Conservation policies fail to reduce degradation in the Brazilian Amazon

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Abstract

Forest degradation causes large declines in carbon stocks, biodiversity, and ecosystem services, despite leaving some trees standing. Over the past two decades, numerous conservation policies to halt deforestation have been rolled out, but relatively little attention has been paid to tackling degradation. More information is needed to understand how deforestation and degradation are linked and how ongoing efforts to reduce deforestation are impacting degradation. With a focus on the case of the Brazilian Amazon, a place with highly dynamic deforestation, degradation, and policy conditions, we examine the effects of four types of deforestation policies on both deforestation and anthropogenic degradation. We find that with very few exceptions, both private supply chain policies and public deforestation policy mixes that successfully reduced deforestation failed to reduce anthropogenic forest degradation. This implies that deforestation control policies alone, which are the dominant approach to the conservation of forests, are insufficient to preserve biodiversity and carbon and safeguard forest-dependent livelihoods. Policy approaches that explicitly address fire, logging, fragmentation and other degradation drivers, are urgently needed to address these major gaps in current conservation policy approaches. Government and companies must also include forest degradation emissions in their evaluations of current policy effectiveness towards meeting emission reduction goals.

Significance statement

We show that conservation policies in the Brazilian Amazon that have effectively reduced deforestation have failed to address forest degradation, which continues to harm carbon stocks, biodiversity, and ecosystem services. There is an urgent need for more comprehensive public and private policies that target both deforestation and degradation, including threats like fragmentation, fire and logging, to effectively preserve the Amazon's ecological health and the livelihoods it supports.

1. Introduction

Tropical forests safeguard global biodiversity and carbon stocks and their conservation is essential to human security and wellbeing (1, 2). However, these ecosystems are threatened by persistent deforestation (the complete removal of tree cover) and degradation (a state of reduced ecological functioning) – both of which threaten the wellbeing of forest-dependent and indigenous people living in these regions (3, 4). Between 2003 and 2014, 68.9% of net losses in carbon in tropical forests were attributable to degradation (5-7) and carbon emissions from tropical forest degradation now exceed emissions from deforestation in nearly a third of all tropical countries (8). Additionally, degradation dramatically decreases the ecosystem and biodiversity resilience to climate change (9-11) and brings local income losses, reduces access to critical community resources, and leads to numerous negative health impacts (3, 12, 13).

Degradation is particularly notable in the Amazon Basin —the world's largest remaining tropical forest. Between 1995 and 2017, 17% (1,036,800 ± 24,800 km2) of the forest area in the Amazon basin had been degraded, accounting for 50 to 200 MT C emissions each year (3). By 2050, degradation is projected to affect the entire Brazilian Amazon (14). For comparison, 11% of the Amazon had been deforested (662,600 ± 23,100 km2), resulting in 60 to 210 MT C (3, 15). Because of the larger extent of forest degradation, and because degradation events may occur several times on the same land, carbon emissions from degradation were up to three times those of deforestation between 2010 and 2019 (16), and yet are largely unaccounted for in carbon emission inventories (17).

The causes of Amazon degradation are largely related to droughts, fires, edge effects, logging and overhunting, and their interactions with deforestation and climate change are complex, as extensively reviewed by Lapola*, et al.* (3). Deforestation has been found to fuel degradation at the edges, generating biomass collapse that drives additional emissions. Accounting for this degradation, the emissions associated with deforestation increase by one-third over the whole Amazon (18). Edge effects were the largest single driver of degradation between 1992 and 2014 in the Brazilian Amazon (19). Anthropogenic fires, often set for deforestation or agricultural management, can also intensify forest degradation in multiple ways. Fire has been found to reduce the aboveground carbon density in the Amazon by 75-92% after multiple fire events (20) and its propagation is higher in forest edges caused by deforestation (21, 22). The coupling between fire and deforestation has been more intense in drought years (23).

Cattle and soy production are important contributors to degradation, both as the largest drivers of deforestation in the Amazon (directly leading to microclimate change, defaunation and biodiversity losses), as well as through increased fragmentation and fires at forest edges (3, 13, 17-19, 22, 24-32). At the local level, the haze from fires together with the high share of land converted to pasture and crops enhance the impact of droughts by raising local temperatures and reducing rainfall (29, 33, 34) which in turn increases fragmentation and fires (35). Commodities production also stimulates local development and immigration in a way that increases urbanization and forest accessibility (36, 37), ease hunting (38) and creates the necessary infrastructure and pool of labor that facilitate logging activities and result in associated degradation.

Until the 5th phase of Plan for Prevention and Control of Deforestation in the Amazon (PPCDAm), beginning in 2023, there were few to no policies focused on degradation in the Amazon. Although a new integrated fire control management system is underway, up to now agricultural fire control policies have often been imperfectly implemented and were at time incongruent with local practices and the increased flammability of a the landscape in a changing climate (39-41). Illegal logging is a widespread practice (42) and, to the best of our knowledge, fragmentation remains unaddressed explicitly. Of the REDD+ initiatives deployed on the ground, only few are addressed at reducing degradation (3), and the European Deforestation Regulation (EUDR) only contemplates deforestation from logging and timber production. This leaves deforestation control, often focused on agricultural systems, as the primary tool currently used to achieve reduction in degradation.

To date substantial research has examined the impacts of public and private deforestation policies on deforestation in the Amazon. Evidence indicates that the PPCDAm, a policy mix introduced in 2004, which includes various designs and instruments at multiple scales in the Amazon, successfully reduced deforestation by 60-80% (43-48). The Priority Municipalities program (PM), a specific policy in the broader PPDCAm policy mix, which focused on credit restrictions to entire municipalities, was found to reduce deforestation by 35% (43). Other studies find that the 2006 Soy Moratorium (SoyM), a sector-wide zero-deforestation policy adopted by soy companies, reduced soy-driven deforestation by 30-50% (49, 50). Evidence on the deforestation impacts of bilateral agreements between state prosecutors and individual companies to remediate past harm from illegal conduct, collectively known as the Terms of Adjustment of Conducts for beef (Beef TAC) and grains is yet inconclusive (51). In the cattle sector, the 2009 Cattle agreement (G4) among the four biggest meatpackers (Marfrig, Minerva, JBS, and Bertin—later purchased by JBS, all also signatories of the Beef TAC) and Greenpeace to not source cattle produced on legally or illegally cleared land after 2009 was found to reduce pasture-driven deforestation by 15% (51).

Despite the widespread prevalence of forest degradation in the Brazilian Amazon and its significant impacts on carbon storage and biodiversity, no causal evaluation has been conducted to assess whether policies aimed at halting deforestation have influenced anthropogenic degradation. Addressing this question is critical, as current policies, which predominantly target deforestation, may be insufficient to mitigate forest degradation. If so, they risk failing to achieve their underlying biodiversity and carbon objectives, necessitating a reassessment of their scope to more explicitly incorporate degradation drivers. This has important implications for public policy, corporate zero-deforestation commitments and emerging trade regulations such as the EUDR, as we return to in the discussion.

In this paper we assess the impact of conservation policies on deforestation and anthropogenic degradation in the Brazilian Amazon. Specifically, we distinguish between their effects on overall degradation and degradation net of deforestation—defined as degradation occurring independently of deforestation. This distinction allows us to assess whether conservation policies address degradation only through reduced deforestation or if they also affect other degradation drivers such as fragmentation, agricultural fire use, logging, and hunting (Figure 1 SI). We hypothesize that the PM policy, which increased law enforcement against environmental crimes including illegal fires and logging at the jurisdictional scale, reduced degradation beyond its direct effect on deforestation. In contrast we expect that supply chain policies (SoyM, G4, TAC) only reduce degradation through their effect on reducing deforestation, with little additional impact on degradation net of deforestation, since degradation drivers often extend beyond property boundaries and operate at the landscape scale (3).

Our analysis focuses on the Amazonian portion of Pará, Rondônia and Mato Grosso (Figure 1). This region encompasses a significant portion of the Amazonian “Arc of Deforestation,” where deforestation has historically been most intense in the Brazilian Amazon. Deforestation and degradation data are sourced from Vancutsem*, et al.* (52), defining deforestation as the clear-cutting of either intact or degraded forest, and degradation as a disturbance that does not result in clear-cutting within the following two years. We define deforestation (of both intact and degraded forest) and degradation as the annual rate of change relative to the previous year’s level. Fires are measured as the density per hectare of high confidence fire hotspots from Modis collection 6.1, NASA (53) and logging is recorded as the volume of timber extraction from IBGE (54) per hectare of forest.

We estimate the impact of policies using an event-study design at the municipality level, accounting for the staggered timing of policy implementation. For each cohort of municipalities undergoing a policy change in the same year, the before-after variation in outcomes is compared to that in municipalities without a policy change. The cohort-specific event study estimates are then averaged across cohorts for each relative time periods since inception. In this design municipalities that are never treated or not yet treated are counterfactual for the treated municipalities under the assumption that treated municipalities would have followed the same trends as untreated had there been no policy (parallel trends assumption - PTA) and that there has been no spillover across units. The degradation data from Vancutsem*, et al.* (52) capture both anthropogenic drivers and natural variability. We obtain anthropogenic degradation statistically, under the assumption that natural variation in degradation due to factors that are common to treated and control units, such as climate extremes, are equally affecting treated and control units after controlling for regional variations in temperature and water balance through SPEI (55) and initial forest stocks through nonparametric land use trends (see method). As a result, natural variation in degradation is accounted for through differencing in both before-after and treatment-control comparisons and the residual variation is attributed to anthropogenic activity (similar to the residual analysis proposed by Evans and Geerken (56)). Thus, the detected policy impacts reflect changes in deforestation and anthropogenic forest degradation and are unlikely to be confounded by spurious correlations with droughts.

Although we use a difference-in-differences approach, our policy impact estimates may still be confounded by selection or targeting effects. For instance, companies adopting supply chain policies might avoid sourcing from high-deforestation areas or prefer more productive regions with recent clearing. We address these potential sources of endogeneity by taking the one-year lag of the policy variables, and by comparing only municipalities with similar pre-policy forest cover levels through land use trends. Should there be selection effects, estimates with and without land use trends differ, and provide upper and lower bound estimates (see methods). We also control for the value of cattle and soy produced in each year, a proxy for productivity, and other policies, including the proportion of land in protected area or indigenous land. In the models for supply chain policies we also control for the number of fines as a proxy for environmental law enforcement - the latter control is omitted from the analysis of PMs, as increased enforcement is part of the program. We follow Assunção and Rocha (43) approach to address spillover concerns by restricting the counterfactual sample for the PM to second order neighbors (see method). We also do not include in the control group not-yet-treated observations, as these might experience higher deforestation rates due to targeting. Finally, we find little evidence of selection effects for most policies, with the exception of TAC. We assess this by comparing policy expansion with historical forest cover, deforestation, and degradation rates (SI 3b). To further separate selection effects from policy impacts, we contrast TAC and G4 market share increases (above 75th vs. below 50th percentiles) with the presence of companies (>0% threshold), which captures selection effects due to sourcing behavior (SI 3d).

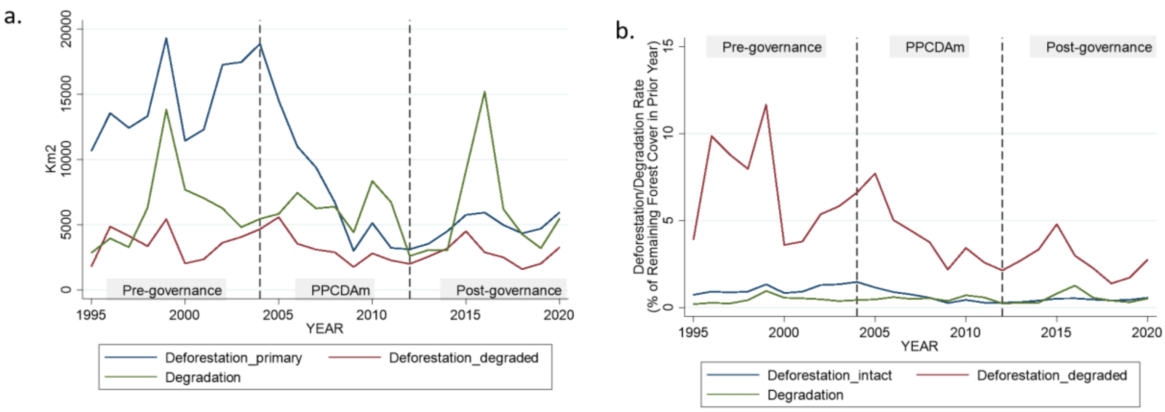
For each policy and outcome we provide estimates for four specifications: with all controls and without controls (except SPEI), and with and without land use trends. Policy implementation may take time, and its impacts can be immediate, gradual, or sustained over time. Additionally, policy effects on degradation may either intensify or diminish when interacting with drought events. We are agnostic about these processes, and we present results for varying time windows of 3, 5 years and the maximum number of years since inception (10 years for SoyM and PM, and 7 years for G4 and TAC).

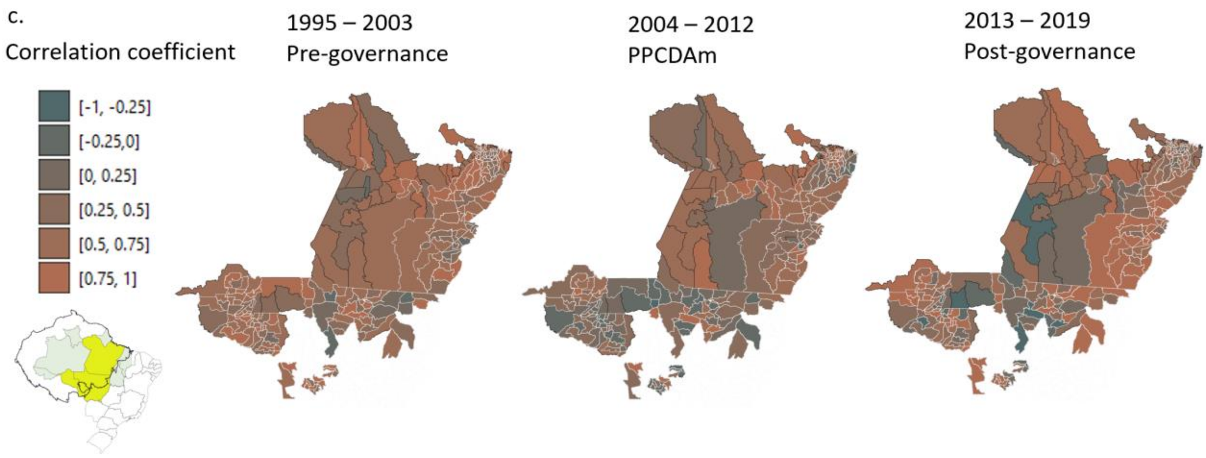
2. Results

a. Deforestation and degradation coupling and decoupling patterns in the study area

Deforestation rates of degraded forests were about one order of magnitude higher than those of intact forests. Much degradation happens in the vicinity of roads and farmland (3), which are also high-risk areas for deforestation. Much deforestation may also be taking place through progressive degradation spanning beyond the two years embedded in the degradation definition of Vancutsem*, et al.* (52) data. The overall area of deforestation of degraded forest was stable across policy periods, yet rates were decreasing because degradation of intact forests was higher than its clearing at every year, resulting in a cumulative increase of degraded forests stock (figure 1a, 1b). We categorize three policy periods based on governance quality Garrett*, et al.* (57): pre-governance, PPCDAm, and post-governance, the latter marked by progressive deregulation. The relationship between deforestation and degradation fluctuated significantly across space and time (Figure 1c). The correlation between deforestation and degradation was weakest (decoupling) during the PPCDAm phase, suggesting that reducing deforestation did not necessarily reduce degradation. During the post-governance period, when deforestation was at its lowest, areas with below-average deforestation rates exhibited a 17% lower correlation (p<0.1) between deforestation and degradation compared to those with above-average deforestation (white-bordered municipalities in Figure 1c, test results in Table SI 2). This further supports the persistence of degradation despite reductions in deforestation.

Figure 1 Coupling and decoupling of deforestation and degradation along the Arc of deforestation.





