathrm{N}^i_{\mathrm{T}_i-1+\ell}} \sum_{i' \in \mathcal{C}_{i,\ell}} \left(\tilde{\mathrm{D}}_{i',\mathrm{T}_i-1+\ell} - \tilde{\mathrm{D}}_{i',\mathrm{T}_i-1}\right) \tag{2}$$

where $\mathcal{C}_{i,\ell}$ is the set of municipalities not yet treated by year $\mathrm{T}_i - 1 + \ell$ and with the same pre-treatment exposure as i (e.g., both untreated in 2006).

This estimator is unbiased under the following conditions (de Chaisemartin and D'Haultfœuille, 2024):

- **(H1) No anticipation:** Potential outcomes at time t depend only on the treatment history up to time t.
- **(H2) Parallel trends:** In the absence of treatment, all municipalities would have experienced similar changes in forest loss.

Our parameter of interest is the average dynamic treatment effect at ℓ:

$$\delta_\ell = \frac{1}{N_\ell} \sum_{i:\ \mathrm{T}_i - 1 + \ell \leq \mathrm{T}} \delta_{i,\ell} \tag{3}$$

where N_ℓ is the number of municipalities for which the effect $\delta_{i,\ell}$ is observable. We estimate δ_ℓ using:

$$\mathrm{DID}_\ell = \frac{1}{N_\ell} \sum_{i:\mathrm{T}_i - 1 + \ell \leq \mathrm{T}} \mathrm{DID}_{i,\ell} \tag{4}$$

There are plausible reasons to suspect anticipatory responses. For example, secondary occupants might preemptively abandon the land, or displaced populations might delay their return in anticipation of policy support. While these mechanisms may bias results if they differ systematically across municipalities, we expect anticipation to be similarly distributed in municipalities with early and late treatment. Thus, our design likely nets out general anticipatory effects.

To examine this assumption and the plausibility of parallel trends, we test for differential pre-treatment forest loss trends. If municipalities with early and late restitution claims exhibit similar forest loss trends before the law's enactment, this would support both the no-anticipation and parallel trends assumptions, lending credibility to our identification strategy.

To further ensure comparability, we restrict the analysis to provinces (sub-departmental administrative units) that include both early- and late-treated municipalities. Although this restriction reduces sample size, it increases internal validity by ensuring a shared institutional and administrative context (see Figure A.3).

Our main analysis thus focuses on municipalities with land restitution claims filed by 2025 and located in provinces with both early and late adopters. Since the earliest claims were filed in 2012 and the panel extends through 2015, we estimate dynamic effects for $\ell = 1$ to 4 using the estimator DID_ℓ. As a robustness check, we also replicate the analysis using the alternative estimators proposed by Callaway and Sant'Anna (2021).

4 Results

We estimate the effects of land restitution on forest dynamics using the difference-in-differences approach outlined above. Figure 2 reports estimates for annual tree cover loss in forested areas (as of 2000), while Figure 3 presents complementary results for forest cover area.

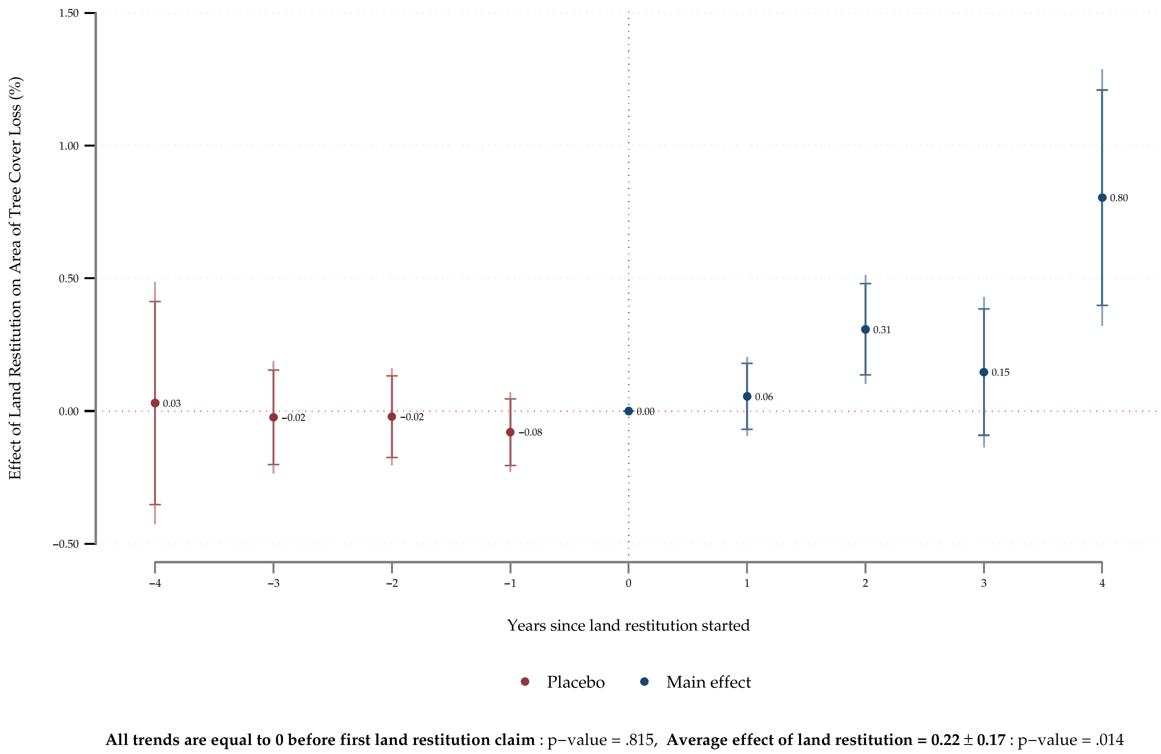


Fig. 2: Effect of Land Restitution on Tree Cover Loss at the Municipal Level. This figure shows the estimated impact of initiating land restitution on annual tree cover loss across municipalities. The x-axis indicates the number of years before and after the first land restitution claim was filed, while the y-axis shows the average effect on tree cover loss area in %. Each dot represents an estimated effect at a specific time; capped vertical lines indicate 90% confidence intervals, and uncapped longer lines represent 95% intervals. Red points reflect pre-treatment differences in trends between municipalities that began processing land restitution claims before 2016 and those that started in 2016 or later; blue points indicate the post-treatment effects of initiating land restitution. **Source**: Data compiled by the authors.

Figure 2 highlights two main findings. First, in the years preceding the initial land restitution claims, there were no statistically significant differences in tree cover loss between municipalities with early and late exposure to the policy. This supports the identifying assumptions of no anticipation and that pre-treatment trends were parallel across the two groups. Second, while no significant change in tree cover loss is detected during the year of the first claim, the effect over the subsequent four years is substantial. On average, municipalities with early land restitution experienced a 22% increase in annual tree cover loss relative to the counterfactual. This effect intensified over time: by 2015, tree cover loss in municipalities where land restitution was initiated in 2012 was 80% higher than expected in the absence of restitution.

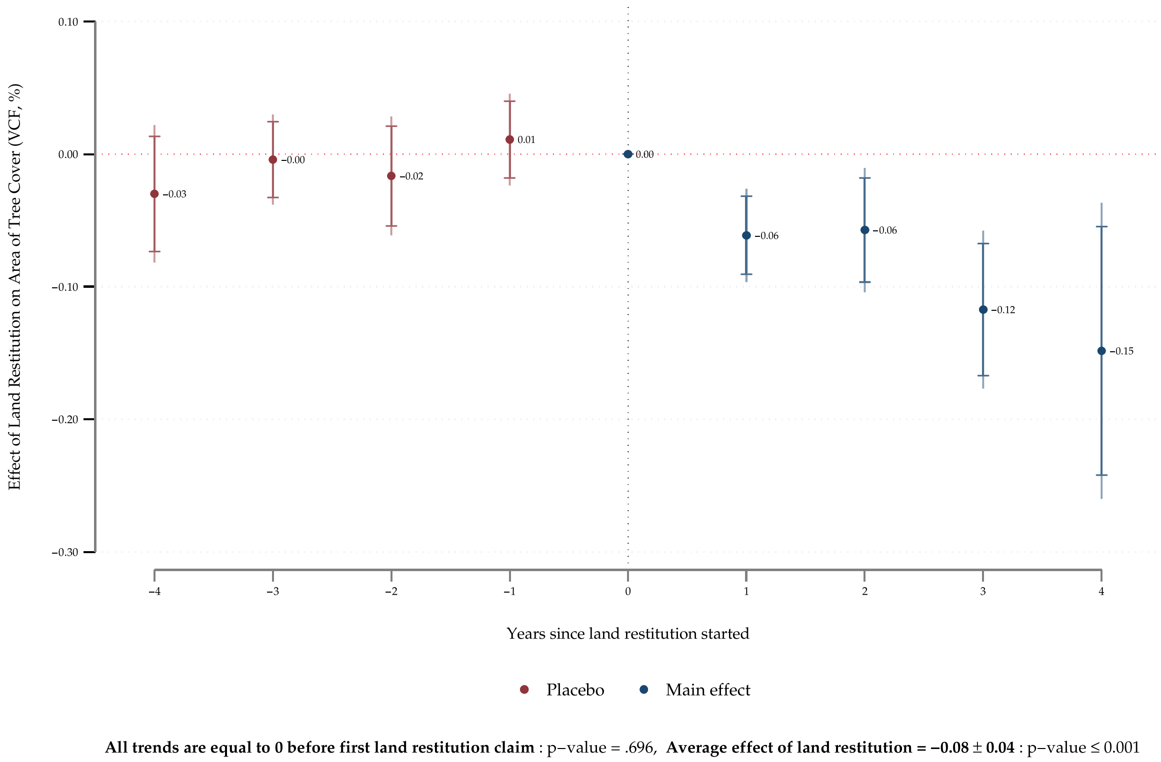


Fig. 3: Effect of Land Restitution on Tree Cover Area at the Municipal Level. This figure complements the findings in Figure 2, presenting a parallel analysis of the impact of initiating land restitution on annual tree cover area in municipalities. Tree cover area is estimated using MODIS Vegetation Continuous Fields (VCF) data, providing an independent measure to validate and extend the previous results. The x-axis shows the number of years before and after the first land restitution claim was filed, while the y-axis reflects the average estimated effect on tree cover area. Each dot represents an estimated effect at a specific time; capped vertical lines indicate 90% confidence intervals, and uncapped longer lines represent 95% intervals. Red points reflect pre-treatment differences in trends between municipalities that began processing land restitution claims before 2016 and those that started in 2016 or later; blue points indicate the post-treatment effects of initiating land restitution. **Source**: Data compiled by the authors.

Figure 3 offers an independent validation using MODIS Vegetation Continuous Fields (VCF) data, which measures tree cover area and is derived from a different satellite system (Terra, rather than Landsat). The trends again indicate that municipalities exposed to early land restitution experienced no differential trends in tree cover area in the five years preceding the policy. After the first claim, however, forest cover declined steadily, with an average reduction of 6% in the year of exposure, increasing to 15% by year four. These estimates imply that early-treated municipalities experienced an average annual net loss of 8% of their tree cover area over a four-year period.

In sum, the evidence from both Landsat and MODIS sources suggests that the initiation of land restitution claims led to a measurable acceleration in forest loss. These patterns are consistent across data sources, robust to alternative estimators (see Figure A.4 and Figure A.5) and sample definitions (see Figure A.6 and Figure A.7).

5 Discussion

To better understand the processes driving the increase in tree cover loss following land restitution, we examine two competing hypotheses. The *primary forest conversion hypothesis* suggests that tree cover loss arises from expanding agricultural activity into primary forest areas. In contrast, the *agricultural reversion hypothesis* argues that tree cover loss reflects the reoccupation of land previously cultivated, later abandoned during displacement, and subsequently recolonized by returnees.

5.1 Primary Forest Conversion

Figure 4 reports the effect of land restitution on tree cover loss specifically within primary forests. Although 37% of all forest loss between 2011 and 2015 occurred in these areas, we find no statistically significant differences between municipalities with early versus late restitution claims, either before or after claims were filed. This result suggests that the observed increase in deforestation was not primarily driven by clearing primary forests, casting doubt on the primary forest conversion hypothesis.

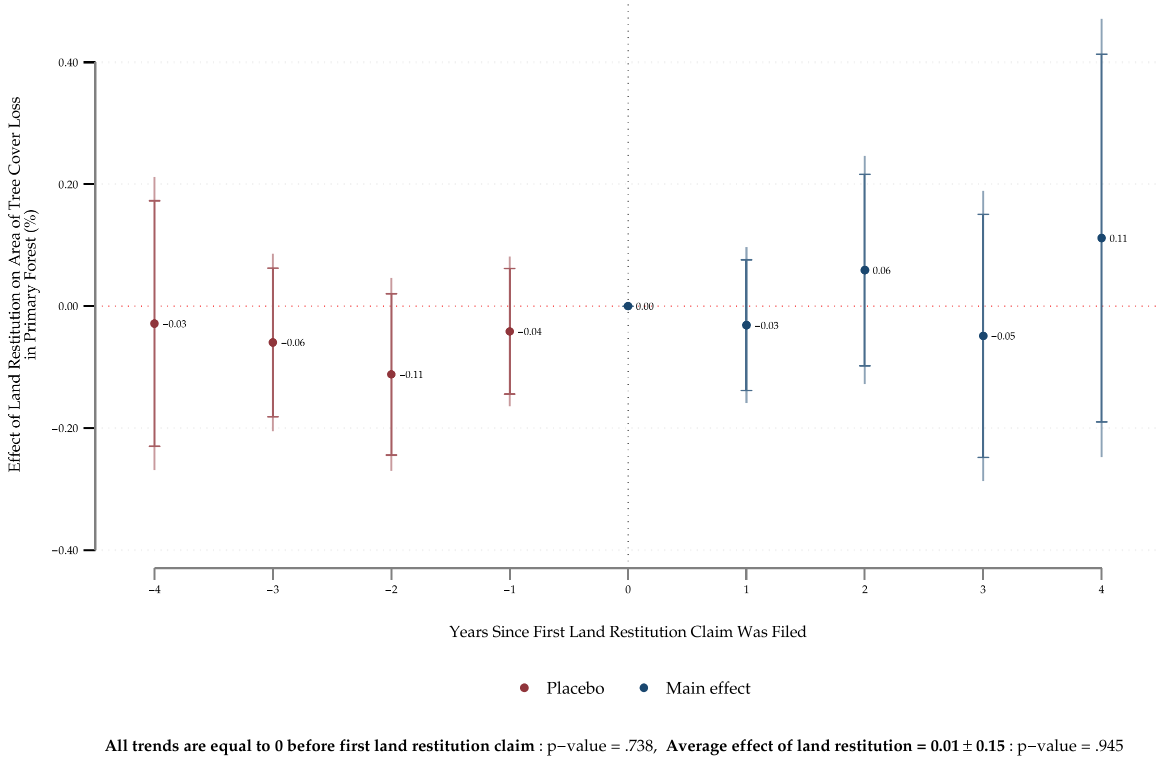


Fig. 4: Effect of Land Restitution on Tree Cover Loss in Primary Forest at the Municipal Level. This figure presents the estimated effect of initiating land restitution on annual tree cover loss in areas classified as primary forest. We use the global map of primary humid tropical forests in 2001 produced by the UMD GLAD team to identify and isolate tree cover loss within Colombian primary forests. The x-axis indicates the number of years before and after the first land restitution claim, and the y-axis represents the average estimated effect on primary forest loss. Each dot represents an estimated effect at a specific time; capped vertical lines indicate 90% confidence intervals, and uncapped longer lines represent 95% intervals. Red points reflect pre-treatment differences in trends between municipalities that began processing land restitution claims before 2016 and those that started in 2016 or later; blue points indicate the post-treatment effects of initiating land restitution. **Source**: Data compiled by the authors.

5.2 Agricultural Reversion

Because fire is a common method for clearing forests for cultivation, we first investigate whether restitution is associated with more fire-related forest loss. Figure 5 shows that fire-related tree cover loss rose by an average of 24% in the four years after the first claim, reaching 69% by 2015 in municipalities with early restitution. This pattern is consistent with the return of displaced landholders or other actors converting forest back into cropland or pasture.[2]

[2]Despite this evidence of fire-driven forest loss, we find little indication of significant agricultural expansion. Municipal-level data from the Ministry of Agriculture suggest that cultivated land increased by only 3% annually in the four years after restitution, though the estimate is imprecise and should be interpreted with caution (see Figure A.8).

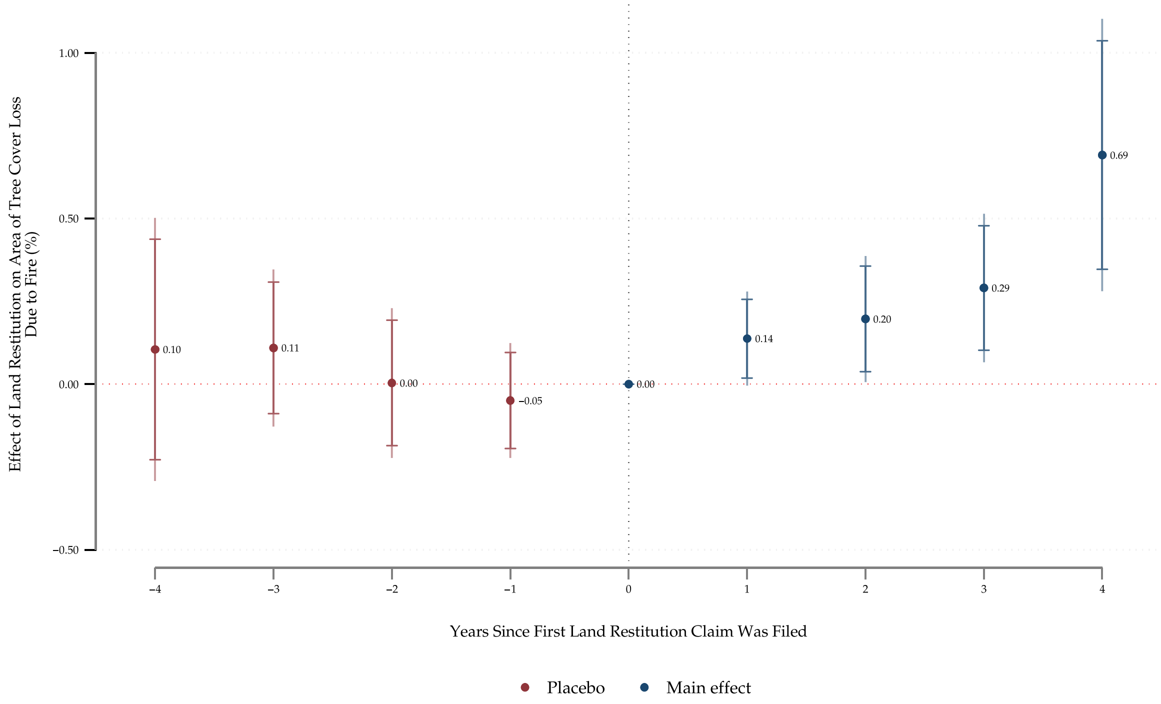
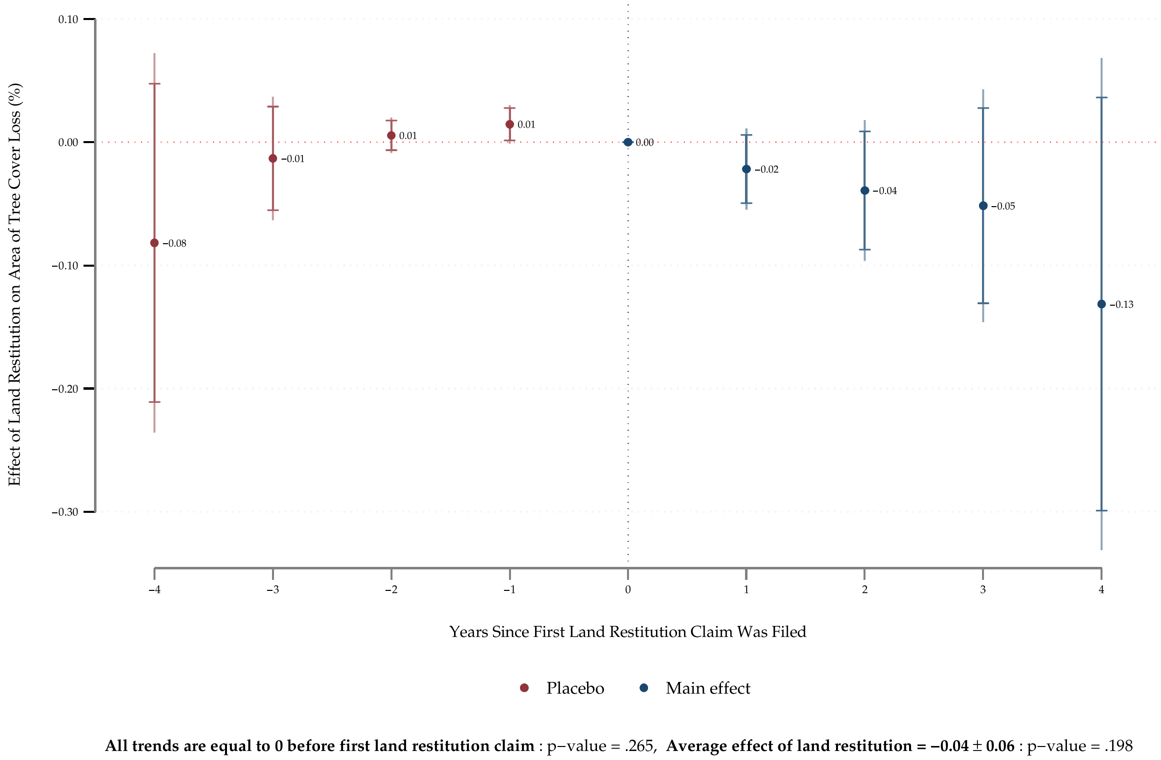