Panels a and b display degradation and deforestation trends from Vancutsem et al. (2021) in the study regions, measured in km² and rates, respectively. Vertical lines mark three governance phases: (1) pre-PPCDAm, (2) PPCDAm implementation until the deforestation minimum in 2012 (coinciding with the New Forest Code approval), and (3) the post-governance period (2013 onward). **Panel c** presents within-municipality temporal correlations between deforestation and degradation rates across the three policy phases (Table SI 2). Dark blue areas indicate negative correlations (i.e., decoupling), which are more pronounced during the PPCDAm and post-governance periods. Municipalities with above-average deforestation have white borders, while others are outlined in black. The study area includes the Amazonian states of Pará, Rondônia, and Mato Grosso (highlighted in yellow), situated within the Amazon biome (outlined in thick black).

b. Conservation policies reduced deforestation, mostly in intact forests

Event study regressions indicate that all policies reduced deforestation within specific time windows and model specifications (Figure SI 4). Cattle supply chain policies are more effective in intact than in degraded forests (Figure SI 4d). G4's impact remained consistent across time periods, with upper-bound estimates aligning with Levy, Cammelli, Munger, Gibbs and Garrett (51). The impact of G4 is likely conservative, as its expansion was concentrated in high-deforestation areas. While deforestation rates in G4-covered areas remained elevated, the counterfactual deforestation levels would have been even higher (Figure SI 2 and 3). TAC estimates frequently violated the PTA for both overall deforestation and deforestation in degraded forests. However, TAC consistently reduced deforestation in intact forests, particularly in the short term (Figure SI 4d). The PTA violations for TAC, and to some extent G4, likely stem from prosecutors initially targeting slaughterhouses most responsible for deforestation (58, 59), and possibly those located around intact areas more than those located around degraded areas.
In contrast to cattle policies, SoyM and PM effectively reduced deforestation in both intact and degraded forests (Figure SI 4d). SoyM had the strongest overall impact on deforestation reduction, and the size is consistent with Gollnow, Cammelli, Carlson and Garrett (49). PM primarily reduced deforestation in its early years, with effects lasting until 2016 (Table SI 8), and the effect size is similar to Assunção and Rocha (43).

c. Supply chain policies had no direct impact on degradation beyond deforestation control

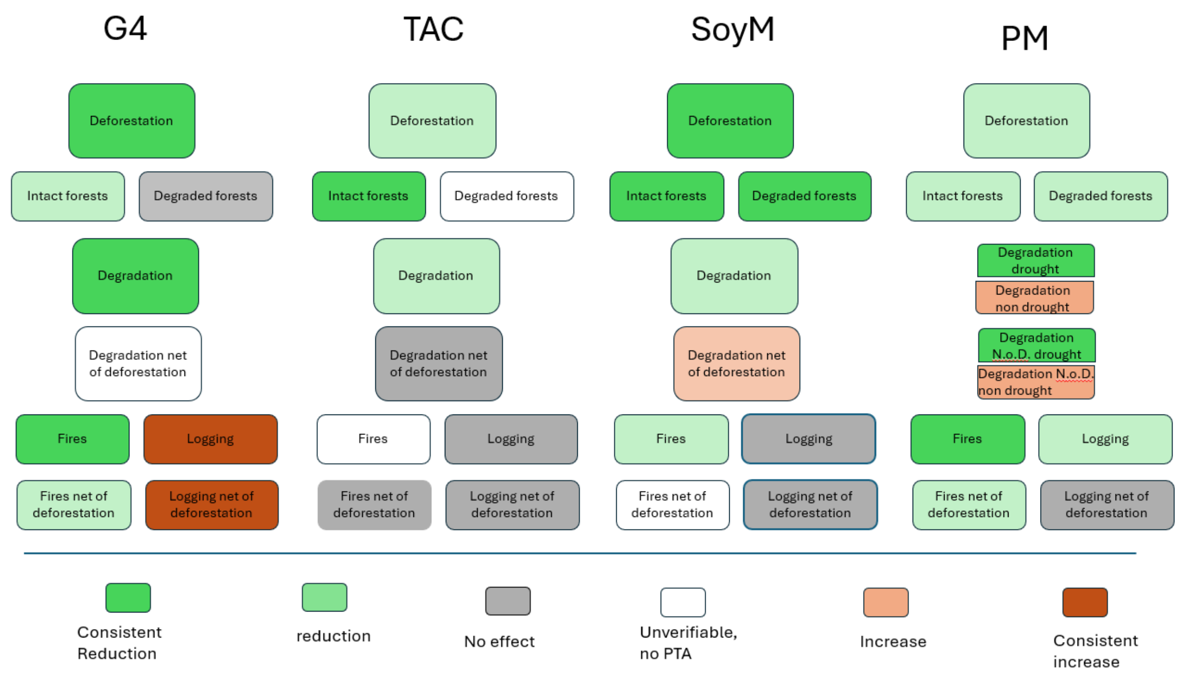
While all supply chain policies reduced degradation, we found no evidence that they lowered degradation independent of deforestation (Figure 2).

Despite its short-term effects on fires and logging independent of deforestation (Figure SI 4d), this increase may be linked to greater fragmentation. This could stem from its focus on soy-related clearing while neglecting deforestation for other land uses within the same properties.

TAC reduces degradation only in the short term, while G4 reduces degradation across all periods possibly as a result of pasture intensification (60). However, TAC appeared to increase degradation net of deforestation, while G4 never met the PTA for this outcome. we compared results from areas with a high market share of committed companies to those where such companies were merely present (above a zero-percent threshold). Change in the presence of these companies reflects a change in sourcing patterns but is not expected to influence outcomes. Instead, it serves as an indicator of selection effects—either towards or away from deforestation or degradation. We find that while effects on overall degradation are valid, the effects of TAC and G4 on forest degradation net of deforestation are compatible with selection effects (Figure SI 3), and are therefore likely spurious. G4 but not TAC caused a reduction in fires both alone and when controlling for deforestation, but the latter effect is compatible with selection effects too. G4 unexpectedly increased timber extraction in a way not explained by selection effects (Figure SI 3), possibly due to a shift in factors of production from cattle ranching to the timber sector.

Overall, we find little to no evidence that any supply chain policy effectively reduced degradation beyond its impact on deforestation. Moreover, our findings suggest that SoyM may have inadvertently increased degradation independent of deforestation, while G4 may have contributed to increased logging.

Figure 2 Qualitative summary of policies effects on deforestation, degradation, fires and logging.



d. The PM program did not reduce degradation in average years, but it outperformed counterfactual municipalities during the 2015-2016 drought

The PM program, which enforces multiple environmental regulations at the jurisdictional level, reduced degradation and degradation net of deforestation in the long term but increased both in the short and medium term (Figure 2). This stands at odds with a consistent negative impact on fires and fires net of deforestation in the medium and long term and on logging and logging net of deforestation (Figure SI 3). The long-term reversal was largely due to PM's strong negative impact on degradation during the 2015-2016 drought, six and seven years after the main cohort of 30 municipalities was blacklisted (Tables SI 10, SI 13). We conclude that the PM program had a unique negative effect on degradation and degradation net of deforestation during the major drought years 2015-2016.

3. Discussion

a. Deforestation control alone cannot curb degradation, leading to ongoing biodiversity loss and carbon emissions

Previous studies have shown a growing decoupling of deforestation and degradation over time (15, 16, 19) alongside rising anthropogenic fires linked to droughts (61). This suggests that the drivers of deforestation and degradation differ, meaning policies effective against one may not address the other. This study provides the first counterfactual analysis evaluating whether deforestation-focused public and private policies also mitigate forest degradation and its drivers. While all policies reduced deforestation and, to some extent, degradation, none significantly decreased degradation net of deforestation—except for the PM program during the 2015-2016 drought. The SoyM may have caused additional degradation net of deforestation due to its narrow scope on sub-property soy fields (i.e. disregarding other property level deforestation or degradation). G4 appears to have driven higher timber extraction, likely due to a shift in economic activity from cattle ranching to logging. The divergence in policy impacts suggests that deforestation and degradation have historically been treated as separate issues, potentially competing for policy attention, as tackling one does not automatically resolve the other (62).

Our finding that G4 reduced overall degradation and fires in the long term, while TAC did not could be due to their distinct patterns of expansion into areas with varying deforestation and degradation rates (SI 3b 3c), as well as the differences in the size of the companies involved and the timing and stringency of the policy efforts. Although G4 companies also signed TAC, G4 implementation began earlier, and it has been found to have spurred cattle intensification (60), which may in turn, through mechanization and infrastructure investments may have led to lower fire use and higher fire control investments (40, 63). There is no evidence that this has happened in areas dominated by slaughterhouses that only signed TAC (64), which tended to be dominated by suppliers that are on average 42% smaller than G4 (SI 3g), and as such more likely to use fire (65). However, these explanations are speculative and require further exploration.

Our results indicate that policy-driven deforestation reductions occurred primarily in intact forests, whereas clearing rates in degraded forests remained higher and more stable. This suggests that degraded forests—often closer to already deforested areas (21, 61, 66),—remained more attractive for clearing. Their proximity to already cleared land likely lowered deforestation opportunity costs and diminished policy effectiveness.

We anticipated that the public PM program would curb degradation by enhancing enforcement against environmental crimes and restricting credit at the jurisdictional level, where degradation drivers interact more strongly than at the property level—the focus of supply chain policies. However, we find that the program only reduced degradation during the extreme drought years of 2015-2016, when annual degradation surged three and fivefold compared to 2014. While the program targeted all environmental crimes, municipalities were removed from the blacklist based solely on deforestation metrics. Nevertheless, the PM program reduced logged volumes and fires independently of deforestation but did not curb degradation in non-drought years. These findings highlight the pressing need to incorporate restoration efforts into the PM policy to address ongoing degradation caused by fragmentation.

b. Extending the scope and target of forest conservation policies towards degradation

Targeting degradation at the local level presents insidious challenges, because it is the result of several interrelated drivers interacting at multiple scales and generating complex liabilities (cf. 67). Fortunately, many policy changes have been recently adopted that hold some promise for tackling degradation. Below we discuss these changes and make suggestions for their implementation and alongside other policy improvements.

In 2023, the PM program was updated (Decree n 11,687/2023) to include forest degradation among the criteria for inclusion and exclusion from the blacklist. According to the new regulation, municipalities exceeding 80 km^2/year of degradation will be blacklisted regardless of their deforestation performance and will need to reduce degradation to less than 40 km^2/year to exit the program (MMA 983/2023). Additionally, municipalities will receive capacity-building and resources to monitor and mitigate both deforestation and degradation, including the establishment of fire brigades (MMA 1030/2024). This is a promising development, as the underlying drivers of degradation—such as logging and fires—are complex and are best addressed at the landscape scale through cross-sector collaboration. Moreover, by actively involving municipalities in policymaking, the program has the potential to spur substantial innovation in policy implementation (68). Notably, the degradation monitoring systems developed for this program could also be adopted by supply chain actors, enabling them to incorporate degradation into their sourcing commitments, further amplifying the program's impact.

Enforcement of the Forest Code norms and implementation of the newly instituted Integrated Fire Management Policy (Law 14.944/2024) that ban unauthorized fire use, and prescribe control measures for authorized fires, would also be promising avenues: between 2002 and 2019, all intense forest fires detected in the Legal Amazon occurred within 0.5 km of forest edges (21), highlighting that agricultural fires are major ignition sources for forest fires. Landowners could be incentivized to cluster their forest reserve into contiguous areas to minimize fragmentation and edge effects, decreasing susceptibility to fires. This could be achieved through land use zoning and agglomeration incentives that reduce fragmentation within and across properties e.g. incentivizing land regularization through restoration or off-farm reserve compensation of continuous forest patches (cf. 69, 70). On the other hand, to avoid negative livelihood impacts on fire-dependent smallholders, fire risk mitigation policies must be coupled with the provision of sufficient training and equipment to adopt safe agricultural fire management practices or fire-free agricultural technologies (12), noting that fire bans alone have proven neither enforceable nor effective (71, 72).

Companies net zero policies need to encompass forest degradation emissions in line with the Science-Based Targets for Forest, Land, and Agriculture (73), and extend their sourcing policies requirements to exclude unauthorized and unsafe use of fire, in line with the Brazilian law (41) though this will require significant investment in monitoring data that is rapidly available for companies to incorporate into their procurement systems. Similar to deforestation criteria, a grievance mechanism should be in place to detect false positives, or when the farmer is not the liable individual (cf. 67). Stricter requirements and controls are also needed in the timber supply chain (including through PMs) to confine these activities within designated concessions and volumes (74), yet the sector has recently been deregulated, and sectoral policies are largely insufficient (42, 75, 76).

c. Implications for emerging zero-deforestation trade policies

These findings have important implications for the EU Deforestation Regulation (EUDR) and similar legislation in the US and UK, which ban imports of commodities causing deforestation and degradation (77). The EU defines forest degradation as the conversion of primary or regenerating forests to other wooded land or planted forest and applies it only to timber products. This definition is too narrow to effectively reduce emissions from deforestation and degradation because it does not address major drivers of anthropogenic degradation in the Amazon, such as fires and fragmentation driven by soy and beef production. Furthermore, degradation should be understood as a landscape level phenomenon, which requires a cross-supply chain and jurisdictional approach. To more effectively address forest degradation, the EU would need to: expand the EUDR definition of degradation, including major drivers of degradation such as fragmentation and fires, expanding the scope of forest degradation impacts beyond timber, and adopt a subnational benchmarking system that includes landscape level forest degradation (e.g., at municipality level).

4. Conclusion

Preserving carbon-rich and biodiverse ecosystems is more critical than ever before. In the Brazilian Amazon, policies have primarily focused on reducing deforestation to achieve this goals. However, growing evidence indicates that biodiversity loss and carbon emissions from large-scale forest degradation can be equally or even more significant than those from deforestation (3, 9, 11, 15, 16, 19). Despite this, degradation and non-deforestation fires remain largely overlooked in policy discussions (67, 78) and persist even after reductions in deforestation. Moreover, these emissions are inadequately accounted for in carbon inventories and climate policies (cf. 3, 17, 18), leading to inflated carbon budgets, insufficient nationally determined contributions under the Paris Agreement, and ineffective corporate net-zero pledges. Consequently, policies that focus solely on deforestation are failing to fully achieve their overarching goals of preserving carbon stocks and protecting biodiversity.

This presents both a challenge and an opportunity. The challenge lies in the fact that the drivers of deforestation and degradation differ, necessitating policies that address both processes simultaneously while considering their distinct underlying causes. The opportunity arises from the potential efficiency gains in environmental policy by incorporating degradation mitigation. The opportunity costs of preventing degradation are largely limited to selective logging and game hunting, whereas protecting and restoring degraded forests can reduce fire risk and enhance the provision of non-timber forest products. Strengthening policies to address degradation offers a cost-effective and impactful pathway to improving conservation and climate outcomes. Greater integration of degradation mitigation into conservation and climate policy is therefore urgently needed.

5. Methods

We assess the impact of conservation policies on both deforestation and degradation in the Amazon and test the hypotheses that policies reducing deforestation (P1) do not significantly affect anthropogenic degradation beyond their impact on deforestation (i.e., degradation net of deforestation) (P2). An exception is expected for the PM jurisdictional policy (P3), which may influence degradation through additional mechanisms beyond deforestation control. We complement the analysis of degradation examining impacts on logging, fires, and deforestation split by intact and degraded forest. Deforestation and degradation are measured as rate of change with respect to forest and intact forest in the previous year. Fires are measured as yearly count per hectare of municipality, and timber extraction is measured in value of timber extraction per hectare of forest. To assess P2 we run separate models for deforestation, degradation and on degradation while controlling for deforestation using a standard mediation procedure (79, 80) where including deforestation as a covariate isolates the policy impact on degradation that occurs independently of deforestation (solid black lines in Figure SI 1), and therefore measures the policy impact through the other channels (gray dotted lines in Figure SI 1). Conversely, omitting deforestation measures the full policy impact on degradation, including all indirect effects via deforestation (solid and dotted lines in Figure 1 SI).

We define private policiey treatment as a binary variable which takes value 1 if the collective sourcing market share of committed companies within a municipality is higher than a threshold (an approach laid out in 49, 51, 81). We consider relative thresholds based on the market share distribution: above vs below 0, above vs below the 50th percentile and above the 75th percentile vs below the 50th percentile for TAC and G4; and only above vs below the 50th percentile for the SoyM, as its market share is skewed and bimodal (see 49). We conduct the analysis of soy and cattle policies only in municipalities that produced soy or cattle during the study period (for the latter we only exclude the Marajó region in Pará). To study the effects of the Brazilian government's PMs program on deforestation we use the same identification strategy employed by Assunção and Rocha (43), by comparing treated municipalities with their second order neighbors (the neighbors of the neighbors) – thereby avoiding confoundedness from spillovers. The effect of the Soy Moratorium (SoyM) is examined from 2007 to 2019, the effect of the cattle company policies (G4 and TAC) is examined from 2010 to 2019, and the effect of the PM program is examined from 2008 to 2019.

We estimated the impact of all policies using an event study design in which municipalities are treated at different points in time or are never treated. We followed Levy et al. (2023) and evaluated TAC and G4 separately because, unlike all other TAC signatories, the companies involved in G4 were much larger, committed to zero gross and not zero illegal deforestation, and started monitoring suppliers earlier. TAC and G4 market shares varied substantially over time, and therefore treatment could switch on and off several times over the study period. We used the De Chaisemartin and d'Haultfoeuille (82) and the Callaway and Sant'Anna (83) estimators, which are robust to dynamic and heterogeneous treatment effects, and the first allows treatment to switch on and off. This method relies on the assumption of pre-treatment parallel trends between treated and control municipalities. However, municipalities are likely to exhibit different levels of production and productivity (84, 85). By construction, if they had different forest cover at the start of policy implementation, they must have experienced different historical deforestation rates and trends at some point in the past. Furthermore, different land-use histories make it unlikely that deforestation-control policies were randomly assigned, which may lead to reverse causality. TAC, G4, and SoyM sourcing may be concentrated in more productive areas and farms that are already compliant, while the PM program targeted areas with higher absolute deforestation. We control for the value of cattle and soy produced each year as a proxy for productivity and lag all potentially endogenous treatment and control variables by one year. We further control for uneven land use history by comparing municipalities that had a similar forest cover share before the policies' introduction by controlling for a non-parametric land use trend, i.e. interacting a categorical variable for each decile of forest cover share in 2005 with a year indicator variable (the general approach is laid out in the appendix of 82 2024). The inclusion of land-use trends estimates effects within municipalities with the same deciles of 2005 forest cover share and therefore controls for selective treatment across deciles. This results into conservative estimates because it ignores genuine impacts occurring between land use deciles. If the effect of the base model is higher than that of the model including land-use trends, most of the policy effect was likely driven by an effect between land-use deciles. The latter may be a genuine effect, or the result of selection away from areas with more deforestation. Conversely, if the effect is higher in the model with land-use trends, this may indicate selection toward areas with higher deforestation and productivity, whereby effects between land-use deciles bias estimates upward. As such, results with and without land use trends have a bracketing property, providing a lower and upper bound estimate of the actual policy effect.