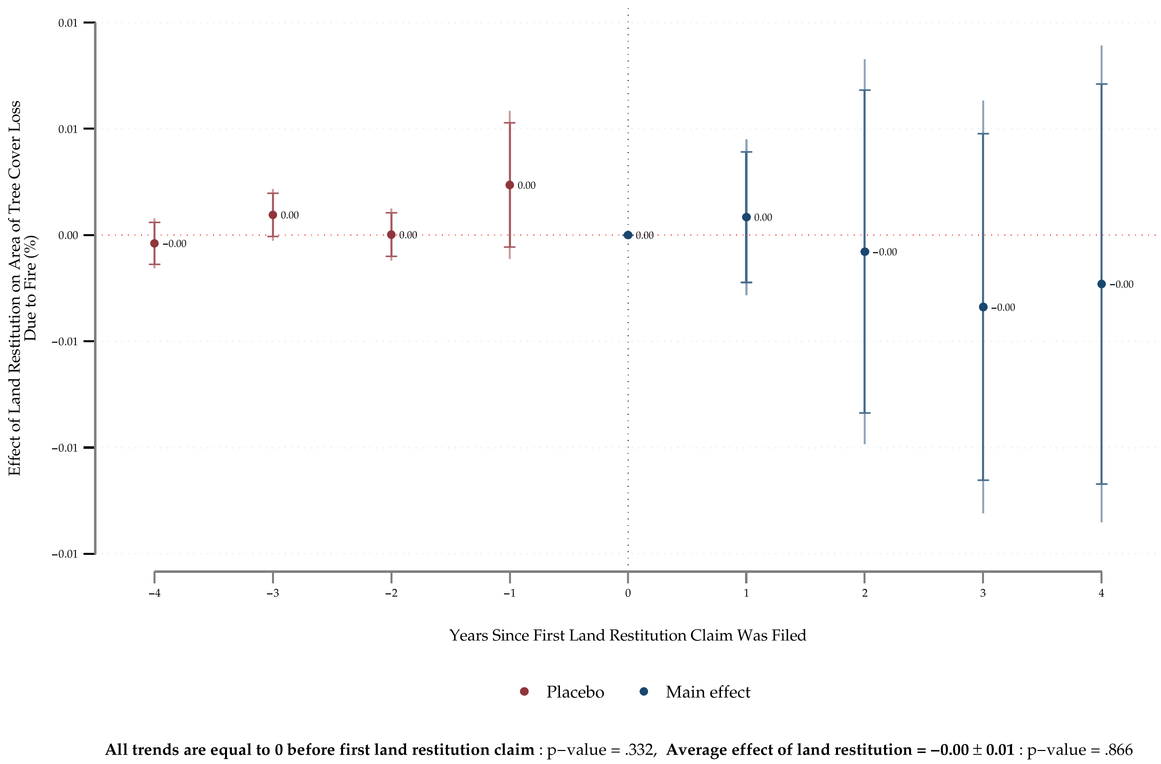
Fig. 5: Effect of Land Restitution on Tree Cover Loss Due to Fire at the Municipal Level. This figure presents the estimated impact of initiating land restitution on annual tree cover loss due to fire, using the global dataset from the UMD GLAD team. The x-axis shows the number of years before and after the first land restitution claim, while the y-axis shows the average effect on fire-related forest loss. Each dot represents an estimated effect at a specific time; capped vertical lines indicate 90% confidence intervals, and uncapped longer lines represent 95% intervals. Red points reflect pre-treatment differences in trends between municipalities that began processing land restitution claims before 2016 and those that started in 2016 or later; blue points indicate the post-treatment effects of initiating land restitution. **Source**: Data compiled by the authors.

If agricultural reversion is the primary mechanism, then forest loss should occur on land with a history of agricultural use. To test this, we first examine plots directly subject to restitution claims. Figure 6 shows no statistically significant differences in total and fire-related forest loss within these plots between plots with early and late claims. This suggests that the additional forest loss observed at the municipal level is not concentrated on the properties with ongoing land restitution claims.

We also find no evidence of increased forest loss immediately surrounding the plots with pending claims (see Figure A.9 and Figure A.10). This indicates that displaced secondary occupants did not relocate by clearing the nearby forest. However, they may have moved further afield, or forest loss may have resulted from returnees reoccupying abandoned land without submitting restitution claims.



(a) Total tree cover loss within plots with a restitution claim.

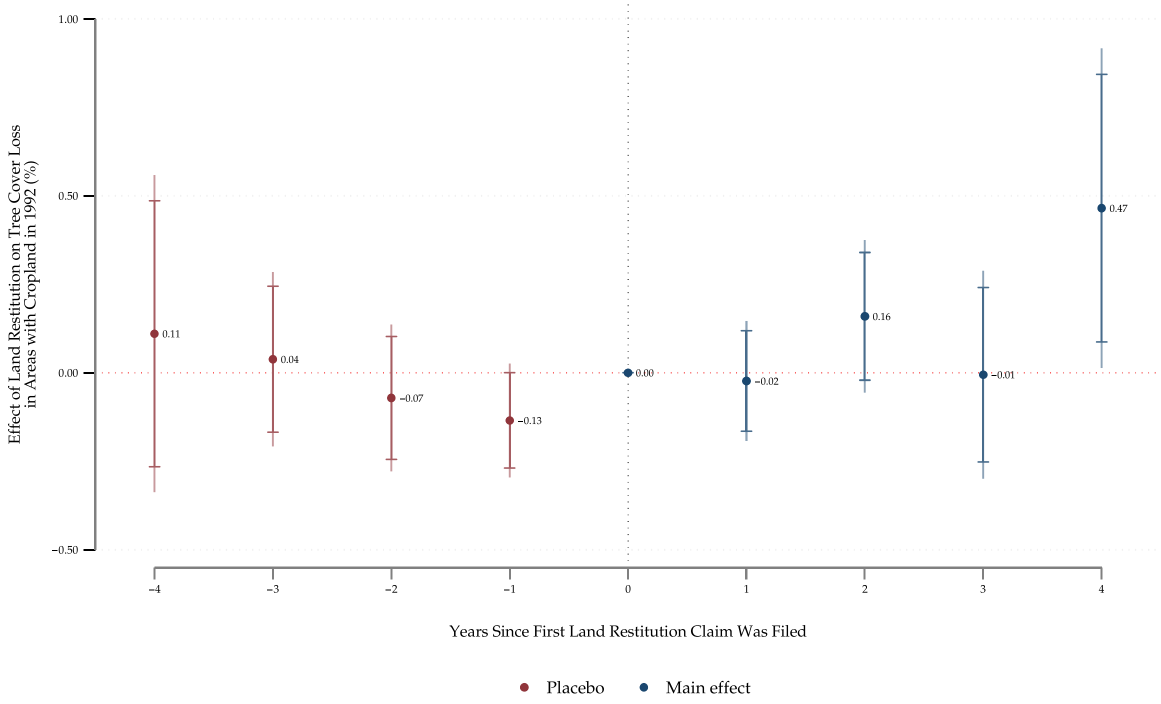


(b) Fire-related tree cover loss within plots with a restitution claim.

Fig. 6: Effect of Land Restitution on Tree Cover Loss Within Restitution Plots. This figure displays the estimated impact of initiating land restitution on annual tree cover loss within plots with pending land restitution claims. Panel (a) presents estimates for total tree cover loss. Panel (b) shows results for fire-related tree cover loss. **Source**: Data compiled by the authors.

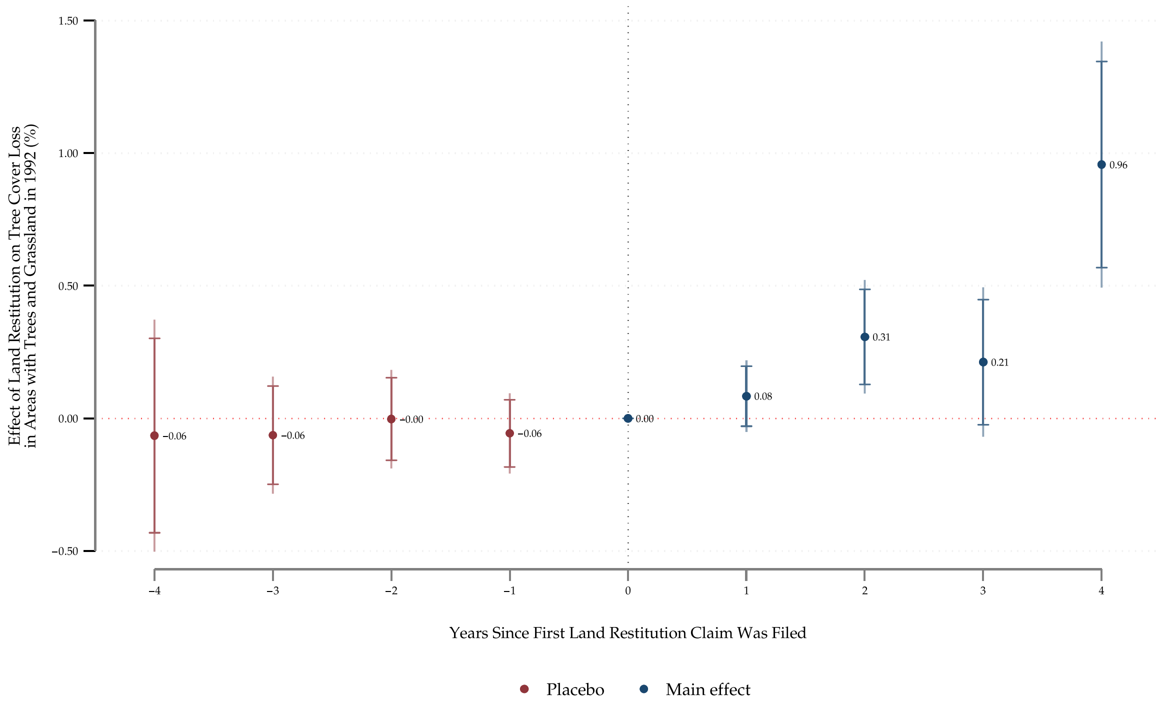
While we cannot directly map abandoned parcels, descriptive evidence sheds light on the types of land subject to restitution claims. As shown in Table A.3, 18% of the claimed area was classified as cropland in 1992, 36% as tree cover, and another 36% as grassland. This indicates that returnees reclaimed not only previously cultivated plots but also land classified as covered with trees or grassland in 1992; likely reflecting natural regrowth on abandoned cropland or misclassification in the land cover data (e.g., tree crops or other agricultural land being labelled as trees or grassland by the algorithm).