We further include controls as described in Section 2. The dependent variables are deforestation (of overall, intact and degraded forest), degradation rates, volume of timber extracted per hectare, and the density of fire hotspots per ha. In all models, units are weighted by the average denominator of the respective dependent variable during the study period in each municipality. Therefore, estimates can be interpreted as the proportion of area change (86). We test the robustness of our results by dropping all controls except for the SPEI index, capturing cross sectional variation in natural drivers of degradation. Full results are provided in Section SI 3f.

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Competing Interests Statement

Rachael Devorah Garrett holds the following additional affiliations, none of which provided oversight over the content of the manuscript

- Advisory Board, Cambridge Institue for Sustainability Leadership Nature Finance Initiative
- Scientific Advisory Board, RAINFOREST BUILDER
- Co-chair of the Scientific Steering Committee Member, Global Land Programme
- Advisory board, “No Trees, No Future – Unlocking the full potential of conservation finance”
- Science Panel Member - United Nations Science Panel for the Amazon
- Research Council Member - Evidensia (Nonprofit institute to provide credible evidence on supply chain initiatives)
- Advisory Council Member - United Nations Forum on Sustainable Standards

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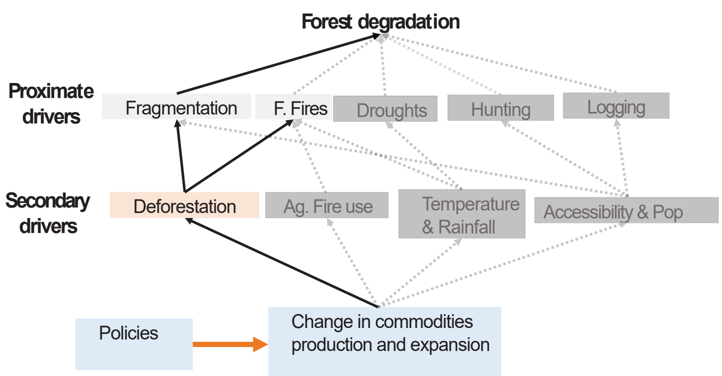
Supplementary materials

1. A conceptual model of the impact of zero-deforestation policies on direct and indirect drivers of forest degradation

We synthesize the existing literature to draw a schematic representation of the proximate and indirect drivers of degradation, highlighting the underlying role of commodity production on degradation and the potential of both public and private policies to reduce degradation (Figure SI 1).

Figure SI 1 Commodities production and policies influence forest degradation



Forest degradation is the outcome of a set of interrelated proximate drivers that act in a self-reinforcing manner (1-3). Increased fragmentation, logging and droughts facilitate the ignition and spread of agricultural fires into forests (4-9). Droughts are largely related to natural climatic oscillations (10), however, at the small scale haze from fires together with the high share of land converted to pasture and crops enhance the impact of droughts by raising local temperatures and reducing rainfall (11-13) which in turn increases fragmentation and fires (14). Increased deforestation and population accentuate hunting pressure, which together with fires and fragmentation reduces the presence of large vertebrates which are responsible for the dispersal of large seeded species, reducing recruit of high wood biomass species and carbon stocks (15, 16).

Commodity expansion exacerbates degradation through three pathways, first as the primary driver of deforestation (17-19), second as a major driver of fire usage, alongside swidden agricultural production (20, 21), and third as a driver of regional development (infrastructure and population). Deforestation is the main direct driver of forest fragmentation and increases the likelihood of forest fires spreading. However not all fires are related to deforestation (22). The total area burnt between 2008 and 2019 in the Amazon biome was more than 10 times larger than the total deforested area.[1] These fires cause substantial additional degradation and

[1] Burnt area data from INPE (https://terrabrasilis.dpi.inpe.br/queimadasqueimadas/aq1km) reveals that 815,001 km^2 burned between 2008 and 2019 in the Amazon biome, equivalent to 19,4% of the area. According to PRODES data

emissions beyond their contribution to deforestation (7, 23-28). Depending on the climatic conditions and on farmers' fire control efforts, agricultural fires may stay within the intended area, or escape, negatively affecting extensive regions of neighboring farms and forests (29). In the 2019 fire season, large and medium landholdings accounted for the majority of the detected fires (30), reflecting the responsibility of large scale commodity production on (intended or unintended) fires. Finally, commodities production stimulates local development and immigration in a way that increases urbanization and forest accessibility (31, 32), ease hunting (16) and creates the necessary infrastructure and pool of labor that facilitate logging activities.

2. Assessing policies impacts on deforestation and degradation

a. Identification and estimation

i. Design and counterfactual

We measure policy impact in an event study design, where municipalities experience treatment at different points in time. Treated and untreated units are assumed to have the same pre-treatment trends (*Parallel Trend Assumption* - PTA), and to experience no treatment spillovers (*Stable Unit Treatment Value* – SUTVA), as we return to below.

We measure private commitments through their market share, i.e. the share of sales to committed buyers in a municipality. Treatment and counterfactuals are defined by the different exposure to commitments over time rather than on a pre-post comparison of areas in and outside companies' supply sheds or on biomes that are covered or not by commitments (e.g. 33, 34). This approach suggests that counterfactual and treatment areas are more similar to each other - and therefore more likely to satisfy parallel trends - than in previous work. However, it could be that the observed market share is the result of companies sourcing away from deforestation or towards more productive areas (where deforestation is more likely), or of farmers selling away from committed companies. Such double selection effect would create reverse causality, a risk which appears particularly prominent when measuring commitments through their market share (33, 35). Turning to priority municipalities we face a problem of targeting. Municipalities entering the Priority list of the Ministry of the Environment need to exceed a set of deforestation criteria which include the overall area deforested, the amount of land cleared in the previous three years and the deforestation rate in the previous 5 years. We tackle the issue of treatment endogeneity in two ways. First by resorting to a temporal lag between the treatment and the dependent variable. Using lagged treatment is only valid up to a certain level of forward thinking behavior of producers and companies. Should farmers anticipate policies, they may avert their impact by changing behavior. Similarly, polices may be implemented with an outlook on future deforestation, rather than current deforestation. We estimate dynamic effects and placebo tests (impacts had there been a policy prior to policy implementation), which jointly test for PTA and anticipating behavior (36), validating the lagged approach. Second, we control for the different land use history prior to treatment

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(http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/amazon/increments) and in the same period, 80,476 km^2 were deforested, a surface equivalent to 1.9% of the biome, i.e. accounting for 9.9% of the burnt area. (Last access 14/09/2020) implementation through non-parametric land use trends for each decile of the share of area in use in 2000, and allow parallel trends to differ across regions with different levels of forest cover, under the assumption that trends are parallel within regions that had similar forest cover share (37).

Testing policies' impact on degradation on the other hand is a simpler endeavor because policies do not target explicitly degradation, but only deforestation, and the former is less likely to be endogenous than the latter. Yet there could be a backdoor path that make policies endogenous to degradation, via deforestation. Therefore, we apply the same identification strategy and model specification for deforestation and degradation.

An additional concern is the potential for violation of PTA and SUTVA via spillovers and leakage i.e. decreased or increased deforestation in the neighborhood of the areas targeted by the policy as a result of treatment contamination or of deforestation displacement. For instance previous studies on PMs found positive spillovers to adjacent municipalities (38-40). Gollnow, Cammelli, Carlson and Garrett (41), Levy, Cammelli, Munger, Gibbs and Garrett (42) and Heilmayr, Rausch, Munger and Gibbs (34) tested for and dismissed private commitment spillovers across municipalities with different market share or across protected and unprotected biomes. We tackle the issue of spillovers by restricting samples to areas that are more likely comparable to each other. For priority municipalities we evaluate impacts against the whole sample and in two restricted samples comprising the first or the second order neighbors of priority municipalities. In line with Assunção and Rocha (38) we expect first order neighbors to be affected by treatment spillovers, while we expect second order neighbors to be the most similar counterfactual sample that is likely to respect PTAs while not violating SUTVA. We analyze the soy commitments on municipalities that were producing soy from the beginning of the study period, and for which there are market share data (cf. 41). Cattle ZDCs are evaluated in the whole study area where all municipalities are cattle producers (a few non-cattle producing municipalities were excluded – i.e. the Marajó region in Pará).

ii. Confounders

Forest degradation depends on an array of anthropogenic and natural factors and on their complex interactions at various spatial and temporal scales. In the main specification for both deforestation and degradation we control for cloud cover distortion in detection, temperature and rainfalls, yearly municipal value of cattle and soy production (which simultaneously account for prices and relevance of each land use), proportion of area in protected areas and indigenous lands, environmental law enforcement (the number of environmental fines handed out), and the other policies (excluding the one being assessed). All these covariates are potentially endogenous to degradation. Temperature and rainfall affect degradation by determining the intensity of droughts. Though locally endogenous – ground temperature and rainfalls are affected by local land use - they are unlikely to be affected by human activities at the scale and time unit of this analysis.

Parks and indigenous lands, priority municipalities and the number of fines handed out for environmental crimes are potentially mitigating and targeted to degradation, and they enter the model with a one year lag. Annual commodity price shocks and the exchange rates are controlled for by including the value of cattle and soy production.

Several municipality specific factors may also affect the impact of ZDCs on deforestation. The amount of infrastructures in a municipality is likely to determine forest accessibility and influence all proximate drivers of deforestation that are anthropic (1). The prevalence of smallholders is also associated with higher fire use (43). We deem infrastructure and prevalence of smallholding to be time invariant within the study period. These and other time unvarying confounders are controlled for by the event study design.

iii. Estimation

We estimate the impact of policies in an event study-style design, taking advantage of policies being adopted at different points in time and space. Never treated and later treated units provide the counterfactual for units experiencing a switch to or off treatment. The treatment impact in an event study design is typically estimated as a weighted average of treatment effects across relative time-cohorts in two-way fixed effect regressions. Recent literature showed that when treatment heterogeneity is sufficiently high (i.e. when units experience differential impacts for the same treatment) coefficient estimates may be biased and even exhibit the wrong sign (44, 45). A number of estimators have been proposed that attempt to address this issue. We evaluate the SoyM and the PM program in a staggered design, using the Callaway and Sant'Anna (46) estimators. For the G4 and TAC cattle agreements we used the De Chaisemartin and d'Haultfoeuille (37) DiDl estimator which allows for treated units to revert to non-treated.

b. Data, study area and variables definition

The study region spans the Amazon biome sections of the states of Mato Grosso, Rondônia and Pará. This region includes the entirety of the Amazonian "arc of deforestation", the region where deforestation has historically been most intense in the Brazilian Amazon. It is also the key region for cattle and soy production and private policies implementation in the Brazilian Amazon, and contains much of the facilities of companies with forest policies in the Brazilian Amazon (41, 42). Data sources are summarized in Table SI 1.

Table SI 1 Data sources

Data	**Source**
Deforestation and degradation	Vancutsem, *et al.* (47)
G4 and TAC market shares	Levy, Cammelli, Munger, Gibbs and Garrett (42)
Soy Market share	Gollnow, Cammelli, Carlson and Garrett (41), TRASE (48)
Land use maps	MapBiomas (49)
Protected areas	UNEP-WCMC-IUCN (50)
Priority municipalities	IBAMA (51)

Fines for environmental crimes	IBAMA (52)
Volume of timber extracted (municipality)	IBGE (53)
Sectoral GDP and value of soy production	IBGE (54)
Value of cattle production	Own estimates of slaughtered proportion of cattle herd based on GTAs obtained by Adepara, herd size and carcass weight by IBGE (55), and prices from government of Parana SIMA (56)
Standardized Precipitation Evapotranspiration Index (SPEI)	Sabater (57), https://spei.csic.es/

c. Unit of analysis and observations weighting

Policies and socioeconomic controls are measured at the municipal level, while biophysical control and outcomes are measured at a higher resolution in a raster format. As a result, the analysis may be conducted at the municipal level on statistics from the biophysical outcomes and controls, or at the point level, downscaling municipal level variables.

We conduct the analysis at the municipal scale to mitigate potential downward bias from under scaling, and because the impact of policies is more likely to be traced at the municipal rather than at a finer scale.

Conducting the analysis at the point level allows to measure the probability that forested points become degraded forests or get cleared. This approach produces population average impact of the policies on the probability of a degradation or deforestation event. However, the same results can be obtained by conducting the analysis on municipal level deforestation and degradation rates (rates of change computed over forest area in the previous year) and weighting municipal level observations by the forest area (58).

On the other hand, downscaling the analysis to the point level raises a number of uncertainties related to over and under-sampling (the number of points), the sampling procedure (whether they should be sampled randomly or along a regular grid, the size of the grid and its starting point) and computational power (a 1km regular grid over the study area comprises over a million points). Further, sampled points are likely strongly spatially correlated compromising the validity of SUTVA and complicating inference, and controlling for such correlation may substantially complicate the analysis by requiring more data and increased number of assumptions about the data generating process. Over disaggregation was also found to cause an error in variable problem which leads to a downward bias, while over aggregation leads to a smoothing of error due to wrong aggregation and therefore decreases the precision of estimates, but does not create bias (59).

Ideally the analyses should take place at the level where the processes occur, and in our case, the scale at which the policy does have an impact. The PMs program is indeed targeting municipalities. Similarly, municipalities are the economically relevant units to measure market share. Market share only exists over an area, and it is therefore a scale dependent measure. It should be defined over a large enough scale to affect farmers' decision, but not over an overly large scale, otherwise its effect may be averaged away. Amazonian municipalities seem to approximate the relevant area to define market share because they cover the typical organizational proximity of farmers (in the sense of Torre and Rallet (60)) within which they establish unions, cooperative and common facilities, and in which they take decisions. It is important to notice that the borders of Amazonian municipalities were indeed born from these organizational proximities. During the colonization of the Amazon it was common for farmers and extractivists' settlements that desired administrative emancipation to turn into independent municipalities. For instance, the Municipality of Ulianopolis was named after the founding family - Familia Uliana, which is still operating much of the land in the municipality. The municipality of Paragominas, founded in 1965, was split several times as the forest frontier moved south along the Belem-Brazilia highway.[2] As a result of this process, towns in the Amazon are often well connected by asphalt roads, yet most rural areas across municipalities are poorly or not at all connected. Because of the relative secludedness of rural areas across municipalities (due to lack of infrastructures) and the high centrality of urban areas within each municipality, we deem safe to assume that markets (and market share) are better defined within municipalities.

d. Treatment variables definition

i. G4 Cattle agreement, TAC, and the SoyM

The policy variable is the market share of TAC and G4 committed slaughterhouses and of SoyM committed traders after the adoption of the policy. Market share for cattle commitment is computed over the period 2010-2018 based on the average sourcing volume for each plant in a radius determined as the 75th percentile of sourced volumes from each slaughterhouse (42). This accounts for uneven slaughtering capacity from each plant, and for the likely longer distance travelled by committed plants to meet their required volumes. Slaughter volumes were modelled based on cattle transactions and a set of municipal level predictors. This variable therefore represents the potential market share, rather than the historical one. As such it is expected to capture the effect of market share on the farmers' expectations about market access and is less likely to be the result of companies sourcing away from deforestation areas. The same argument applies to the market share of SoyM committed companies, which was computed by TRASE for the period 2006-2018 using a cost-distance optimization algorithm based on plants locations, soy area and trade flows (41, 48).

We evaluate G4 and TAC market shares as binary variables in an event study regression. Three binary treatment variables were produced at three thresholds over the market share distribution: above vs below 0% market share, above vs below 50th percentile of the distribution

[2] For an account of the histories of Brazilian municipalities see https://cidades.ibge.gov.br/

(median) and above 75th percentile vs bottom 50th percentile of the distribution (excluding observations in between). The counterfactual group (observations below the median market share) is constant across the second and the third treatment variables and allows to test whether the treatment effects increase over increasing market share. We do not analyze further thresholds to avoid pre-test bias (61) , i.e. cherry picking on parallel trends. We do not analyze the SoyM market share as continuous because its distribution is extremely skewed at both extremes (cf. 41) and its impact would be poorly interpretable as marginal change. In the main specification the G4 and TAC treatment status is allowed to revert when market share falls below the threshold. This is particularly appropriate in the context of the cattle market which is dominated by spot contracts. On the other hand the SoyM market shares almost never revert below the set threshold, partly because of how data were generated by TRASE. In line with Gollnow, Cammelli, Carlson and Garrett (41) we assume that farmers "remember" the impact of the policy and we do not allow treatment to revert.

ii. Public policy: The Priority Municipality program

In the Brazilian Amazon environmental laws and the Forest Code are enforced on rural owners by IBAMA, the federal environmental agency which may emit fines and embargoes. Additionally, since 2008, when municipalities exceed a set of deforestation criteria, they may enter the priority list of the Ministry of the Environment and being cut-off from fiscal transfers from the central government and access to rural credit. The deforestation criteria include the overall area deforested, the amount of land cleared in the previous three years and the deforestation rate in the previous five years. Since the onset of the program, new municipalities entered the list and other exited it after remediation. We considered municipalities that exit the black list as still treated.

iii. Deforestation and Degradation

Municipal level estimates of deforestation and degradation are extracted from the JRC TMF product documented by Vancutsem*, et al.* (47). Rates are obtained as difference between the variable value in one year and the previous year and the difference is divided by the previous year value.

iv. Fires

Fires are the count of fires (detected with 70% or higher confidence) per hectare of municipality

v. Logging:

Hundreds of cubic meters of wood extracted per hectare of forest as per Map Biomas Collection 6 class 3.

vi. Confounders:

We built an annualized Standardized Precipitation Evapotranspiration Index (SPEI) as the average of the monthly SPEI in the municipality during the calendar year. Prices of cattle and soy and the exchange rate have been shown to affect deforestation substantially (62), and they are incorporated in the value of soy and cattle production. The value of cattle was computed as the municipal herd size times the deflated national cattle prices times the yearly slaughter rate (computed on 3 years GTA data from Para). The value of soy was provided by IBGE national accounting. Soy and cattle value simultaneously account for prices and relevance of each land

use.
The share of the municipal area that is protected through parks and indigenous lands is computed based on the WDPA database.
We account for enforcement through the number of fines for environmental crimes handed out and are obtained from IBAMA, the federal inspection agency.