Figure 7 confirms this pattern. Tree cover loss in areas classified as cropland in 1992 was, on average, 8% higher in municipalities with early restitution, rising to 47% by 2015. Similarly, areas labelled as trees or grassland in 1992 saw losses of tree cover 26% higher on average, reaching 96% by 2015. These findings support the agricultural reversion hypothesis: much of the observed tree cover loss following restitution efforts reflects reuse of land abandoned during displacement, rather than primary forest.



All trends are equal to 0 before first land restitution claim : p−value = .377, **Average effect of land restitution = 0.08 ± 0.18** : p−value = .39

(a) Tree cover loss in areas with cropland in 1992.



All trends are equal to 0 before first land restitution claim : p−value = .89, **Average effect of land restitution = 0.26 ± 0.17** : p−value = .003

(b) Tree cover loss in areas with trees and grassland cover in 1992.

Fig. 7: Effect of Land Restitution on Tree Cover Loss in Areas Likely to Have Been Abandoned. This figure presents the estimated impacts of initiating land restitution on annual tree cover loss in areas that were either classified as cropland or as tree/grassland in 1992 and had tree cover in 2000. Land cover in 1992 is identified using the ESA CCI Land Cover series. Panel (a) shows estimates for areas classified as cropland in 1992. Panel (b) reports results for areas classified as tree cover or grassland in 1992. **Source**: Data compiled by the authors.

6 Conclusion

In Colombia, the Land Restitution Law was introduced to redress historical injustices and restore land to victims displaced by the armed conflict. In this study, we examine the environmental consequences of this post-conflict land reform, focusing specifically on its impact on deforestation.

Using a staggered difference-in-differences design and satellite-based measures of forest cover, we find that land restitution efforts led to a measurable increase in tree cover loss in municipalities where claims were filed. To investigate the processes behind this increase, we tested the *primary forest conversion hypothesis*, where deforestation results from the expansion of agriculture into primary forests, and the *agricultural reversion hypothesis*, where tree cover loss reflects the reoccupation of previously cultivated land that had been abandoned during displacement. Our results provide little support for primary forest conversion, as we find no evidence of increased loss in primary humid tropical forests. Instead, the evidence points toward agricultural reversion: fire-related forest loss rose significantly after restitution, consistent with land being cleared for cultivation, and most loss occurred on land classified as cropland or with tree cover in 1992 rather than on plots with pending restitution claims.

These findings highlight a key policy trade-off. While land restitution supports transitional justice and facilitates the reintegration of displaced populations, it may also accelerate land clearing if environmental safeguards are not in place. This risk is especially salient as restitution efforts expand and the eligibility window is debated, potentially extending to displacements occurring before 1991 or after 2011.

To align social and environmental goals, land restitution could incorporate targeted support for sustainable land-use practices. Policies that promote payment for ecosystem services, agroforestry, soil restoration, and regenerative agriculture can help mitigate the risk of deforestation while fostering resilient rural livelihoods. In this way, land reform can contribute not only to reconciliation and justice but also to long-term ecological sustainability.

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Appendices

Table A.1: Correlates of Land Restitution Claims

	Marginal effects (1)	(2)
Land area (log hectares)	0.0480	0.0465
	(0.037)	(0.036)
Altitude (km)	0.0060	0.0092
	(0.026)	(0.025)
Total population (2000-2010, log persons)	-0.1147***	-0.1081***
	(0.033)	(0.032)
Municipal agricultural GDP (2000-2010, log LCU)	0.0797***	0.0774***
	(0.018)	(0.018)
Multidimensional Poverty Index (2005)	-0.0166***	-0.0162***
	(0.002)	(0.002)
Refugees leaving per year (1993–2010, ihs persons)	0.3164***	0.3132***
	(0.026)	(0.024)
Refugees hosted per year (1993–2010, ihs persons)	-0.0486*	-0.0508**
	(0.026)	(0.025)
Average number of attacks per year (2005-2010, ihs count)	-0.0227	-0.0203
	(0.023)	(0.022)
Tree cover in 2000 (log hectares)	-0.0758**	-0.0768***
	(0.031)	(0.030)
Number of municipalities	1,097	1,122
$\mathbb{P}$ (First claim submitted by June 2025 $= 1$)	0.43	0.43
LR Test	3.7e-55	7.1e-57

Note: The table reports marginal effect estimates of municipal characteristics on the likelihood that a municipality has at least one land restitution claim filed by 2025. Data on agricultural GDP and the multidimensional poverty index are missing for 25 and 9 municipalities, respectively. Column (1) reports marginal effects using a sample restricted to the 1,097 municipalities with complete data. Column (2) presents estimates from a specification in which missing values for both variables are replaced with their predicted values based on the following municipal characteristics: land area, altitude, area covered by cropland in 1992, area with built-up land in 1992, area with forest cover in 1992, and average population size between 2000 and 2009.

Robust standard errors are in parentheses. Significance levels: * p<0.10, ** p<0.05, *** p<0.01.

Table A.2: Correlates of Early Land Restitution

	Marginal effects
Land area (log hectares)	-0.0490
	(0.058)
Altitude (km)	-0.1162***
	(0.040)
Total population (2000-2010, log persons)	-0.0798**
	(0.038)
Municipal agricultural GDP (2000-2010, log LCU)	0.0715***
	(0.023)
Poverty Index (2005)	-0.0092***
	(0.003)
Refugees leaving per year (1993–2010, log persons)	0.1103***
	(0.039)
Refugees hosted per year (1993–2010, log persons)	0.0189
	(0.038)
Average number of attacks per year (2005-2010, log count)	0.0369
	(0.028)
Tree cover in 2000 (log hectares)	0.0011
	(0.050)
Number of municipalities	477
$\mathbb{P}$ (First demand submitted by 2015 $= 1$)	0.35
LR Test	8.8e-09

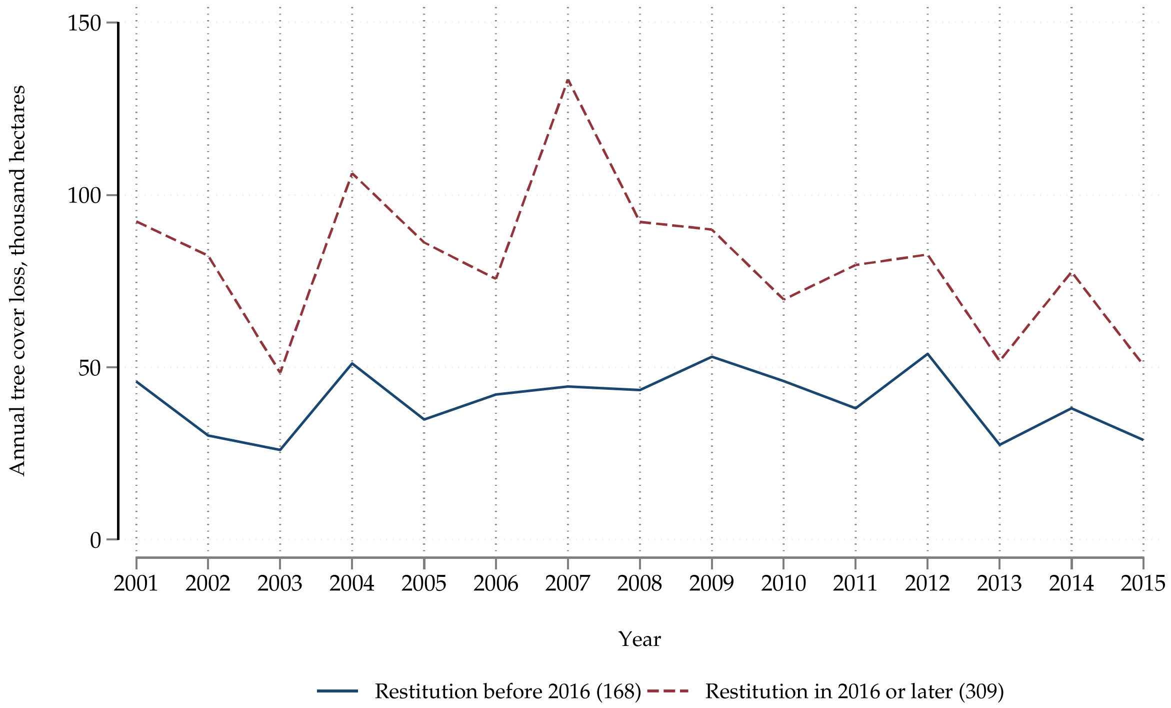
Note The table reports marginal effect estimates of municipal characteristics on the likelihood that the first land restitution claim was filed by 2015.

Robust standard errors are in parentheses. Significance levels: * p<0.10, ** p<0.05, *** p<0.01.

Table A.3: Land Cover Characteristics, Restitution Claims, and Forest Dynamics in Municipalities with Claims Filed by 2025

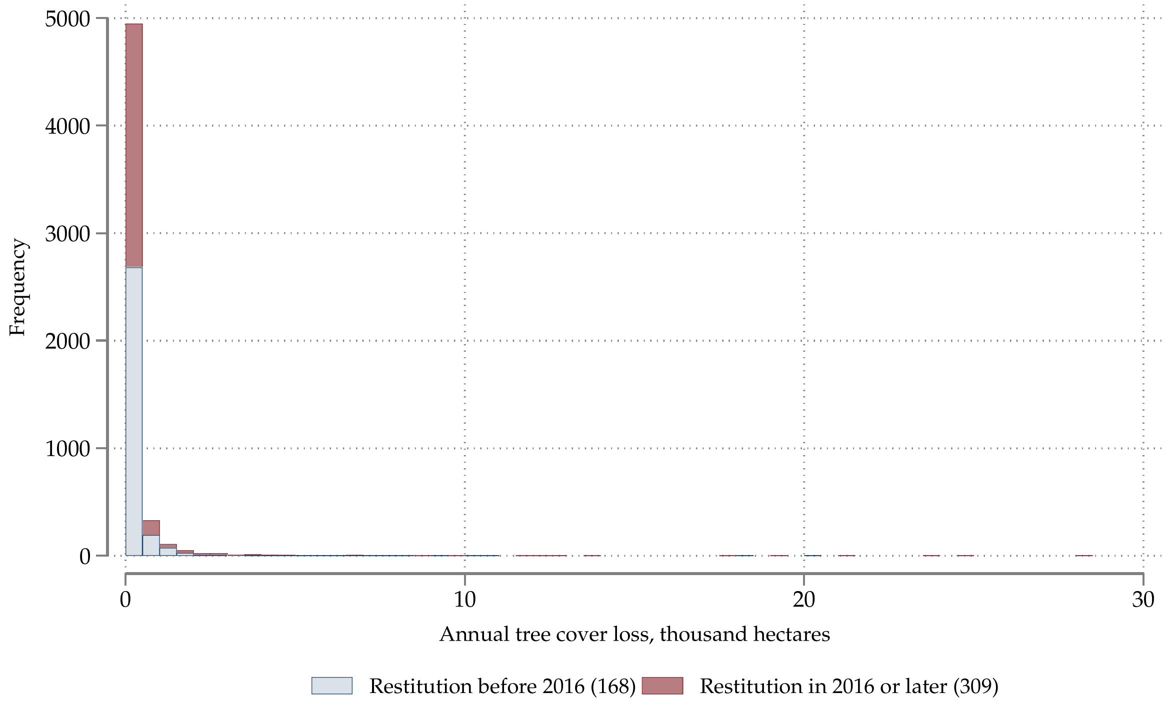
	Obs	Min	Mean	Median	Max
A. Land area					
Total land area	477	3.7	106.1	44.5	6545.2
- Cropland area	477	0.0001	18.5	7.3	269.5
- Tree cover area	477	0	57.2	19.8	4124.3
- Grassland area	477	0	19.7	0.2	2221.3
- Shrubland area	477	0	6.8	2.1	87.1
- Other land cover	477	0	3.5	0.2	316.9
B. Land restitution					
Area under restitution claim (by 2025)	477	0.000 002	1.1	0.09	156.9
- with cropland	477	0	0.2	0.005	7.8
- with trees	477	0	0.4	0.03	19.1
- with grassland	477	0	0.4	0	145.6
- with shrubland	477	0	0.07	0	7.0
- with other land cover	477	0	0.006	0	1.0
C. Tree cover in 2000					
Tree cover (total)	477	0.5	58.6	21.3	4059.2
- with cropland	477	0.000 004	5.5	2.5	81.3
- with trees	477	0	47.7	14.2	3762.4
- with grassland	477	0	2.3	0.04	238.5
- with shrubland	477	0	2.6	1.0	37.2
- with other land cover	477	0	0.4	0.02	50.9
D. Tree cover loss (2006–2010)					
Tree cover loss (total)	477	0.003	1.4	0.4	59.9
- with cropland	477	0	0.3	0.06	5.1
- with trees	477	0	1.0	0.2	54.7
- with grassland	477	0	0.06	0.0003	2.4
- with shrubland	477	0	0.07	0.01	2.6
- with other land cover	477	0	0.006	0.0002	0.3
E. Tree cover loss (2011–2015)					
Tree cover loss (total)	477	0.003	1.1	0.3	47.5
- with cropland	477	0	0.2	0.04	3.2
- with trees	477	0	0.9	0.2	45.4
- with grassland	477	0	0.03	0.0002	2.2
- with shrubland	477	0	0.04	0.008	0.8
- with other land cover	477	0	0.005	0.0001	0.2

Note: This table summarizes land cover characteristics and restitution activity for municipalities with at least one land restitution claim filed by 2025. All area values are reported in thousands of hectares (000 ha). Land cover types are based on the 1992 global land cover map from the Climate Change Initiative of the European Space Agency (European Space Agency, 2017). The category "Other land cover" includes bare land, built-up areas, sparse vegetation, wetlands, and water bodies as classified in 1992.



Source: Authors' own elaboration.

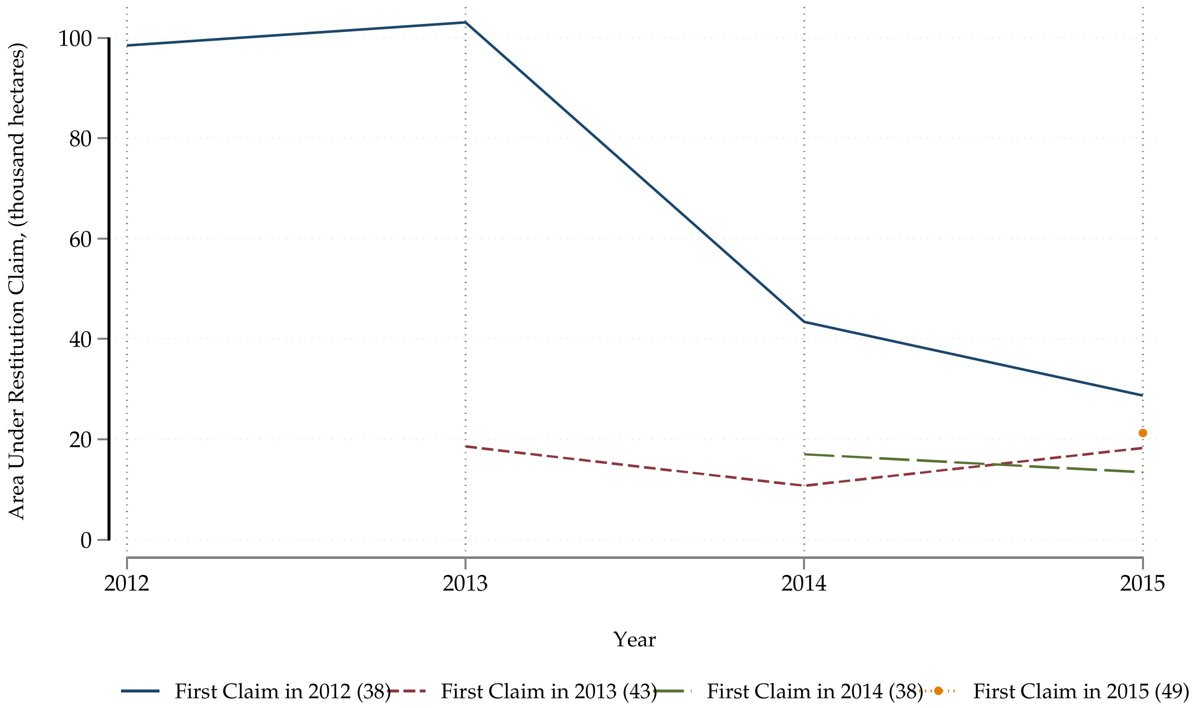
(a) Average total annual tree cover loss over time.



Source: Authors' own elaboration.

(b) Distribution of total annual tree cover loss at the municipality level.

Fig. A.1: Forest Cover Loss in Municipalities with Early and Late Land Restitution Claims. This figure compares annual municipal-level tree cover loss between municipalities with first land restitution claims before 2016 (blue) and those with later claims (red). Panel (a) plots the average annual tree cover loss over time, highlighting differences in trends between the two groups. Panel (b) shows the histogram of annual tree cover loss values for each group. **Source**: Data compiled by the authors.



Source: Authors' own elaboration.

Fig. A.2: Annual Area Under Restitution Claim by Timing of First Municipal Claim. This figure displays the total area of properties newly subject to restitution claims each year, disaggregated based on the timing of each municipality's first land restitution claim. The blue line represents municipalities where the first claim was filed in 2012, the red line shows those with first claims in 2013, the green line indicates those where the first claim occurred in 2014, and the orange circle represents those with initial claims in 2015. **Source**: Data compiled by the authors.