3. Full results

a. Coupling and decoupling across deforestation and forest cover

Table SI 2 Mean correlation and standard deviations of within municipality deforestation and degradation across three time periods, and test of differences in this correlation between municipalities above and below average deforestation between 1996 and 2005 and forest cover share in 2005.

	Overall	high deforestation	low deforestation	Mean difference p value	high forest cover	low forest cover	Mean difference p value
1995-2003	0.568	0.561	0.570	0.857	0.582	0.532	0.298
	0.213	0.245	0.198		0.180	0.274	
2004-2012	0.396	0.376	0.412	0.458	0.396	0.395	0.990
	0.271	0.297	0.279		0.271	0.278	
2013-2019	0.465	0.586	0.410	0.087	0.434	0.538	0.273
	0.367	0.358	0.363		0.377	0.340	

b. Potential selection effects: except for TAC, policies expand evenly across historical deforestation and degradation gradients

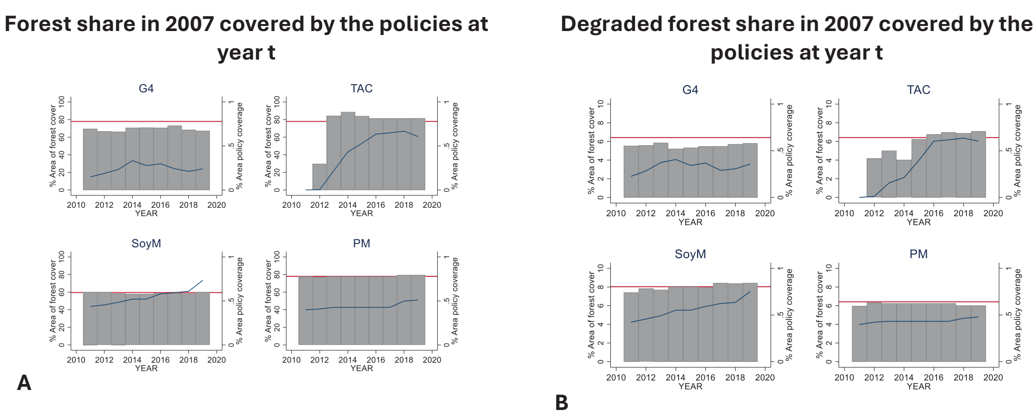
To understand policy expansion vis-à-vis forest cover, deforestation and degradation rates (natural and anthropogenic), we plot the share of area covered by a policy (Figure SI 2 - blue lines), and the average forest cover in 2007, and the average deforestation and degradation rate for the 1996 – 2005 period in the municipalities in which the policies were present (Figure SI 2 – grey bars and red lines). Policies are measured as in the main models presented in the body of the paper.

We find that the PM, G4 and SoyM supply chain policies' expands over time in a way that keeps average historical forest cover, deforestation and degradation rates constant across the treated and control groups (Figure SI 2 – grey bars). Average degradation and deforestation rates are highest in the subsample of soy producing municipalities compared to the whole sample

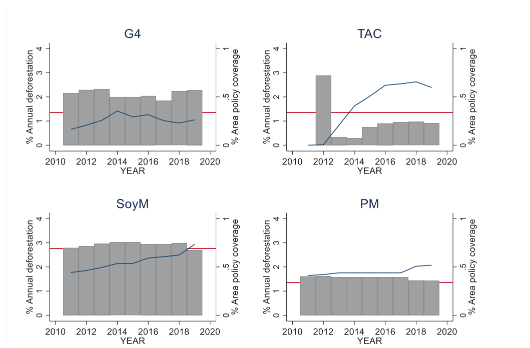
(Figure SI 2 – red lines). G4 expands through acquisition of new slaughtering plants in areas with above average historical deforestation and degradation rates and below average forest cover. TAC expanded as the public prosecutor targeted more companies and as already targeted companies acquired new plants in municipalities that had a higher forest area and share of degraded forests, and increasingly towards areas with higher deforestation and degradation rates. Rates variables are null and spike in 2011 and 2012, however this is because only 0 and 3 municipalities were treated at the 75th in those years (Table SI 15).

We conclude that there is potential for selection effects for TAC, which we test further in the next section.

Figure SI 2 Policy coverage over pre-treatment forest cover, degradation, deforestation and degradation rates. The blue line is the policy coverage level indicated on the second Y axis. The horizontal red line indicates the average level of the variable on the left Y axis, and it is different between the whole sample and the soy producing municipalities only

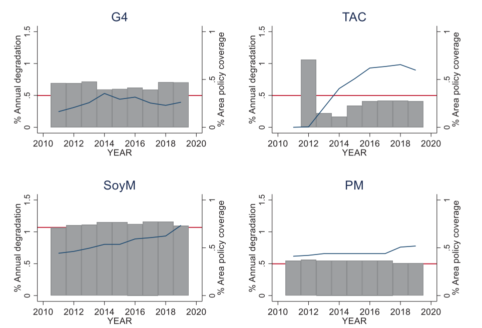


Average deforestation rate 1996-2005 in areas covered by the policies at year t



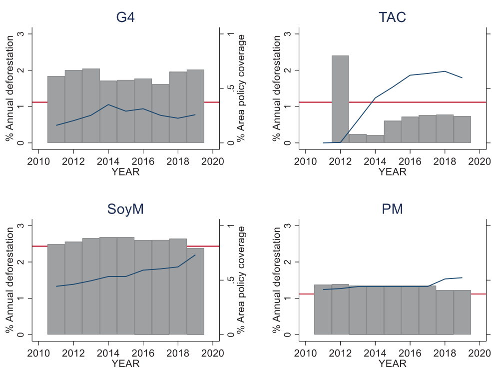
C

Average degradation rate 1996-2005 in areas covered by the policies at year t



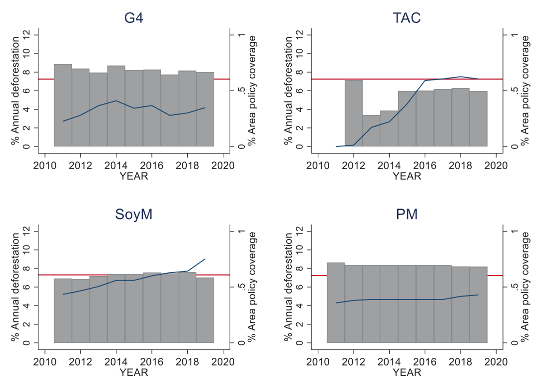
D

Average deforestation rate of intact forest in 1996-2005 covered by the policies at year t



E

Average deforestation rate of degraded forest in 1996-2005 covered by the policies at year t



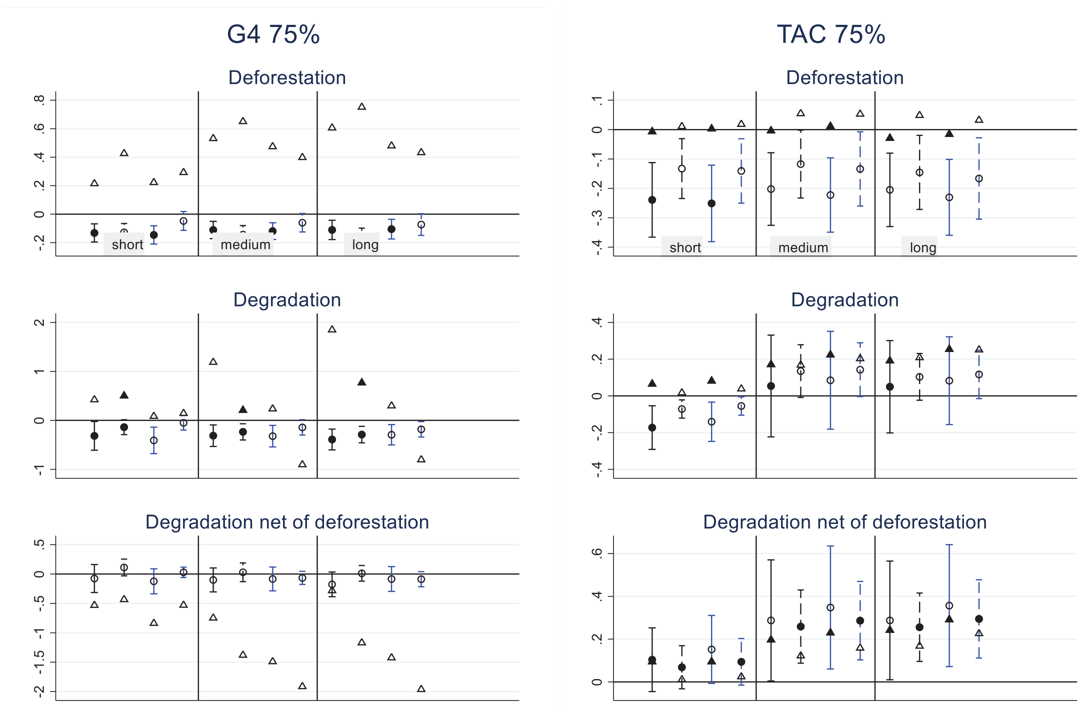
F

c. TAC and G4 impacts on degradation net of deforestation are spurious, G4 impacts on deforestation and degradation are conservative

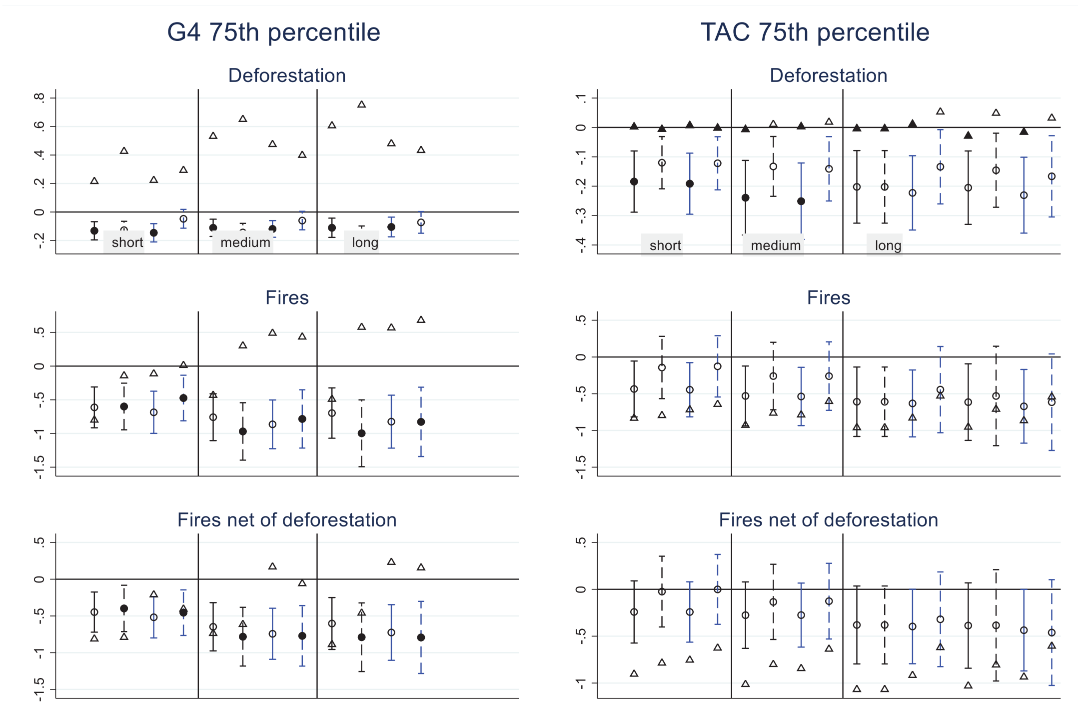
We further enquire selection effects by overlaying point estimates at the 0% market share (triangles) with estimated impacts at the 75% market share. We show that TAC and G4 impact on degradation is spurious, and G4 policies impact on deforestation is conservative. For TAC we observe that estimates at the 0% market share fall within the confidence intervals, for degradation net of deforestation, and for G4 they were even lower than coefficient estimates. Conversely, G4 impacts on deforestation were substantially lower than estimates at the 0% threshold. We also found that impacts of TAC on fires are compatible with selection effects, while the long-term impact of G4 on overall fires is not. The positive impact of G4 on logging is also not compatible with selection effects.

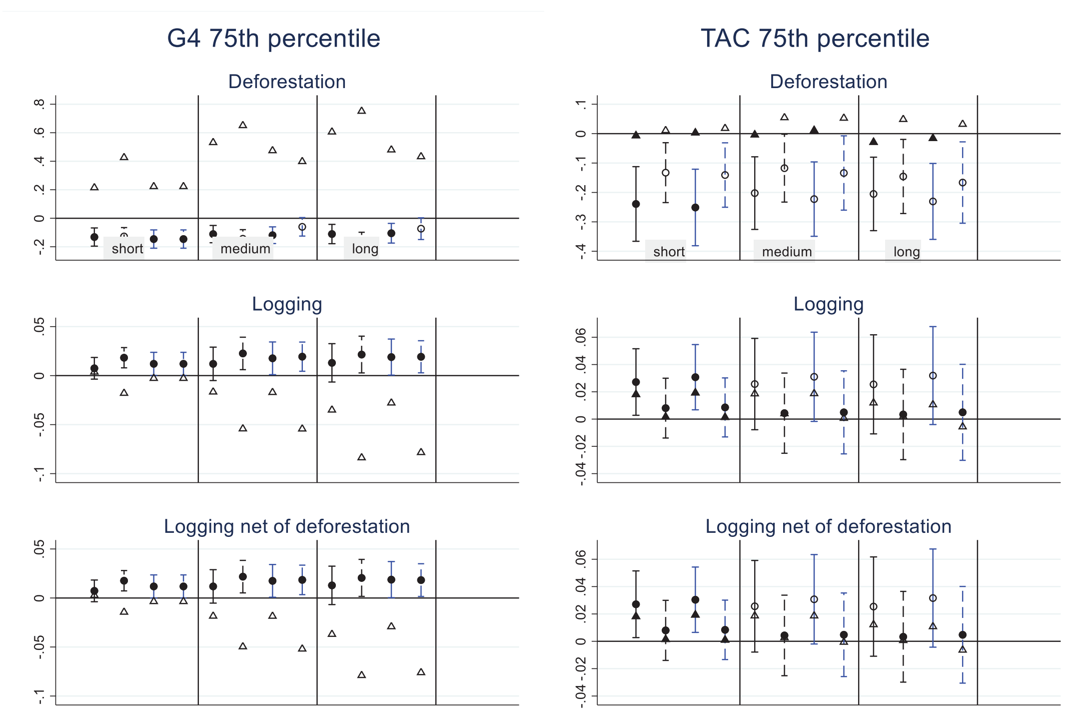
For each policy, outcome and period, the four estimates refer to different regression specifications. From left to right: the base model (black solid line), the base model with land use trends (black dashed line), dropping all controls (blue solid line), and dropping all controls and including land use trends (blue dashed line). Dots representing point estimates are full when parallel trends are met, and empty when they are not i.e. when an F test rejects the hypothesis that pre-policy (placebo) coefficients are simultaneously different from zero. Confidence intervals are truncated when exceeding the graphs limits for ease of representation.

Figure SI 3 Point estimates and 90% confidence intervals of the average treatment effect for each policy at the 75% market share threshold (points) and 0% (triangles) on deforestation, degradation and degradation conditional on deforestation, and for the very short, short, medium and long terms.