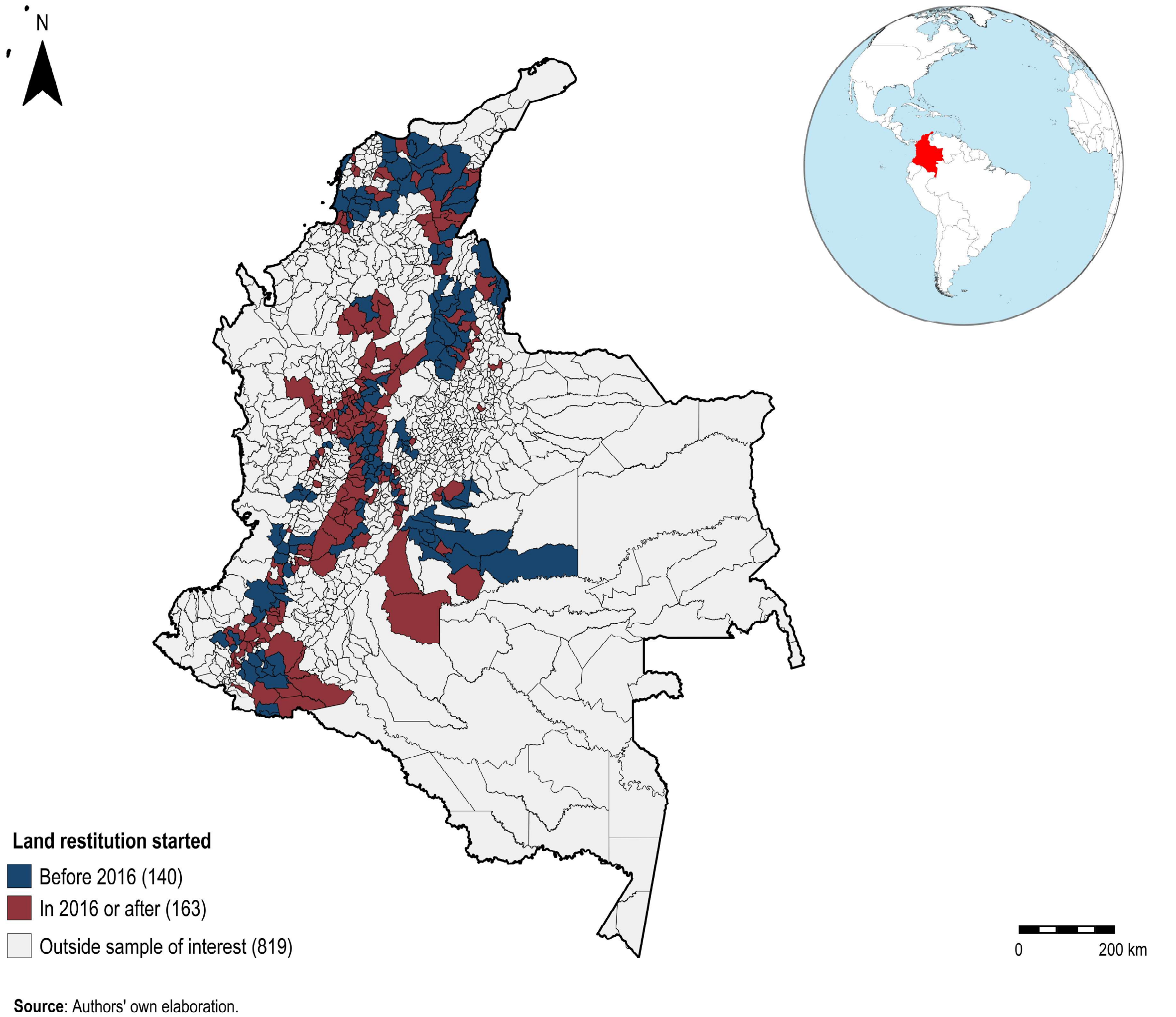
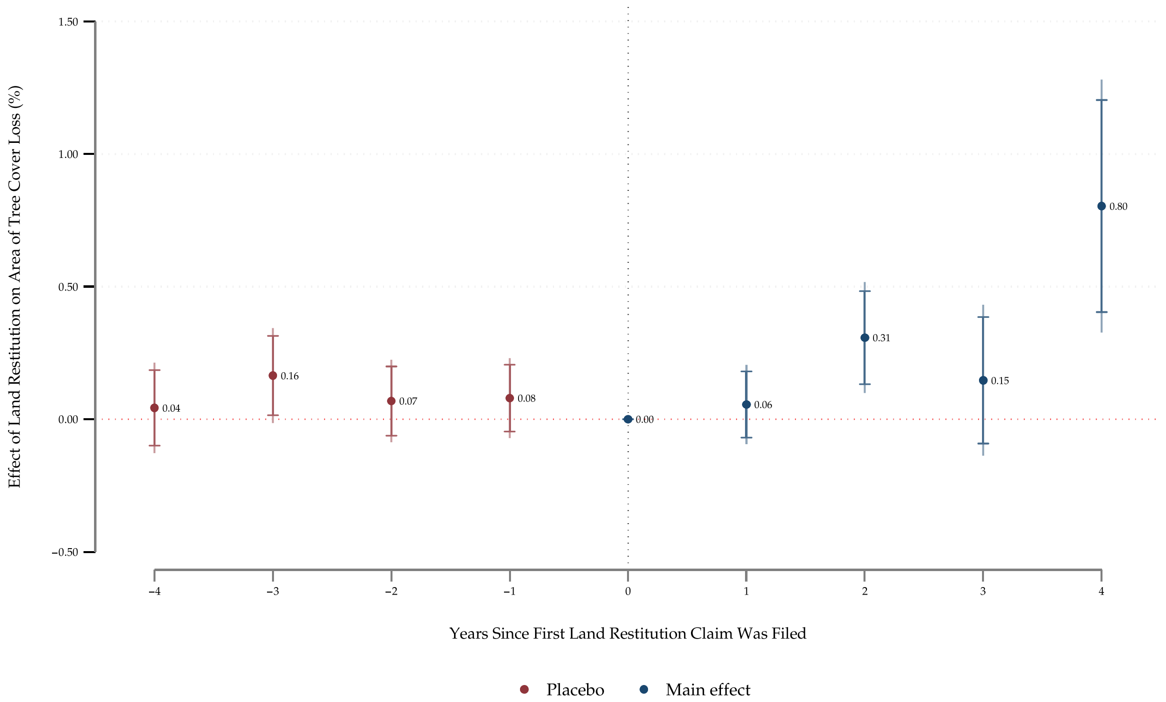


Fig. A.3: Map of Municipalities Included in the Main Analytical Sample. This map shows the spatial distribution of municipalities with land restitution claims filed by June 2025. The sample is limited to municipalities located in provinces that contain at least one municipality where claims were first filed before 2016 (in blue) and at least one where claims were filed in 2016 or later (in red). This restriction helps us use within-province variation in treatment timing and facilitates more credible comparisons by controlling for unobserved province-level characteristics that vary over time. **Source**: Data compiled by the authors.



Average effect before restitution = 0.09 ± 0.14 : p−value = .2, **Average effect of land restitution = 0.33 ± 0.22** : p−value = .003

Fig. A.4: Effect of Land Restitution on Tree Cover Loss at the Municipal Level Using Alternative Estimator. This figure shows the estimated impact of initiating land restitution on annual tree cover loss across municipalities, using the estimator proposed by Callaway and Sant'Anna (2021) applied to the main analytical sample. The x-axis indicates the number of years before and after the first land restitution claim was filed, while the y-axis shows the average effect on tree cover loss area. Each dot represents an estimated effect at a specific time. Capped vertical lines show 90% confidence intervals; uncapped longer lines show 95% confidence intervals. Red points reflect pre-treatment differences in trends between municipalities that began processing land restitution claims before 2016 and those that started in 2016 or later. Blue points show the post-treatment effects of initiating land restitution. **Source**: Data compiled by the authors.

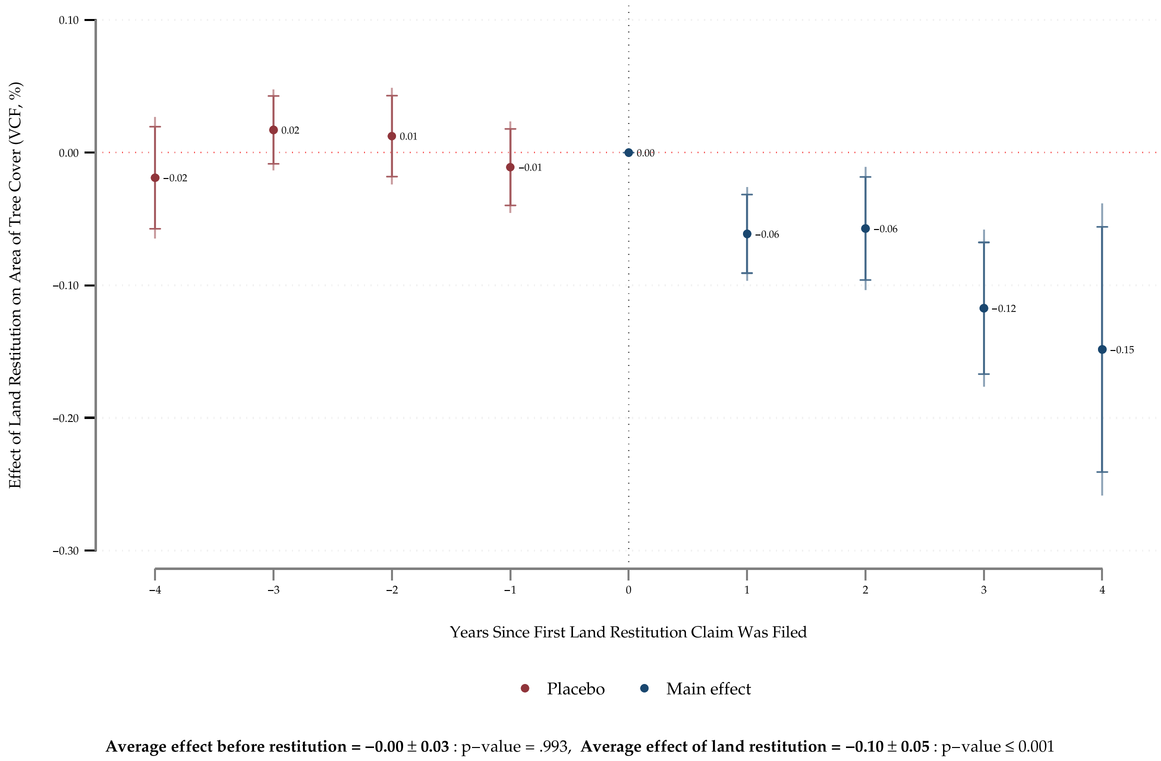


Fig. A.5: Effect of Land Restitution on Tree Cover Area at the Municipal Level Using Alternative Estimator. This figure shows the estimated impact of initiating land restitution on annual tree cover area in municipalities, using the estimator proposed by Callaway and Sant'Anna (2021) applied to the main analytical sample. Tree cover area is estimated using MODIS VCF data. The x-axis shows the number of years before and after the first land restitution claim was filed, while the y-axis reflects the average estimated effect on tree cover area. Each point represents an effect estimate for a given year. Capped vertical lines indicate 90% confidence intervals; uncapped longer lines indicate 95% confidence intervals. Red points capture pre-treatment differences in trends between municipalities that initiated land restitution before 2016 and those that began in 2016 or later. Blue points show the estimated post-treatment effects. **Source**: Data compiled by the authors.

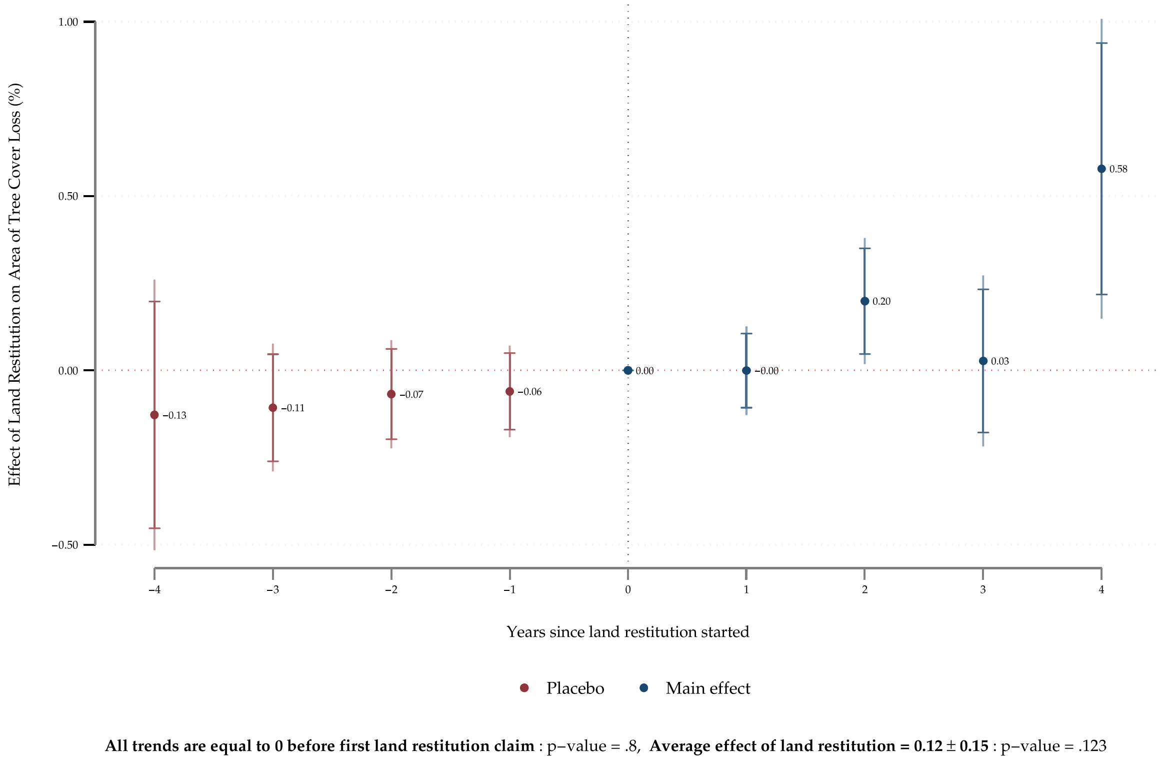


Fig. A.6: Effect of Land Restitution on Tree Cover Loss at the Municipal Level (Full Sample). This figure shows the estimated impact of initiating land restitution on annual tree cover loss across municipalities, using the full sample of municipalities where claims were filed by June 2025. The x-axis indicates the number of years before and after the first land restitution claim was filed, while the y-axis shows the average effect on tree cover loss area. Each dot represents an estimated effect at a specific time. Capped vertical lines show 90% confidence intervals; uncapped longer lines show 95% confidence intervals. Red points reflect pre-treatment differences in trends between municipalities that began processing land restitution claims before 2016 and those that started in 2016 or later. Blue points show the post-treatment effects of initiating land restitution. **Source**: Data compiled by the authors.