P



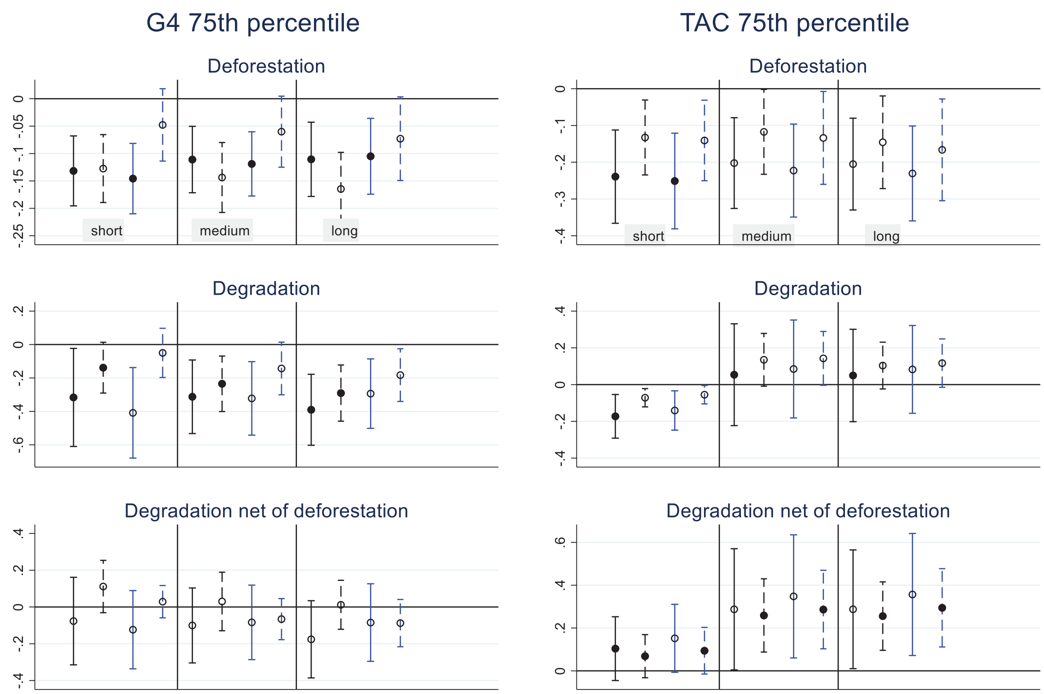


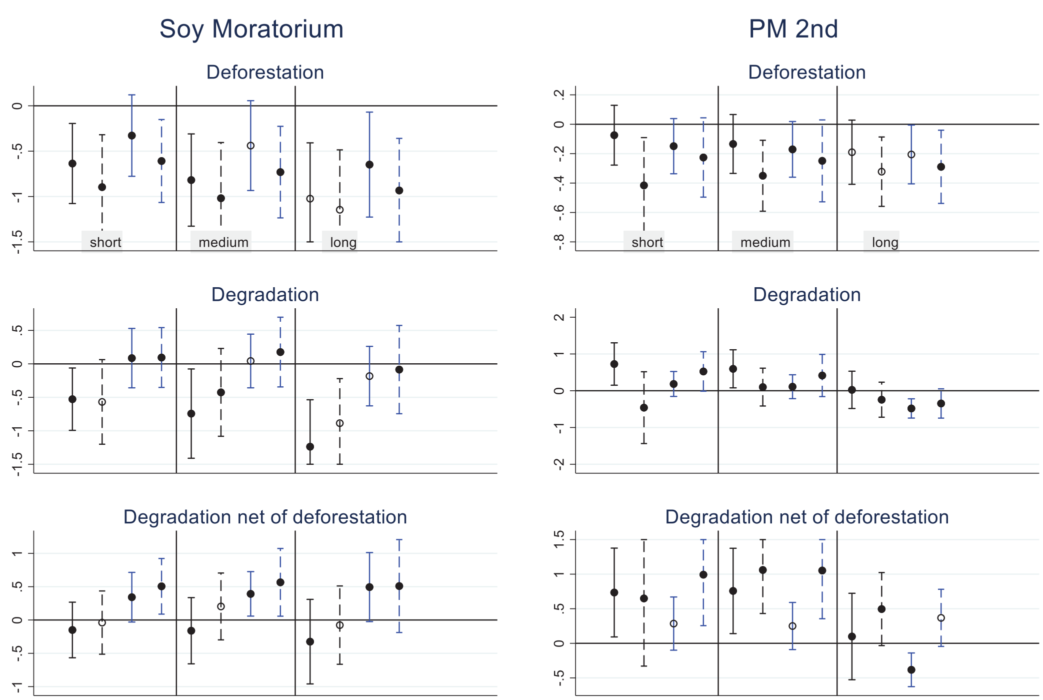
d. Summary of policies impacts on all outcomes

For each policy, outcome and period, the four estimates refer to different regression specifications. From left to right: the base model (black solid line), the base model with land use trends (black dashed line), dropping all controls (blue solid line), and dropping all controls and including land use trends (blue dashed line). Dots representing point estimates are full when parallel trends are met, and empty when they are not i.e. when an F test rejects the hypothesis that pre-policy (placebo) coefficients are simultaneously different from zero. Confidence intervals are truncated when exceeding the graphs limits for ease of representation.

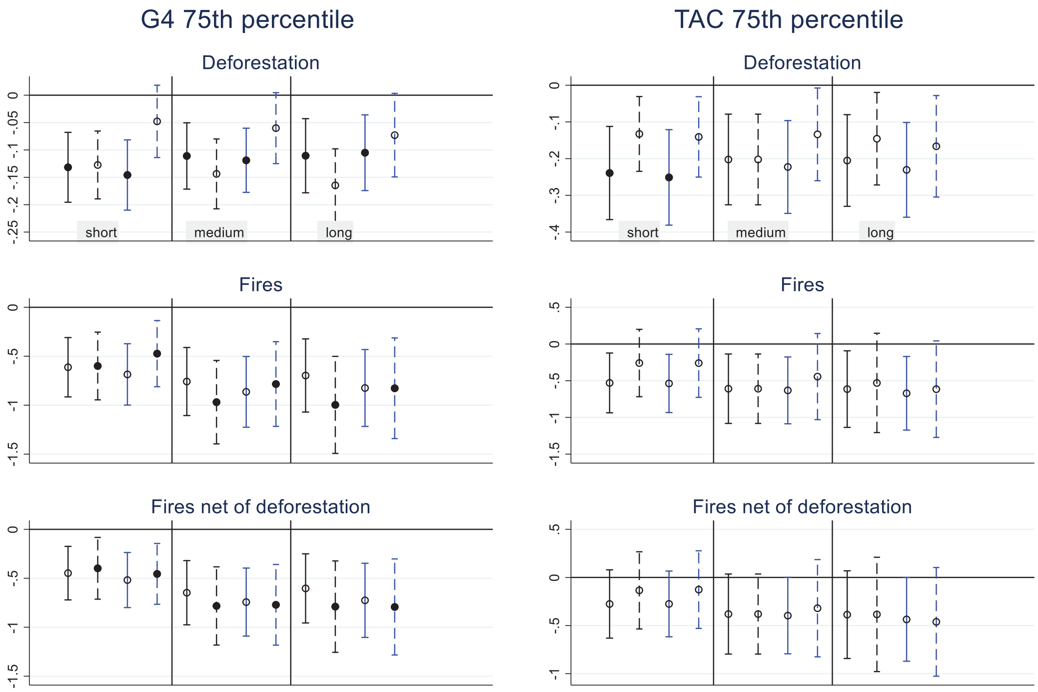
Figure SI 4 Point estimates and 90% confidence intervals of the average treatment effect for each policy and outcome and for the very short, short, medium and long terms.

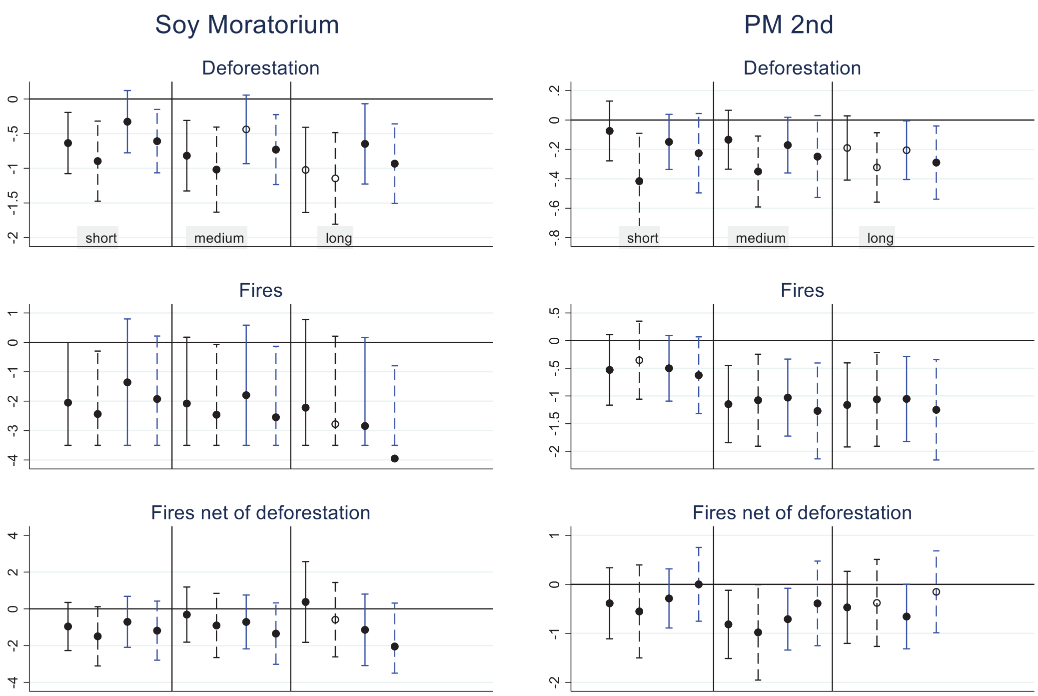
a.



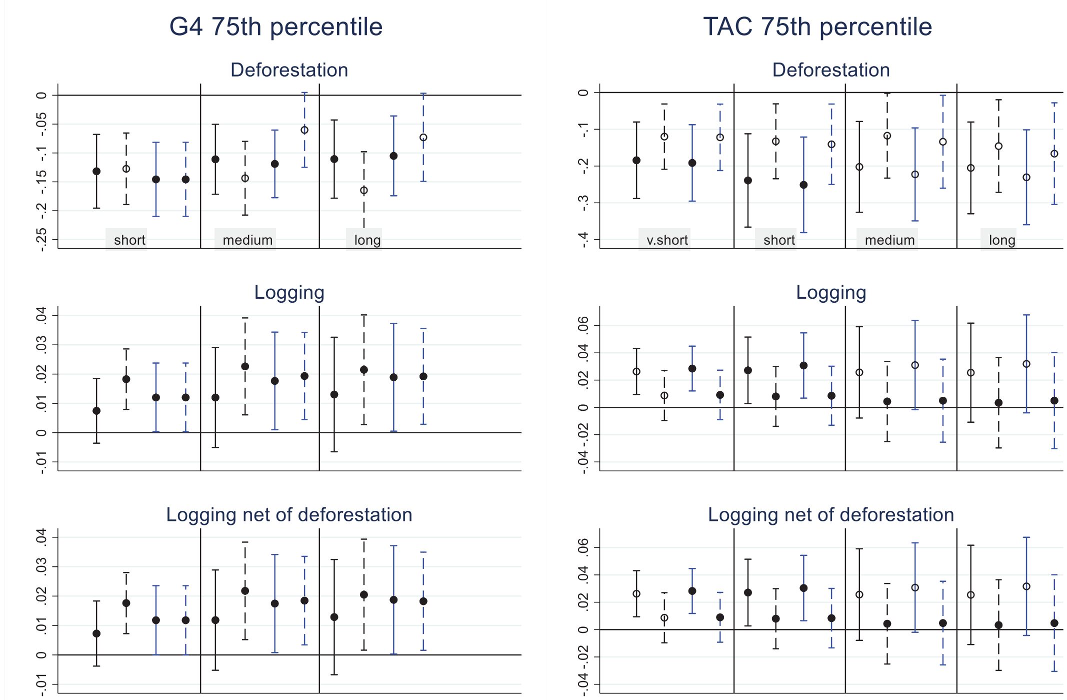


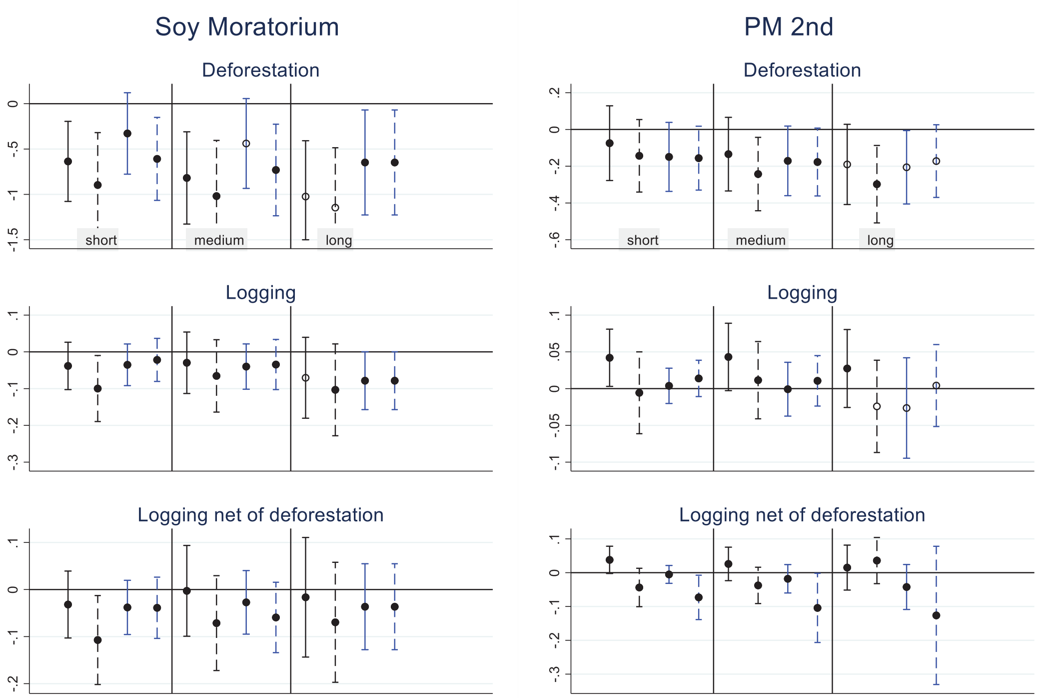
b.


G4 75th percentile
TAC 75th percentile
Deforestation
Fires
Fires net of deforestation
short
medium
long

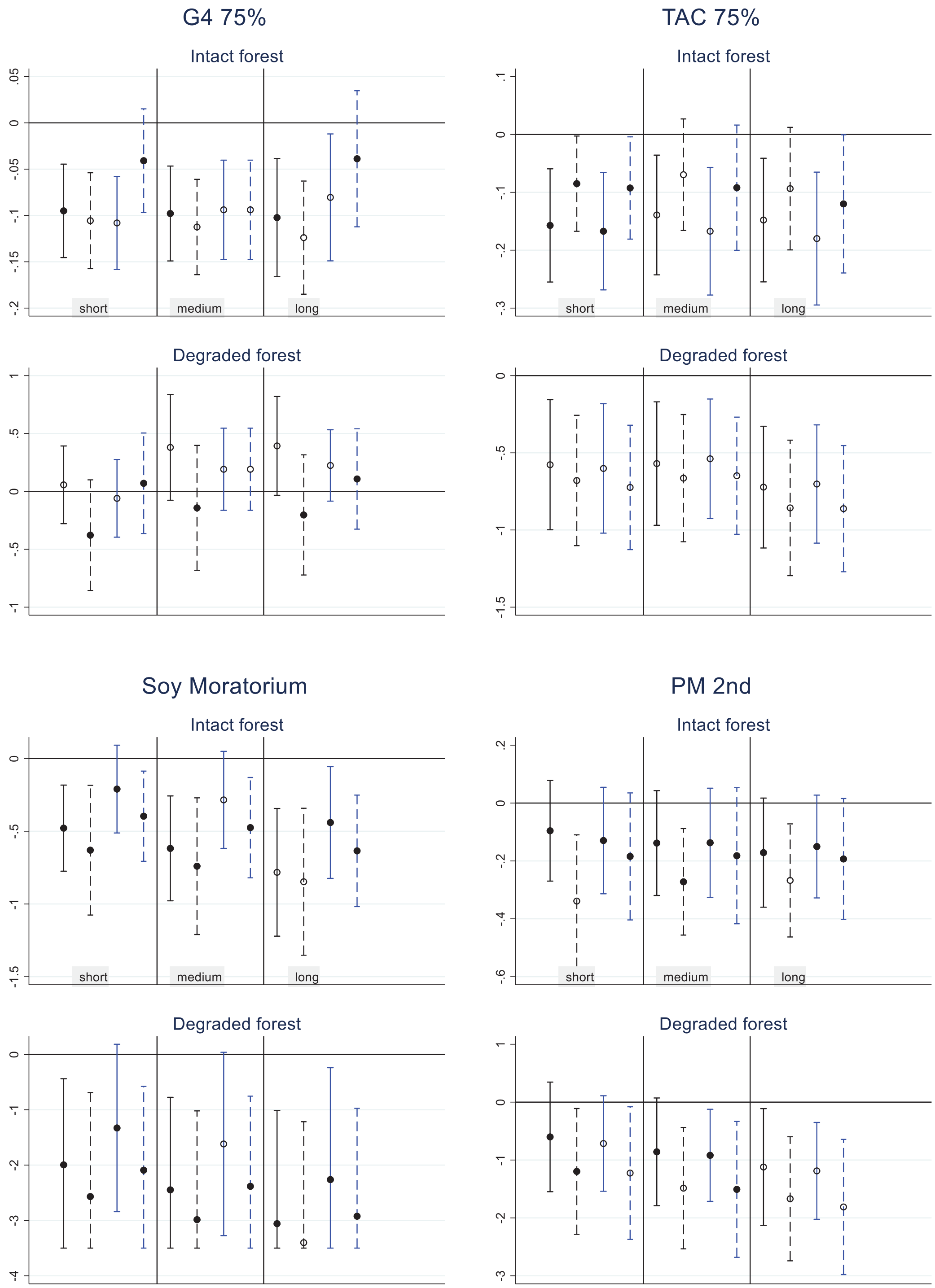

Soy Moratorium
PM 2nd
Deforestation
Fires
Fires net of deforestation
short
medium
long

c.


G4 75th percentile
TAC 75th percentile
Deforestation
short
medium
long
v.short
Logging
Logging net of deforestation


Soy Moratorium
PM 2nd
Deforestation
short
medium
long
Logging
Logging net of deforestation

d.



Panel A. report estimates for deforestation and degradation. Panel b for fires and c for logging. Panel d present split results for deforestation of intact and degraded forests. For each policy, outcome and period, the four estimates refer to different regression specifications. From left to right: the base model, the base model with land use trends, dropping all controls, and dropping all controls and including land use trends. Dots representing point estimates are full when parallel trends are met, and empty when they are not i.e. when an F test rejects the hypothesis that pre-policy (placebo) coefficients are simultaneously different from zero. Confidence intervals are truncated when exceeding the graphs limits for ease of representation. For the full results with all specifications see SI section 3.

e. PM has a stronger impact on degradation during the 2015-2016 drought

We report results for deforestation, degradation and fires aggregated by calendar year for PM and SoyM for all the four models using the Callaway and Sant'Anna (46) estimator.

The PM but not the SoyM display the highest effect against degradation and degradation net of deforestation during the 2015 and 2016 drought years (Tables SI 5, SI 10). However, these effects are not especially higher for fires or deforestation.

Table SI 3 SoyM impact on deforestation by calendar year

	Deforestation			
VARIABLES	Base model	Base model with LUT	No control	No control with LUT
CAverage	-1.019***	-1.183***	-0.656*	-0.938***
	(0.383)	(0.425)	(0.365)	(0.358)
T2008	-1.485**	-1.907**	-1.233*	-1.552**
	(0.672)	(0.794)	(0.636)	(0.644)
T2009	-0.865	-1.316**	-0.558	-0.971*
	(0.574)	(0.672)	(0.579)	(0.574)
T2010	-0.693*	-1.020*	-0.514	-0.658
	(0.413)	(0.569)	(0.428)	(0.407)
T2011	-0.718**	-0.909**	-0.472	-0.755**
	(0.347)	(0.434)	(0.339)	(0.324)
T2012	-1.592***	-1.483**	-0.530	-0.745*
	(0.541)	(0.643)	(0.443)	(0.414)
T2013	-1.222***	-1.378***	-0.576	-0.891**
	(0.466)	(0.499)	(0.409)	(0.411)
T2014	-1.317***	-1.592***	-0.689*	-0.834**
	(0.426)	(0.463)	(0.367)	(0.366)
T2015	-0.870*	-1.202**	-0.593	-0.751*
	(0.484)	(0.528)	(0.391)	(0.416)
T2016	-0.675	-1.271*	-0.386	-0.731
	(0.481)	(0.680)	(0.430)	(0.535)
T2017	-0.790**	-0.694	-0.520	-0.890***
	(0.356)	(0.463)	(0.387)	(0.340)
T2018	-1.245***	-1.151**	-0.937**	-1.259***
	(0.401)	(0.491)	(0.364)	(0.368)
T2019	-0.760*	-0.269	-0.865***	-1.211***
	(0.457)	(0.795)	(0.335)	(0.369)
Observations	741	741	741	741

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table SI 4 SoyM impact on deforestation of intact and degraded forests

	Deforestation of intact forests				Deforestation of degraded forests			
VARIABLES	Base model	Base model with LUT	No control	No control with LUT	Base model	Base model with LUT	No control	No control with LUT
CAverage	-0.762***	-0.864***	-0.444*	-0.631***	-3.105**	-3.574**	-2.301*	-3.026**
	(0.267)	(0.307)	(0.238)	(0.234)	(1.285)	(1.424)	(1.285)	(1.228)
T2008	-0.940**	-1.235**	-0.783**	-0.977**	-5.411**	-6.485**	-4.436**	-5.654**
	(0.416)	(0.505)	(0.391)	(0.393)	(2.350)	(2.674)	(2.225)	(2.199)
T2009	-0.506	-0.852*	-0.331	-0.597	-3.402*	-4.439**	-2.554	-3.782**
	(0.410)	(0.489)	(0.386)	(0.394)	(1.749)	(2.034)	(1.911)	(1.838)
T2010	-0.436	-0.740*	-0.335	-0.439	-2.605*	-3.639	-1.973	-2.430*
	(0.303)	(0.399)	(0.307)	(0.289)	(1.514)	(2.292)	(1.479)	(1.434)
T2011	-0.561**	-0.681*	-0.322	-0.498**	-2.015*	-2.659*	-1.753	-2.558**
	(0.273)	(0.350)	(0.254)	(0.228)	(1.129)	(1.455)	(1.122)	(1.120)
T2012	-1.096***	-1.064**	-0.336	-0.500*	-4.744***	-4.650**	-2.025	-2.533*
	(0.371)	(0.448)	(0.297)	(0.279)	(1.735)	(2.056)	(1.483)	(1.370)
T2013	-1.022***	-1.226***	-0.359	-0.543*	-3.202**	-3.319**	-2.217*	-2.974**
	(0.362)	(0.385)	(0.291)	(0.284)	(1.441)	(1.655)	(1.345)	(1.367)
T2014	-0.996***	-1.252***	-0.484*	-0.541**	-3.508**	-3.670***	-2.306*	-2.892**
	(0.308)	(0.408)	(0.248)	(0.252)	(1.412)	(1.353)	(1.240)	(1.191)
T2015	-0.854**	-1.224***	-0.488*	-0.557**	-1.845	-2.014	-1.768	-2.323*
	(0.367)	(0.468)	(0.259)	(0.274)	(1.499)	(1.514)	(1.362)	(1.370)
T2016	-0.465	-1.004*	-0.271	-0.524	-2.922**	-3.598**	-1.635	-2.332*
	(0.365)	(0.604)	(0.316)	(0.402)	(1.329)	(1.448)	(1.244)	(1.323)

T2017	-0.608**	-0.565	-0.327	-0.622***	-2.437**	-2.238*	-1.971*	-2.533**
	(0.267)	(0.378)	(0.273)	(0.235)	(1.173)	(1.177)	(1.184)	(1.108)
T2018	-0.944***	-0.612	-0.698***	-0.944***	-3.467***	-3.891***	-2.518**	-3.133***
	(0.281)	(0.461)	(0.258)	(0.250)	(1.226)	(1.235)	(1.130)	(1.194)
T2019	-0.714**	0.0851	-0.586**	-0.830***	-1.697	-2.286	-2.453**	-3.173***
	(0.306)	(0.781)	(0.240)	(0.264)	(1.245)	(1.429)	(0.997)	(1.119)
Observations	741	741	741	741	741	741	741	741

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table SI 5 SoyM impact on degradation and degradation net of deforestation by calendar year

	Degradation				Degradation net of deforestation			
VARIABLES	Base model	Base model with LUT	No control	No control with LUT	Base model	Base model with LUT	No control	No control with LUT
CAverage	-1.075***	-0.843**	-0.194	-0.152	-0.220	-0.0482	0.415	0.472
	(0.402)	(0.411)	(0.292)	(0.366)	(0.314)	(0.297)	(0.253)	(0.333)
T2008	-0.683	-0.803	-0.538	-0.749	-0.0610	0.688	-0.0801	0.256
	(0.475)	(0.678)	(0.510)	(0.527)	(0.283)	(0.595)	(0.309)	(0.387)
T2009	-0.640	-0.969*	-0.376	-0.470	-0.0548	-0.0898	-0.0938	0.150
	(0.473)	(0.525)	(0.462)	(0.485)	(0.298)	(0.233)	(0.190)	(0.186)
T2010	-0.320	-0.396	-0.00421	0.181	4.61e-05	-0.522	0.266	0.560
	(0.558)	(0.642)	(0.614)	(0.522)	(0.508)	(0.795)	(0.575)	(0.547)
T2011	-0.0980	-0.0693	-0.0988	0.0149	0.301	0.0218	0.162	0.244
	(0.351)	(0.506)	(0.395)	(0.489)	(0.298)	(0.578)	(0.361)	(0.467)
T2012	-0.699	-0.444	-0.170	0.0815	0.479	0.334	0.375*	0.660***
	(0.500)	(0.680)	(0.379)	(0.394)	(0.323)	(0.489)	(0.196)	(0.227)
T2013	-0.703	-0.990	-0.247	-0.503	0.0419	-0.407	-0.00927	-0.224
	(0.458)	(0.880)	(0.312)	(0.738)	(0.400)	(0.719)	(0.271)	(0.675)
T2014	-1.131**	-0.598	-0.345	-0.0204	-0.0415	0.223	0.180	0.407*
	(0.459)	(0.387)	(0.303)	(0.317)	(0.351)	(0.302)	(0.233)	(0.224)
T2015	-0.379	-0.539	0.0880	0.135	0.0226	-0.0447	-0.145	0.460
	(0.640)	(0.686)	(0.351)	(0.501)	(0.569)	(0.598)	(0.522)	(0.420)
T2016	-7.783***	-6.912**	-1.182	-1.467	-4.381*	-3.854	2.961	1.365
	(2.377)	(2.873)	(1.441)	(2.669)	(2.496)	(2.910)	(2.617)	(3.284)
T2017	0.491	1.403*	0.807**	0.998***	0.955*	1.879**	0.983**	1.108**
	(0.457)	(0.784)	(0.408)	(0.387)	(0.547)	(0.782)	(0.475)	(0.437)
T2018	-0.293	0.876	0.156	0.144	0.471	1.293*	0.562*	0.487
	(0.385)	(0.732)	(0.340)	(0.370)	(0.478)	(0.760)	(0.333)	(0.359)
T2019	-0.657	-0.681	-0.414	-0.175	-0.375	-0.0996	-0.183	0.188
	(0.523)	(0.991)	(0.293)	(0.348)	(0.551)	(0.924)	(0.275)	(0.310)
Observations	741	741	741	741	741	741	741	741

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table SI 6 SoyM impact on fires and fires net of deforestation by calendar year

	Fires				Fires net of deforestation			
VARIABLES	Base model	Base model with LUT	No control	No control with LUT	Base model	Base model with LUT	No control	No control with LUT
CAverage	-1.511	-2.320*	-1.991	-2.936**	1.224	0.181	-0.438	-0.848
	(1.372)	(1.206)	(1.437)	(1.485)	(1.284)	(1.245)	(1.146)	(1.362)
T2008	-1.291	-2.902	-1.116	-1.855	0.0695	-0.790	-0.186	-0.165
	(2.092)	(2.124)	(2.226)	(2.331)	(1.417)	(1.486)	(1.657)	(1.822)
T2009	-2.097	-3.511**	-1.143	-2.171	-0.933	-1.664	-0.498	-0.905
	(1.767)	(1.767)	(2.147)	(2.083)	(1.331)	(1.273)	(1.719)	(1.842)
T2010	-2.637*	-2.551*	-2.062	-2.210	-2.566*	-3.547*	-1.857	-2.510
	(1.529)	(1.538)	(1.598)	(1.519)	(1.423)	(1.819)	(1.489)	(1.631)
T2011	-3.131**	-3.548*	-2.595	-3.401**	-0.726	-1.003	-0.972	-1.656
	(1.463)	(1.979)	(1.631)	(1.531)	(1.002)	(1.879)	(1.160)	(1.253)
T2012	-0.660	-2.184	-1.197	-2.246	1.760	-0.124	0.206	-0.551
	(1.423)	(1.936)	(1.482)	(1.467)	(1.235)	(1.506)	(1.098)	(1.293)
T2013	-2.614	-2.955	-2.604*	-2.764*	2.711	1.454	0.554	0.530
	(2.198)	(2.538)	(1.561)	(1.476)	(2.689)	(2.679)	(1.648)	(1.488)
T2014	-2.481	-3.743	-2.426*	-3.394**	0.956	-0.746	-0.366	-0.657
	(2.138)	(2.316)	(1.338)	(1.485)	(2.353)	(2.472)	(1.191)	(1.677)
T2015	-0.277	-0.765	-2.066	-2.656	3.902*	2.490	0.0744	0.467
	(2.027)	(2.168)	(2.004)	(2.115)	(2.327)	(2.297)	(1.842)	(2.189)
T2016	-1.224	-2.687	-1.946	-2.932*	2.109	0.105	-0.208	-0.287
	(1.561)	(1.795)	(1.374)	(1.633)	(1.991)	(2.125)	(1.274)	(1.850)
T2017	0.421	0.788	-1.815	-2.966*	3.955**	4.282**	0.153	-0.543
	(1.587)	(1.768)	(1.467)	(1.523)	(1.894)	(2.137)	(1.420)	(1.732)
T2018	-1.389	-2.277	-2.519*	-3.433**	2.457	0.897	-0.765	-0.581
	(1.497)	(1.386)	(1.332)	(1.584)	(1.816)	(1.749)	(1.177)	(1.736)
T2019	-0.753	-1.500	-2.410**	-5.205***	0.999	0.818	-1.394	-3.321**
	(1.837)	(2.254)	(1.189)	(1.433)	(2.023)	(2.394)	(1.111)	(1.506)
Observations	741	741	741	741	741	741	741	741

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table SI 7 SoyM impact on logging and logging net of deforestation

	Logging				**Logging net of deforestation**			
VARIABLES	Base model	Base model with LUT	No control	No control with LUT	Base model	Base model with LUT	No control	No control with LUT
CAverage	-0.0583	-0.0886	-0.0692	-0.0688	-0.0135	-0.0664	-0.0376	-0.0603
	(0.0589)	(0.0656)	(0.0459)	(0.0502)	(0.0676)	(0.0661)	(0.0509)	(0.0507)
T2008	-0.0212	-0.0141	-0.0207	-0.0135	-0.0228*	-0.0187	-0.0222	-0.0175
	(0.0142)	(0.0132)	(0.0174)	(0.0162)	(0.0138)	(0.0122)	(0.0169)	(0.0156)
T2009	-0.0736	-0.0898*	-0.129*	-0.118**	-0.0572	-0.0845	-0.125*	-0.119**
	(0.0566)	(0.0518)	(0.0666)	(0.0593)	(0.0619)	(0.0524)	(0.0666)	(0.0582)
T2010	-0.0624	-0.0668	-0.0707	-0.0635	-0.0555	-0.0762	-0.0688	-0.0750
	(0.0525)	(0.0488)	(0.0556)	(0.0487)	(0.0545)	(0.0526)	(0.0556)	(0.0494)
T2011	-0.0433	-0.0799	-0.0625	-0.0532	-0.0332	-0.0678	-0.0592	-0.0575
	(0.0566)	(0.0589)	(0.0644)	(0.0572)	(0.0573)	(0.0620)	(0.0631)	(0.0571)
T2012	-0.0155	-0.138	-0.0630	-0.0544	0.0495	-0.184	-0.0441	-0.104
	(0.0950)	(0.154)	(0.0689)	(0.0756)	(0.106)	(0.168)	(0.0680)	(0.0817)
T2013	0.0430	0.0979	0.00800	0.0423	0.168	0.111	0.0873	0.0429
	(0.104)	(0.104)	(0.0525)	(0.0686)	(0.141)	(0.102)	(0.0950)	(0.0714)
T2014	-0.0202	0.0369	-0.0252	-0.0206	0.0575	0.0911	0.0363	0.0341
	(0.0902)	(0.0958)	(0.0456)	(0.0505)	(0.0987)	(0.0970)	(0.0626)	(0.0614)
T2015	0.0182	0.0624	-0.0485	-0.0312	0.115	0.139	0.00220	0.0103
	(0.0957)	(0.110)	(0.0576)	(0.0646)	(0.117)	(0.113)	(0.0661)	(0.0723)
T2016	-0.155*	-0.218**	-0.110**	-0.131	-0.0996	-0.155	-0.0550	-0.0953
	(0.0805)	(0.111)	(0.0556)	(0.0821)	(0.0960)	(0.114)	(0.0674)	(0.0912)
T2017	-0.245***	-0.314***	-0.169***	-0.230***	-0.233**	-0.281***	-0.126*	-0.227***
	(0.0882)	(0.0836)	(0.0626)	(0.0745)	(0.1000)	(0.0850)	(0.0738)	(0.0808)
T2018	-0.114	-0.210*	-0.121*	-0.141*	-0.0546	-0.139	-0.0629	-0.109
	(0.0985)	(0.126)	(0.0639)	(0.0808)	(0.111)	(0.131)	(0.0698)	(0.0856)
T2019	-0.00983	-0.129	-0.0177	-0.0122	0.00397	-0.130	-0.0132	-0.00696
	(0.0781)	(0.142)	(0.0578)	(0.0532)	(0.0816)	(0.134)	(0.0555)	(0.0530)
Observations	734	734	734	734	734	734	734	734

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table SI 8 PM impact on deforestation by calendar year