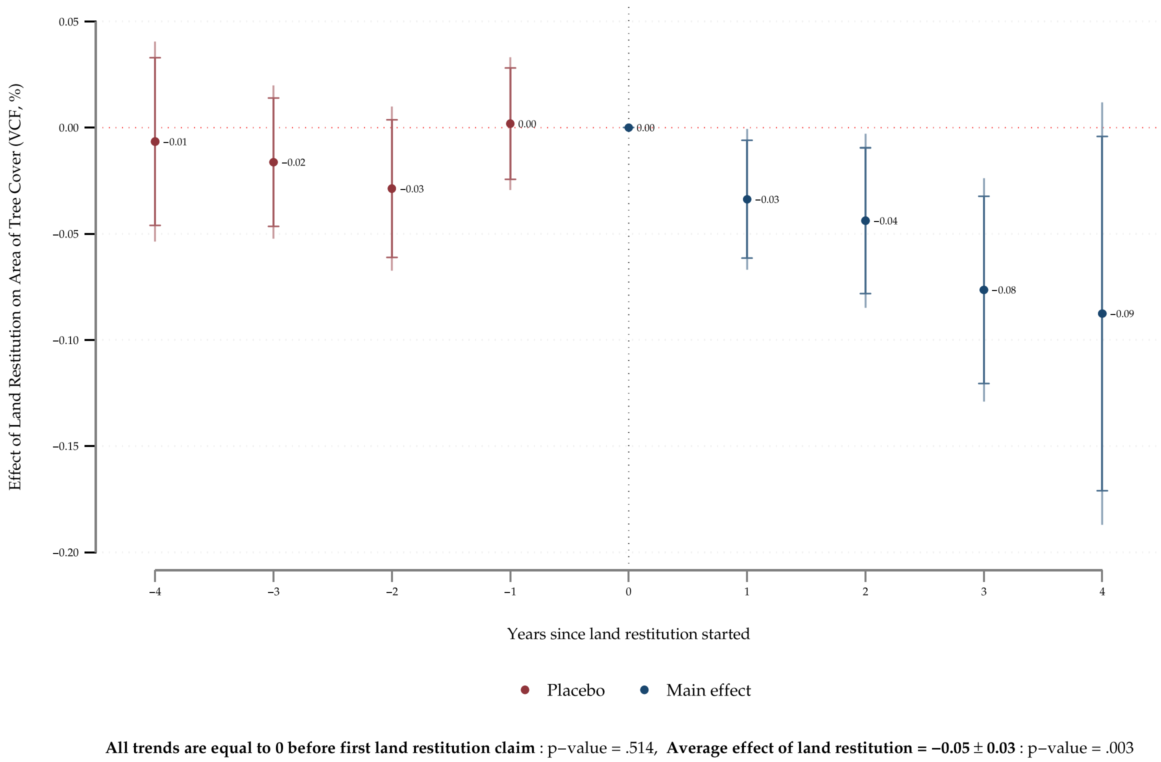


Fig. A.7: Effect of Land Restitution on Tree Cover Area at the Municipal Level (Full Sample). This figure shows the estimated impact of initiating land restitution on annual tree cover area in municipalities, using the full sample of municipalities where claims were filed by June 2025. Tree cover area is estimated using MODIS VCF data. The x-axis shows the number of years before and after the first land restitution claim was filed, while the y-axis reflects the average estimated effect on tree cover area. Each point represents an effect estimate for a given year. Capped vertical lines indicate 90% confidence intervals; uncapped longer lines indicate 95% confidence intervals. Red points capture pre-treatment differences in trends between municipalities that initiated land restitution before 2016 and those that began in 2016 or later. Blue points show the estimated post-treatment effects. **Source**: Data compiled by the authors.

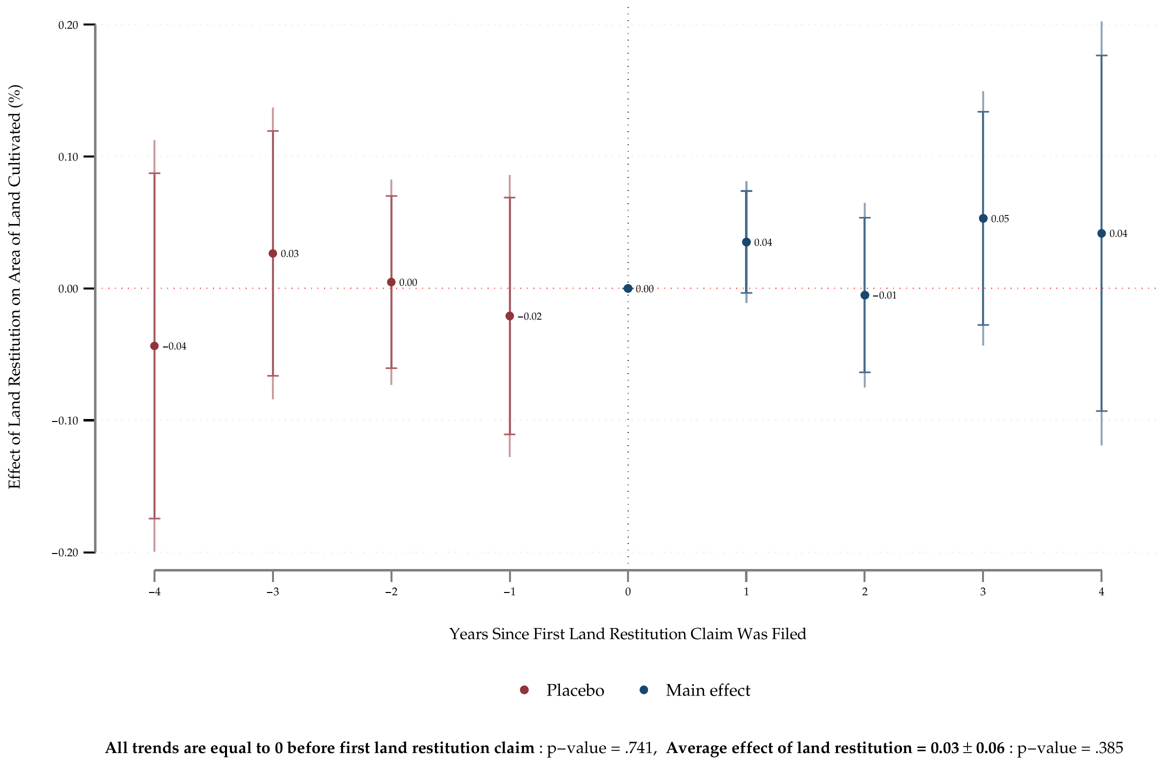
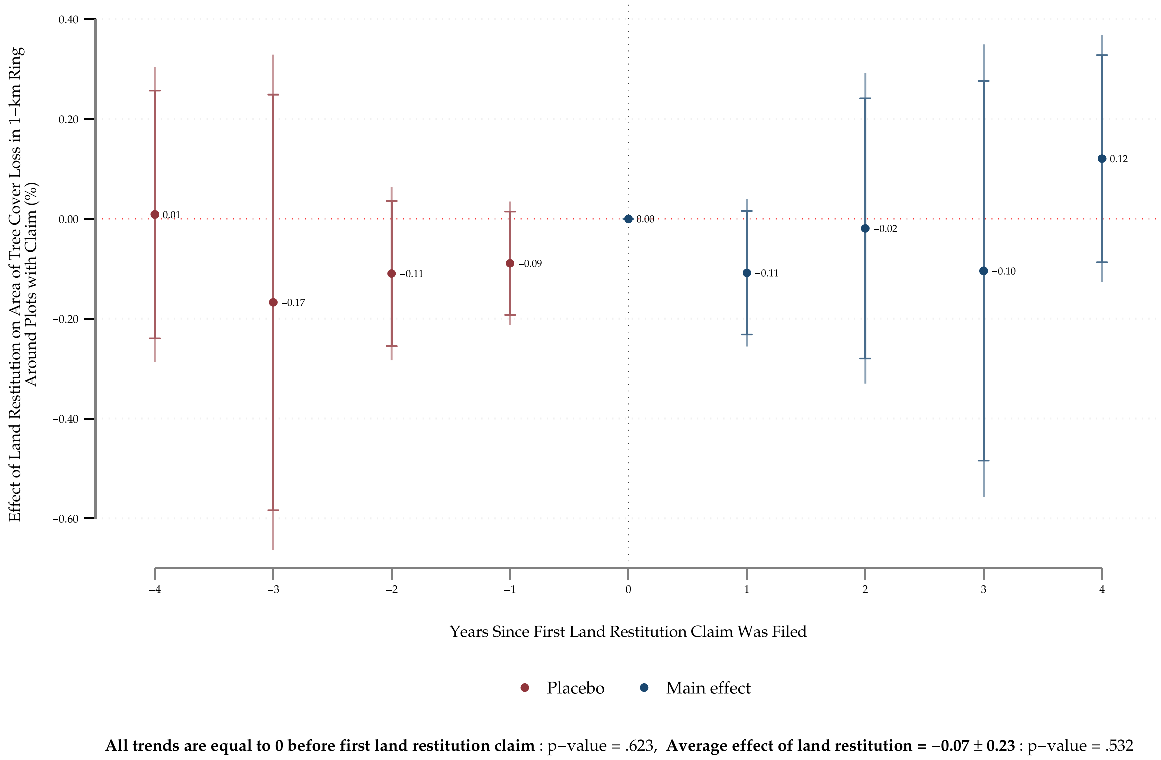
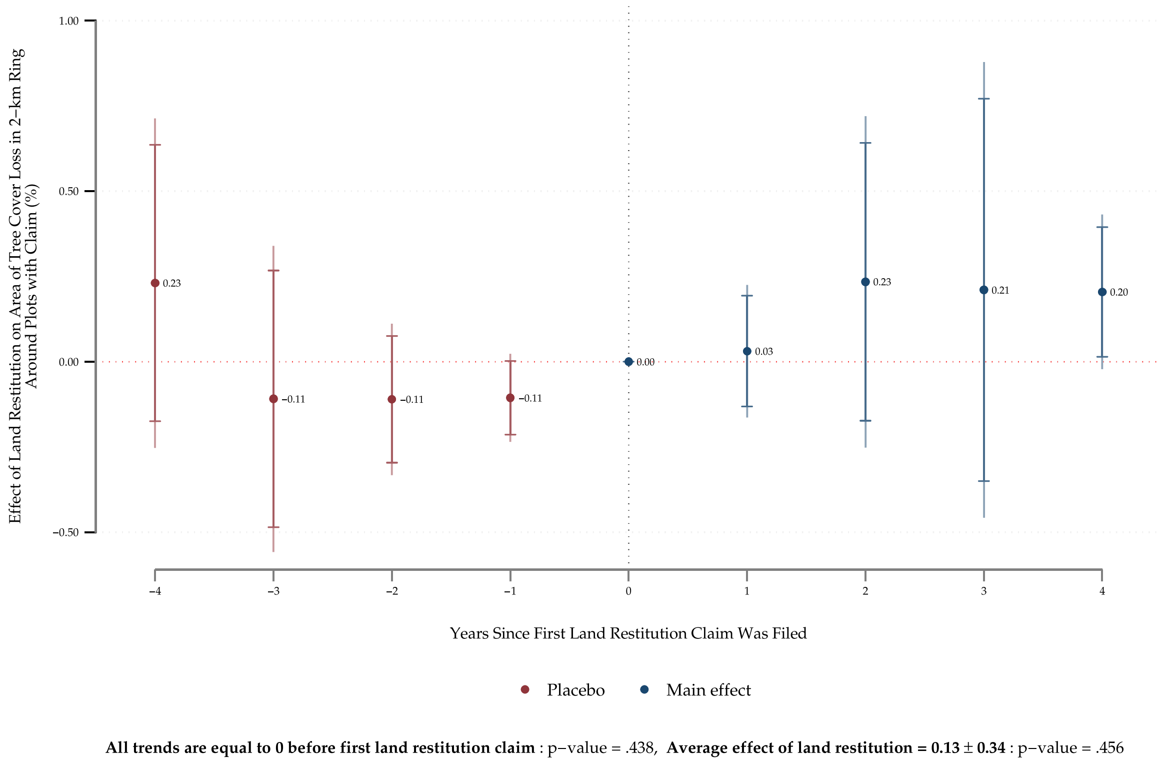