	Deforestation			
VARIABLES	Base model	Base model with LUT	No control	No control with LUT
CAverage	-0.199	-0.328**	-0.216*	-0.296**
	(0.130)	(0.143)	(0.119)	(0.150)
T2009	-0.430***	-0.654***	-0.383*	-0.720***
	(0.167)	(0.204)	(0.204)	(0.238)
T2010	0.180	0.494**	0.0435	0.192
	(0.192)	(0.221)	(0.117)	(0.149)
T2011	-0.324**	-0.387***	-0.192	-0.422***
	(0.135)	(0.117)	(0.122)	(0.160)
T2012	-0.281*	-0.374**	-0.294*	-0.564***
	(0.159)	(0.175)	(0.174)	(0.207)
T2013	-0.292**	-0.508**	-0.223*	-0.401**
	(0.131)	(0.236)	(0.135)	(0.169)
T2014	-0.221	-0.612*	-0.159	-0.336*
	(0.174)	(0.319)	(0.162)	(0.199)
T2015	-0.540**	-0.657**	-0.437	-0.154
	(0.255)	(0.291)	(0.310)	(0.180)
T2016	-0.576*	-0.591*	-0.722*	-0.529*
	(0.325)	(0.351)	(0.389)	(0.298)
T2017	-0.106	0.509	-0.188	-0.0305
	(0.166)	(0.394)	(0.172)	(0.236)
T2018	0.146	-0.303	0.0286	-0.217
	(0.159)	(0.250)	(0.135)	(0.157)
T2019	0.260	-0.520*	0.154	-0.0771
	(0.160)	(0.272)	(0.134)	(0.155)
Observations	756	756	756	756

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table SI 9 PM impact on deforestation of intact and degraded forests

Deforestation of intact forests	**Deforestation of degraded forests**

VARIABLES	Base model	Base model with LUT	No control	No control with LUT	Base model	Base model with LUT	No control	No control with LUT
CAverage	-0.180	-0.276**	-0.160	-0.202	-1.119*	-1.659**	-1.188**	-1.810**
	(0.112)	(0.119)	(0.107)	(0.126)	(0.614)	(0.651)	(0.509)	(0.708)
T2009	-0.369**	-0.513***	-0.312*	-0.540***	-2.389***	-3.643***	-2.118***	-3.584***
	(0.144)	(0.169)	(0.166)	(0.194)	(0.717)	(0.836)	(0.724)	(0.934)
T2010	0.107	0.314**	-0.000402	0.192	1.009	1.920**	0.579	0.582
	(0.156)	(0.144)	(0.105)	(0.120)	(0.771)	(0.801)	(0.653)	(0.706)
T2011	-0.292**	-0.364***	-0.184	-0.368**	-0.639	-1.214*	-0.452	-0.999
	(0.123)	(0.114)	(0.129)	(0.150)	(0.680)	(0.622)	(0.623)	(0.736)
T2012	-0.261*	-0.339**	-0.215	-0.401**	-1.502**	-2.332***	-1.670***	-2.761***
	(0.139)	(0.141)	(0.154)	(0.170)	(0.716)	(0.887)	(0.641)	(0.912)
T2013	-0.264**	-0.411**	-0.197	-0.306**	-1.224*	-1.838**	-0.957	-1.750**
	(0.120)	(0.178)	(0.125)	(0.141)	(0.628)	(0.740)	(0.611)	(0.842)
T2014	-0.202	-0.477**	-0.111	-0.229	-1.428**	-2.511***	-1.089**	-2.332***
	(0.164)	(0.241)	(0.156)	(0.173)	(0.644)	(0.738)	(0.537)	(0.820)
T2015	-0.381*	-0.522**	-0.190	-0.144	-1.816	-1.819**	-2.127	-1.412*
	(0.197)	(0.219)	(0.146)	(0.133)	(1.113)	(0.893)	(1.353)	(0.771)
T2016	-0.506**	-0.589**	-0.532*	-0.374	-2.317**	-2.574**	-2.719***	-3.210***
	(0.246)	(0.276)	(0.309)	(0.233)	(1.105)	(1.174)	(0.984)	(1.104)
T2017	-0.172	0.296	-0.184	-0.00328	-0.290	0.0130	-0.757	-1.016
	(0.131)	(0.322)	(0.144)	(0.213)	(0.694)	(0.750)	(0.561)	(0.630)
T2018	0.131	-0.115	0.0359	-0.0716	-1.093**	-2.151***	-1.125**	-2.041***
	(0.129)	(0.167)	(0.113)	(0.124)	(0.528)	(0.644)	(0.506)	(0.681)
T2019	0.227*	-0.312	0.133	0.0261	-0.626	-2.102***	-0.630	-1.392**
	(0.133)	(0.222)	(0.111)	(0.117)	(0.500)	(0.559)	(0.488)	(0.606)
Observations	756	756	756	756	756	756	756	756

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table SI 10 PM impact on degradation and degradation net of deforestation by calendar year

	Degradation				Degradation net of deforestation			
VARIABLES	Base model	Base model with LUT	No control	No control with LUT	Base model	Base model with LUT	No control	No control with LUT
CAverage	0.0785	-0.203	-0.450***	-0.329	0.131	0.511	-0.338**	0.344
	(0.323)	(0.299)	(0.157)	(0.241)	(0.394)	(0.327)	(0.156)	(0.262)
T2009	0.439	0.0765	-0.0174	-0.290	1.279**	0.927**	0.479*	0.943***
	(0.377)	(0.393)	(0.301)	(0.225)	(0.503)	(0.466)	(0.291)	(0.292)
T2010	1.057**	1.435***	0.417**	0.886***	0.193	1.414***	0.118	0.917**
	(0.514)	(0.436)	(0.185)	(0.211)	(0.622)	(0.483)	(0.429)	(0.373)
T2011	0.705**	0.647*	0.371	0.376*	0.648	0.149	0.442	0.617
	(0.344)	(0.367)	(0.229)	(0.203)	(0.545)	(0.914)	(0.308)	(0.628)
T2012	0.408	0.00208	-0.0498	-0.311*	1.005**	0.891*	0.372	0.704***
	(0.339)	(0.355)	(0.241)	(0.185)	(0.413)	(0.460)	(0.227)	(0.231)
T2013	0.271	-0.296	0.0107	-0.209	0.716**	0.278	0.341	0.615***
	(0.249)	(0.323)	(0.222)	(0.165)	(0.352)	(0.398)	(0.232)	(0.215)
T2014	0.461	-0.0265	0.0509	-0.280	1.148***	0.866**	0.498**	0.828***
	(0.318)	(0.356)	(0.250)	(0.187)	(0.407)	(0.390)	(0.230)	(0.239)
T2015	-0.671	-1.549	-0.481	0.391	-1.338*	-2.573	-1.173*	-0.377
	(0.429)	(1.621)	(0.358)	(0.460)	(0.752)	(2.768)	(0.672)	(1.564)
T2016	-3.251***	-4.025***	-4.233***	-3.927***	-3.957*	-4.536***	-4.152***	-2.973**
	(0.815)	(0.904)	(0.847)	(1.131)	(2.075)	(1.403)	(1.049)	(1.178)
T2017	-0.203	1.657	-1.316*	-0.0498	-0.889	3.272**	-1.703*	-0.0567
	(0.777)	(1.394)	(0.775)	(0.675)	(1.482)	(1.520)	(0.967)	(0.932)
T2018	0.762*	-0.0177	0.0745	-0.153	1.232***	2.586***	0.437**	1.307***
	(0.449)	(0.572)	(0.293)	(0.240)	(0.424)	(0.808)	(0.217)	(0.437)
T2019	0.885**	-0.138	0.228	-0.0553	1.407***	2.349***	0.622***	1.263***
	(0.430)	(0.526)	(0.291)	(0.186)	(0.386)	(0.689)	(0.218)	(0.372)
Observations	756	756	756	756	756	756	756	756

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table SI 11 PM impact on fires and fires net of deforestation by calendar year

	Fires				Fires net of deforestation			
VARIABLES	Base model	Base model with LUT	No control	No control with LUT	Base model	Base model with LUT	No control	No control with LUT
CAverage	-1.038**	-0.952*	-1.079**	-1.267**	-0.404	-0.521	-0.752*	-0.122

	(0.481)	(0.535)	(0.494)	(0.574)	(0.471)	(0.532)	(0.400)	(0.489)
T2009	-2.287***	-2.934***	-1.913**	-2.931***	-1.411**	-2.616***	-1.082**	-1.119
	(0.748)	(0.861)	(0.745)	(0.920)	(0.623)	(0.800)	(0.504)	(0.703)
T2010	2.085**	3.254***	1.230	2.807***	-0.321	2.885***	-0.0239	1.126
	(1.049)	(1.071)	(0.912)	(1.040)	(1.283)	(1.078)	(0.910)	(1.072)
T2011	-2.226***	-2.233***	-1.965***	-2.394***	-1.222**	-1.488**	-1.349**	-0.878
	(0.744)	(0.729)	(0.748)	(0.794)	(0.607)	(0.599)	(0.578)	(0.588)
T2012	-0.805	-1.016*	-0.623	-1.114*	-0.354	-0.786	-0.138	0.000561
	(0.532)	(0.575)	(0.538)	(0.639)	(0.517)	(0.566)	(0.429)	(0.532)
T2013	-3.072***	-3.162***	-2.645***	-3.581***	-2.049***	-2.558***	-1.832***	-1.501**
	(0.792)	(0.803)	(0.842)	(0.937)	(0.642)	(0.766)	(0.584)	(0.750)
T2014	-1.998***	-2.272***	-1.729**	-2.496***	-1.274**	-2.278***	-1.049*	-0.775
	(0.707)	(0.781)	(0.721)	(0.893)	(0.636)	(0.783)	(0.558)	(0.751)
T2015	-1.205**	-1.402**	-1.086	-1.571*	-0.225	-0.723	-0.737	0.110
	(0.602)	(0.712)	(0.704)	(0.847)	(0.668)	(0.823)	(0.594)	(0.838)
T2016	-1.314*	-0.985	-1.649**	-1.184	-0.852	0.130	-1.702**	-0.686
	(0.764)	(0.804)	(0.758)	(0.758)	(0.985)	(0.880)	(0.800)	(0.790)
T2017	-0.482	0.912	-1.045	-0.334	1.364	3.052**	-0.721	0.818
	(0.567)	(1.006)	(0.709)	(0.601)	(1.266)	(1.349)	(0.525)	(0.669)
T2018	-0.568	-1.123*	-0.794	-1.183**	-0.0850	-2.251*	-0.548	-0.194
	(0.627)	(0.599)	(0.627)	(0.593)	(0.638)	(1.225)	(0.547)	(0.508)
T2019	0.459	0.486	0.356	0.0411	1.988***	0.903	0.913**	1.761***
	(0.509)	(0.576)	(0.517)	(0.504)	(0.529)	(1.022)	(0.414)	(0.425)
Observations	756	756	756	756	756	756	756	756

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table SI 12 PM impact on logging and logging net of deforestation

VARIABLES	(1) Base model	(2) Base model with LUT	(3) No control	(4) No control with LUT	(5) Base model	(6) Base model with LUT	(7) No control	(8) No control with LUT
CAverage	-0.00680	-0.0110	-0.00825	-0.0123	-0.000950	-0.00499	-0.00487	-0.00792
	(0.0202)	(0.0217)	(0.0197)	(0.0214)	(0.0202)	(0.0222)	(0.0210)	(0.0229)
T2009	-0.00813	-0.0170	-0.00400	-0.00388	0.00233	-0.00591	-0.00285	0.00531
	(0.0217)	(0.0217)	(0.0183)	(0.0179)	(0.0217)	(0.0206)	(0.0206)	(0.0187)
T2010	-0.000399	-0.00154	-0.00226	-0.00399	-0.00468	-0.00762	-0.00461	-0.00923
	(0.0148)	(0.0156)	(0.0149)	(0.0155)	(0.0150)	(0.0170)	(0.0161)	(0.0173)
T2011	-0.00201	-0.00401	-0.00169	-0.00531	-0.00438	-0.00736	-0.000913	-0.00748
	(0.0166)	(0.0179)	(0.0151)	(0.0162)	(0.0168)	(0.0185)	(0.0160)	(0.0171)
T2012	0.00589	0.00365	0.00314	0.000572	0.00845	0.00636	0.00179	0.000799
	(0.0254)	(0.0284)	(0.0251)	(0.0276)	(0.0264)	(0.0302)	(0.0275)	(0.0309)
T2013	-0.0148	-0.0182	-0.0185	-0.0202	-0.00830	-0.0124	-0.0221	-0.0194
	(0.0350)	(0.0383)	(0.0338)	(0.0368)	(0.0355)	(0.0403)	(0.0364)	(0.0410)
T2014	-0.0202	-0.0221	-0.0240	-0.0263	-0.0143	-0.0170	-0.0241	-0.0257
	(0.0361)	(0.0387)	(0.0348)	(0.0374)	(0.0366)	(0.0407)	(0.0372)	(0.0415)
T2015	-0.0123	-0.0169	-0.0157	-0.0207	-0.000641	-0.00361	-0.00961	-0.0104
	(0.0248)	(0.0270)	(0.0232)	(0.0262)	(0.0247)	(0.0275)	(0.0251)	(0.0284)
T2016	-0.0195	-0.0275	-0.0218	-0.0289	-0.00868	-0.0165	-0.0124	-0.0206
	(0.0248)	(0.0270)	(0.0238)	(0.0272)	(0.0244)	(0.0272)	(0.0252)	(0.0291)
T2017	-0.0157	-0.0279	-0.0152	-0.0254	-0.00671	-0.0207	-0.00593	-0.0219
	(0.0258)	(0.0276)	(0.0253)	(0.0283)	(0.0252)	(0.0277)	(0.0267)	(0.0301)
T2018	0.00279	-0.000405	-0.000150	-0.00710	0.00795	0.00651	0.00834	0.00134
	(0.0246)	(0.0257)	(0.0219)	(0.0231)	(0.0240)	(0.0264)	(0.0235)	(0.0257)
T2019	0.00953	0.0113	0.00928	0.00640	0.0185	0.0233	0.0188	0.0202
	(0.0281)	(0.0295)	(0.0243)	(0.0255)	(0.0274)	(0.0305)	(0.0261)	(0.0285)
Observations	2,840	2,840	2,840	2,840	2,840	2,840	2,840	2,840

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

f. Full results, policies impact on deforestation, degradation, fires, logging, and by intact and degraded forest

Table SI 13 Number of treated (1) and control (0) units at every calendar period for all policies

	SoyM			PM			G4			TAC		
YEAR	0	1	Total	0	1	Total	0	1	Total	0	1	Total
2007	57	0	57	.	.	.	.	.	.	.	.	.
2008	49	8	57	63	0	63	.	.	.	.	.	.
2009	45	12	57	33	30	63	.	.	.	.	.	.
2010	41	16	57	27	36	63	.	.	.	.	.	.
2011	38	19	57	27	36	63	125	19	144	230	0	230
2012	36	21	57	24	39	63	125	38	163	163	3	166
2013	33	24	57	22	41	63	101	54	155	146	18	164
2014	30	27	57	22	41	63	103	72	175	142	21	163
2015	30	27	57	22	41	63	124	80	204	96	42	138
2016	27	30	57	22	41	63	124	83	207	82	107	189
2017	26	31	57	22	41	63	141	49	190	84	118	202
2018	25	32	57	17	46	63	133	56	189	87	128	215
2019	23	34	57	15	48	63	113	52	165	58	107	165

i. G4 and TAC cattle agreement:

TAC and G4 policies are evaluated by discretizing the continuous market share variable at various thresholds: below/above zero, below/above the median and above 75% vs below 50% (i.e. dropping observations between the median and the top 25% of the distribution). The first threshold represents the presence vs absence of the policy, while the other two, when evaluated together, indicate whether the impact of the policy is monotonically increasing in market share, as posited by Garrett et al. (2019). The preferred specification is at the highest threshold

In result tables, each set of three columns reports on a different threshold. The three sub columns report the p-value of the placebo F test for parallel trends, the estimated average treatment effect and its p-value. Results are aggregated for a different number of periods pre and post treatment: Short=3 periods; Medium=5 periods; Long=7 periods

a. G4 cattle agreement:

Table SI 14 Summary results G4: deforestation, degradation and degradation net of deforestation