Fig. A.8: Effect of Land Restitution on Land Area Cultivated at the Municipal Level. This figure presents estimated effects of initiating land restitution on the annual area of land cultivated, using data from the CEDE Municipal Panel and the Ministry of Agriculture. The x-axis shows the number of years before and after the first land restitution claim was filed. The y-axis reflects the average estimated effect on the area of land cultivated within each municipality. Each point represents the estimated effect for a specific year. Capped vertical lines indicate 90% confidence intervals; uncapped longer lines represent 95% confidence intervals. Red points reflect pre-treatment differences in trends between municipalities that began processing land restitution claims before 2016 and those that started in 2016 or later; blue points indicate the post-treatment effects of initiating land restitution. **Source**: Data compiled by the authors.

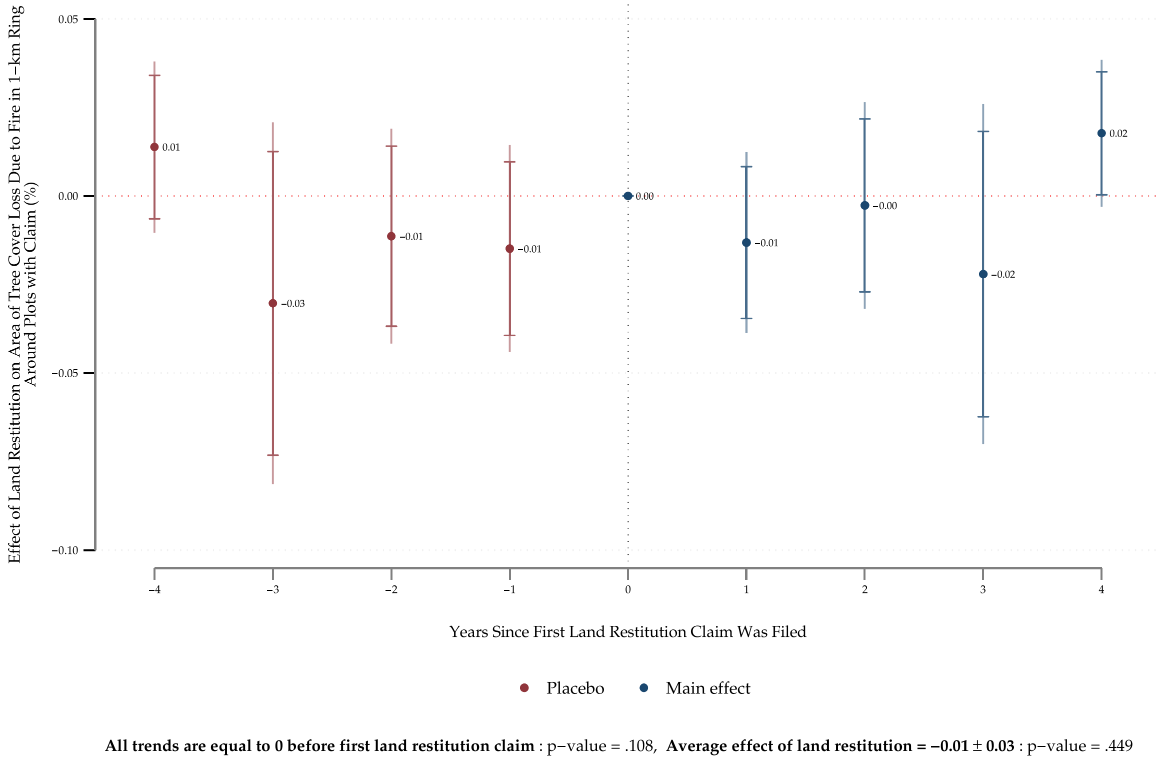


(a) Effect on tree cover loss within a 1-km buffer around plots with a restitution claim.

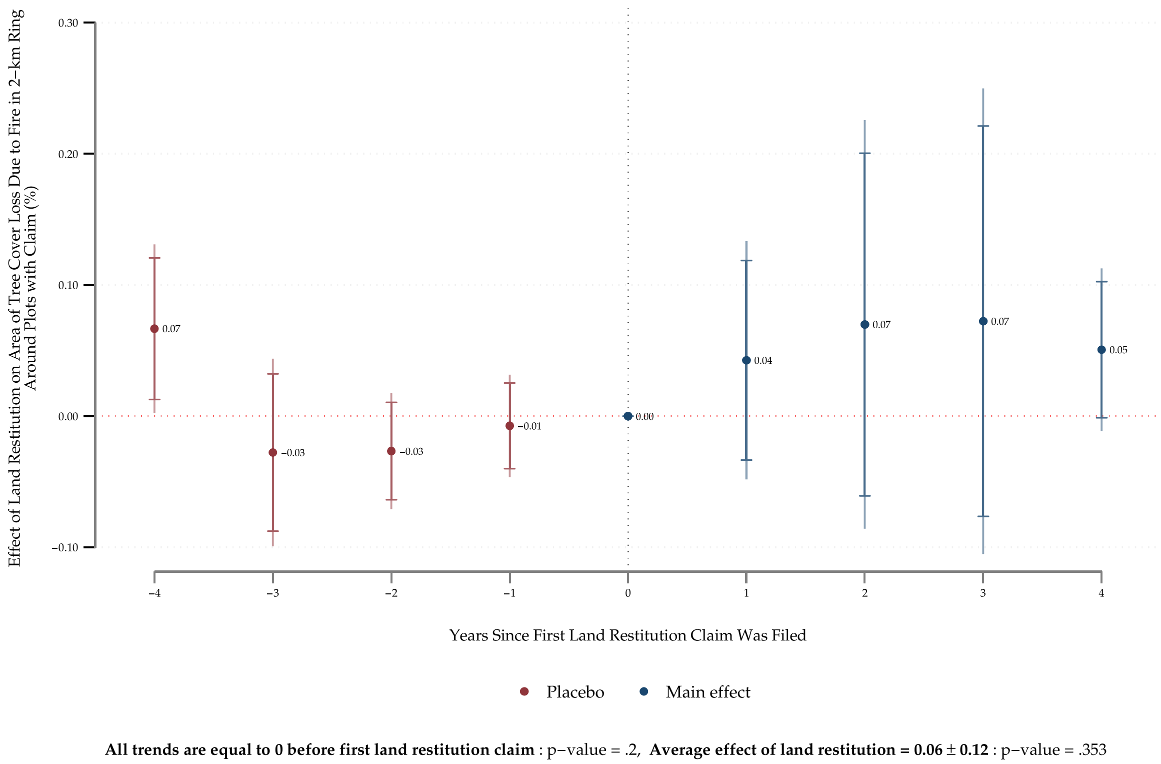


(b) Effect on tree cover loss within a 2-km buffer around plots with a restitution claim.

Fig. A.9: Effect of Land Restitution on Tree Cover Loss in Areas Surrounding Restitution Plots. This figure displays the estimated impact of initiating land restitution on annual tree cover loss in surrounding areas of the claimed plots. Panel (a) presents estimates for a 1-kilometer buffer zone around each plot. Panel (b) extends the analysis to a 2-kilometer buffer. These surrounding areas help assess whether land restitution influences nearby forest clearing beyond the boundaries of the claimed land. **Source**: Data compiled by the authors.



(a) Effect on tree cover loss due to fire within a 1-km buffer around plots with a restitution claim.



(b) Effect on tree cover loss due to fire within a 2-km buffer around plots with a restitution claim.

Fig. A.10: Effect of Land Restitution on Fire-Related Tree Cover Loss in Areas Surrounding Restitution Plots. This figure displays the estimated impact of initiating land restitution on annual fire-related tree cover loss in the surrounding areas of the claimed plots. Panel (a) presents estimates for a 1-kilometer buffer zone around each plot. Panel (b) extends the analysis to a 2-kilometer buffer. These surrounding areas help assess whether land restitution influences nearby forest clearing beyond the boundaries of the claimed land. **Source**: Data compiled by the authors.

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