	G4			G4			G4		
Threshold	0			50			75		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
Short term									
	base								
def	0.000	0.215	0.040	0.101	-0.172	0.010	0.264	-0.132	0.001
deg	0.010	0.423	0.164	0.737	-0.351	0.020	0.222	-0.316	0.075
degCdef	0.000	-0.531	0.030	0.012	-0.100	0.495	0.053	-0.077	0.595
	LUT								
def	0.000	0.426	0.000	0.000	-0.341	0.000	0.014	-0.127	0.001
deg	0.259	0.501	0.070	0.999	-0.464	0.000	0.141	-0.138	0.133
degCdef	0.011	-0.433	0.096	0.000	0.048	0.701	0.042	0.111	0.197
					no controls				
def	0.000	0.223	0.016	0.073	-0.172	0.013	0.193	-0.146	0.000
deg	0.002	0.085	0.362	0.067	-0.524	0.000	0.004	-0.409	0.013
degCdef	0.000	-0.837	0.001	0.000	-0.249	0.025	0.072	-0.124	0.338
					no controls LUT				
def	0.000	0.293	0.006	0.000	-0.341	0.000	0.080	-0.048	0.232
deg	0.041	0.145	0.203	0.593	-0.563	0.000	0.018	-0.050	0.576
degCdef	0.023	-0.529	0.033	0.000	-0.036	0.757	0.000	0.029	0.587
Medium term									
	base								
def	0.000	0.532	0.007	0.101	-0.030	0.802	0.264	-0.111	0.003
deg	0.010	1.188	0.313	0.737	-0.391	0.037	0.222	-0.312	0.019
degCdef	0.000	-0.747	0.385	0.012	-0.401	0.031	0.053	-0.100	0.416
	LUT								
def	0.000	0.651	0.002	0.000	-0.267	0.039	0.014	-0.144	0.000
deg	0.259	0.207	0.827	0.999	-0.895	0.000	0.141	-0.235	0.019
degCdef	0.011	-1.379	0.042	0.000	-0.465	0.046	0.042	0.030	0.756
	no controls								
def	0.000	0.475	0.002	0.073	-0.097	0.233	0.193	-0.119	0.001
deg	0.002	0.237	0.521	0.067	-0.617	0.000	0.004	-0.322	0.016
degCdef	0.000	-1.490	0.001	0.000	-0.532	0.001	0.072	-0.084	0.496
	no controls LUT								
def	0.000	0.399	0.016	0.000	-0.341	0.001	0.080	-0.060	0.126
deg	0.041	-0.903	0.071	0.593	-1.151	0.000	0.018	-0.143	0.133
degCdef	0.023	-1.914	0.000	0.000	-0.618	0.005	0.000	-0.066	0.330
Long term									

	base								
def	0.000	0.606	0.010	0.101	0.046	0.746	0.264	-0.111	0.007
deg	0.010	1.850	0.286	0.737	-0.372	0.073	0.222	-0.390	0.002
degCdef	0.000	-0.281	0.830	0.012	-0.594	0.007	0.053	-0.176	0.167
	LUT								
def	0.000	0.752	0.002	0.000	-0.170	0.227	0.014	-0.165	0.000
deg	0.259	0.767	0.515	0.999	-0.885	0.000	0.141	-0.290	0.004
degCdef	0.011	-1.169	0.138	0.000	-0.681	0.004	0.042	0.012	0.883
	no controls								
def	0.000	0.480	0.002	0.073	-0.050	0.648	0.193	-0.105	0.012
deg	0.002	0.298	0.350	0.067	-0.642	0.000	0.004	-0.294	0.020
degCdef	0.000	-1.423	0.010	0.000	-0.704	0.001	0.072	-0.085	0.507
	no controls LUT								
def	0.000	0.433	0.005	0.000	-0.259	0.024	0.080	-0.073	0.115
deg	0.041	-0.802	0.049	0.593	-1.163	0.000	0.018	-0.183	0.055
degCdef	0.023	-1.963	0.000	0.000	-0.824	0.000	0.000	-0.088	0.260

Table SI 15 Summary results G4: deforestation, fires and fires net of deforestation

	G4			G4			G4		
	0			50			75		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
Short term									
	base								
def	0.000	0.215	0.040	0.101	-0.172	0.010	0.264	-0.132	0.001
fires	0.000	-0.800	0.044	0.476	-0.650	0.009	0.013	-0.612	0.001
firesCdef	0.000	-0.812	0.046	0.012	-0.475	0.042	0.002	-0.447	0.007
	LUT								
def	0.000	0.426	0.000	0.000	-0.341	0.000	0.014	-0.127	0.001
fires	0.000	-0.142	0.751	0.934	-0.247	0.556	0.290	-0.600	0.004
firesCdef	0.001	-0.790	0.075	0.350	0.126	0.774	0.345	-0.398	0.037
	no controls								
def	0.000	0.223	0.016	0.073	-0.172	0.013	0.193	-0.146	0.000
fires	0.000	-0.113	0.744	0.200	-0.498	0.037	0.010	-0.686	0.000
firesCdef	0.000	-0.210	0.556	0.006	-0.342	0.130	0.004	-0.518	0.002
	No controls LUT								
def	0.000	0.293	0.006	0.000	-0.341	0.000	0.080	-0.048	0.232
fires	0.000	0.011	0.976	0.513	-0.186	0.653	0.421	-0.473	0.021
firesCdef	0.006	-0.405	0.298	0.140	0.178	0.681	0.471	-0.455	0.016
Medium term									
	base								
def	0.000	0.532	0.007	0.101	-0.030	0.802	0.264	-0.111	0.003
fires	0.000	-0.432	0.559	0.476	-0.430	0.201	0.013	-0.758	0.000

firesCdef	0.000	-0.737	0.358	0.012	-0.442	0.155	0.002	-0.647	0.001
	LUT								
def	0.000	0.651	0.002	0.000	-0.267	0.039	0.014	-0.144	0.000
fires	0.000	0.302	0.672	0.934	0.241	0.665	0.290	-0.969	0.000
firesCdef	0.001	-0.614	0.391	0.350	0.501	0.358	0.345	-0.782	0.001
	no controls								
def	0.000	0.475	0.002	0.073	-0.097	0.233	0.193	-0.119	0.001
fires	0.000	0.490	0.400	0.200	-0.276	0.380	0.010	-0.864	0.000
firesCdef	0.000	0.169	0.778	0.006	-0.180	0.537	0.004	-0.743	0.000
	No controls LUT								
def	0.000	0.399	0.016	0.000	-0.341	0.001	0.080	-0.060	0.126
fires	0.000	0.433	0.427	0.513	0.083	0.866	0.421	-0.784	0.003
firesCdef	0.006	-0.059	0.916	0.140	0.429	0.402	0.471	-0.771	0.002
Long term									
	base								
def	0.000	0.606	0.010	0.101	0.046	0.746	0.264	-0.111	0.007
fires	0.000	-0.491	0.610	0.476	-0.353	0.434	0.013	-0.697	0.002
firesCdef	0.000	-0.888	0.401	0.012	-0.428	0.283	0.002	-0.603	0.005
	LUT								
def	0.000	0.752	0.002	0.000	-0.170	0.227	0.014	-0.165	0.000
fires	0.000	0.577	0.484	0.934	0.280	0.614	0.290	-0.997	0.001
firesCdef	0.001	-0.460	0.561	0.350	0.434	0.415	0.345	-0.789	0.005
	no controls								
def	0.000	0.480	0.002	0.073	-0.050	0.648	0.193	-0.105	0.012
fires	0.000	0.568	0.490	0.200	-0.130	0.765	0.010	-0.825	0.001
firesCdef	0.000	0.231	0.777	0.006	-0.069	0.855	0.004	-0.725	0.002
	no control LUT								
def	0.000	0.433	0.005	0.000	-0.259	0.024	0.080	-0.073	0.115
fires	0.000	0.680	0.292	0.513	0.214	0.673	0.421	-0.827	0.008
firesCdef	0.006	0.156	0.808	0.140	0.474	0.345	0.471	-0.793	0.008

Table SI 16 Summary results G4: deforestation, logging and logging net of deforestation

	G4			G4			G4		
	0			50			75		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
Short term									
	base								
def	0.000	0.215	0.040	0.101	-0.172	0.010	0.264	-0.132	0.001
logging	0.000	0.004	0.826	0.000	0.010	0.605	0.563	0.007	0.265
loggingCdef	0.000	0.003	0.870	0.000	0.011	0.585	0.569	0.007	0.279
	LUT								
def	0.000	0.426	0.000	0.000	-0.341	0.000	0.014	-0.127	0.001

logging	0.000	-0.018	0.353	0.000	-0.027	0.585	0.623	0.018	0.004
loggingCdef	0.000	-0.014	0.456	0.000	-0.027	0.587	0.629	0.018	0.005
	no controls								
def	0.000	0.223	0.016	0.073	-0.172	0.013	0.193	-0.146	0.000
logging	0.000	-0.003	0.881	0.019	0.009	0.665	0.525	0.012	0.091
loggingCdef	0.000	-0.004	0.844	0.019	0.009	0.644	0.528	0.012	0.098
	No controls LUT								
def	0.000	0.223	0.016	0.073	-0.172	0.013	0.193	-0.146	0.000
logging	0.000	-0.003	0.881	0.019	0.009	0.665	0.525	0.012	0.091
loggingCdef	0.000	-0.004	0.844	0.019	0.009	0.644	0.528	0.012	0.098
Medium term									
	base								
def	0.000	0.532	0.007	0.101	-0.030	0.802	0.264	-0.111	0.003
logging	0.000	-0.017	0.640	0.000	0.023	0.329	0.563	0.012	0.246
loggingCdef	0.000	-0.018	0.604	0.000	0.023	0.330	0.569	0.012	0.252
	LUT								
def	0.000	0.651	0.002	0.000	-0.267	0.039	0.014	-0.144	0.000
logging	0.000	-0.054	0.093	0.000	-0.018	0.755	0.623	0.023	0.024
loggingCdef	0.000	-0.050	0.124	0.000	-0.018	0.759	0.629	0.022	0.030
	no controls								
def	0.000	0.475	0.002	0.073	-0.097	0.233	0.193	-0.119	0.001
logging	0.000	-0.017	0.604	0.019	0.016	0.493	0.525	0.018	0.080
loggingCdef	0.000	-0.018	0.572	0.019	0.017	0.489	0.528	0.017	0.084
	No controls LUT								
def	0.000	0.475	0.002	0.073	-0.097	0.233	0.193	-0.119	0.001
logging	0.000	-0.017	0.604	0.019	0.016	0.493	0.525	0.018	0.080
loggingCdef	0.000	-0.018	0.572	0.019	0.017	0.489	0.528	0.017	0.084
Long term									
	base								
def	0.000	0.606	0.010	0.101	0.046	0.746	0.264	-0.111	0.007
logging	0.000	-0.035	0.487	0.000	0.024	0.327	0.563	0.013	0.272
loggingCdef	0.000	-0.037	0.463	0.000	0.024	0.341	0.569	0.013	0.279
	LUT								
def	0.000	0.752	0.002	0.000	-0.170	0.227	0.014	-0.165	0.000
logging	0.000	-0.084	0.054	0.000	-0.003	0.954	0.623	0.021	0.058
loggingCdef	0.000	-0.079	0.067	0.000	-0.004	0.953	0.629	0.020	0.073
	no controls								
def	0.000	0.480	0.002	0.073	-0.050	0.648	0.193	-0.105	0.012
logging	0.000	-0.028	0.498	0.019	0.017	0.498	0.525	0.019	0.090
loggingCdef	0.000	-0.029	0.475	0.019	0.017	0.504	0.528	0.019	0.094
	no controls LUT								
def	0.000	0.433	0.005	0.000	-0.259	0.024	0.080	-0.073	0.115
logging	0.000	-0.078	0.075	0.000	-0.014	0.826	0.650	0.019	0.053
loggingCdef	0.000	-0.076	0.086	0.000	-0.014	0.825	0.677	0.018	0.071

Table SI 17 Summary results G4: deforestation of intact and degraded forests

	G4			G4			G4		
	0			50			75		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
Short term									
	base								
def int for	0.000	0.224	0.000	0.002	-0.087	0.062	0.398	-0.095	0.002
def deg for	0.000	1.030	0.076	0.000	-1.353	0.001	0.004	0.057	0.780
	LUT								
def int for	0.000	0.322	0.000	0.000	-0.203	0.015	0.041	-0.106	0.001
def deg for	0.005	1.817	0.007	0.000	-1.659	0.000	0.160	-0.378	0.192
	no control								
def int for	0.000	0.167	0.001	0.043	-0.106	0.025	0.042	-0.108	0.000
def deg for	0.000	1.211	0.016	0.000	-1.178	0.003	0.037	-0.060	0.768
	LUT no control								
def int for	0.000	0.218	0.000	0.000	-0.219	0.005	0.507	-0.041	0.229
def deg for	0.000	1.568	0.014	0.000	-1.481	0.000	0.109	0.070	0.790
Medium term									
	base								
def int for	0.000	0.478	0.000	0.002	0.006	0.941	0.398	-0.098	0.002
def deg for	0.000	2.208	0.102	0.000	-0.530	0.438	0.004	0.380	0.170
	LUT								
def int for	0.000	0.497	0.000	0.000	-0.163	0.144	0.041	-0.112	0.000
def deg for	0.005	3.089	0.014	0.000	-1.062	0.036	0.160	-0.142	0.663
	no control								
def int for	0.000	0.381	0.000	0.043	-0.049	0.414	0.042	-0.094	0.004
def deg for	0.000	1.735	0.042	0.000	-0.841	0.048	0.037	0.191	0.374
	no control lut								
def int for	0.000	0.381	0.000	0.043	-0.049	0.414	0.042	-0.094	0.004
def deg for	0.000	1.735	0.042	0.000	-0.841	0.048	0.037	0.191	0.374
Long term									
	base								
def int for	0.000	0.547	0.000	0.002	0.078	0.417	0.398	-0.102	0.008
def deg for	0.000	2.634	0.156	0.000	-0.486	0.497	0.004	0.393	0.129
	LUT								
def int for	0.000	0.575	0.000	0.000	-0.072	0.529	0.041	-0.124	0.001
def deg for	0.005	3.574	0.032	0.000	-0.962	0.059	0.160	-0.203	0.518
	no controls								
def int for	0.000	0.407	0.000	0.043	0.006	0.938	0.042	-0.080	0.053
def deg for	0.000	1.507	0.099	0.000	-0.842	0.109	0.037	0.224	0.230
	no controls LUT								
def int for	0.000	0.364	0.000	0.000	-0.143	0.158	0.507	-0.039	0.384

def deg for	0.000	1.734	0.070	0.000	-1.248	0.000	0.109	0.107	0.683

b. TAC terms of adjustments of conduct

Table SI 18 Summary results TAC: deforestation, degradation and degradation net of deforestation

	TAC			TAC			TAC		
	0.000			50.000			75.000		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
Short term									
	base								
def	0.747	-0.007	0.931	0.053	-0.163	0.011	0.503	-0.239	0.002
deg	0.411	0.065	0.437	0.000	-0.001	0.994	0.252	-0.173	0.016
degCdef	0.317	0.095	0.189	0.016	0.152	0.033	0.348	0.104	0.250
	LUT								
def	0.001	0.011	0.797	0.000	-0.123	0.058	0.007	-0.133	0.032
deg	0.001	0.017	0.596	0.000	0.064	0.134	0.003	-0.071	0.018
degCdef	0.002	0.011	0.776	0.109	0.168	0.001	0.836	0.069	0.261
	no control								
def	0.770	0.003	0.971	0.099	-0.174	0.010	0.430	-0.251	0.001
deg	0.184	0.081	0.232	0.000	0.011	0.877	0.034	-0.141	0.030
degCdef	0.197	0.095	0.258	0.003	0.176	0.020	0.070	0.152	0.114
	LUT no control								
def	0.005	0.018	0.672	0.000	-0.133	0.052	0.002	-0.141	0.034
deg	0.000	0.039	0.241	0.000	0.073	0.097	0.000	-0.055	0.070
degCdef	0.002	0.025	0.585	0.020	0.185	0.000	0.223	0.094	0.154
Medium term									
	base								
def	0.873	-0.004	0.967	0.087	-0.119	0.071	0.044	-0.202	0.007
deg	0.524	0.171	0.152	0.000	0.198	0.099	0.384	0.054	0.748
degCdef	0.414	0.197	0.056	0.036	0.312	0.008	0.005	0.287	0.094
	LUT								
def	0.003	0.055	0.276	0.000	-0.087	0.199	0.011	-0.117	0.093
deg	0.000	0.168	0.012	0.000	0.230	0.001	0.008	0.135	0.121
degCdef	0.000	0.122	0.096	0.145	0.307	0.000	0.140	0.259	0.013
	no controls								
def	0.881	0.011	0.897	0.166	-0.137	0.050	0.095	-0.223	0.004
deg	0.272	0.224	0.027	0.000	0.215	0.071	0.067	0.085	0.598
degCdef	0.273	0.229	0.068	0.007	0.350	0.004	0.020	0.348	0.046
	no controls LUT								
def	0.011	0.053	0.321	0.000	-0.102	0.158	0.004	-0.134	0.080
deg	0.000	0.203	0.003	0.000	0.244	0.001	0.000	0.143	0.108

degCdef	0.000	0.159	0.059	0.028	0.334	0.000	0.127	0.286	0.010
Long term									
	base								
def	0.873	-0.029	0.779	0.087	-0.126	0.064	0.044	-0.205	0.007
deg	0.524	0.191	0.077	0.000	0.199	0.064	0.384	0.050	0.744
degCdef	0.414	0.242	0.017	0.036	0.319	0.006	0.005	0.288	0.087
	LUT								
def	0.003	0.049	0.328	0.000	-0.096	0.172	0.011	-0.146	0.056
deg	0.000	0.209	0.000	0.000	0.220	0.001	0.008	0.104	0.180
degCdef	0.000	0.168	0.014	0.145	0.303	0.000	0.140	0.256	0.008
	no controls								
def	0.881	-0.016	0.856	0.166	-0.149	0.039	0.095	-0.231	0.003
deg	0.272	0.254	0.004	0.000	0.219	0.041	0.067	0.083	0.568
degCdef	0.273	0.291	0.035	0.007	0.364	0.003	0.020	0.357	0.039
	no controls LUT								
def	0.011	0.032	0.564	0.000	-0.119	0.119	0.004	-0.166	0.047
deg	0.000	0.251	0.000	0.000	0.239	0.000	0.000	0.117	0.143
degCdef	0.000	0.226	0.009	0.028	0.343	0.000	0.127	0.294	0.008

Table SI 19 Summary results TAC: deforestation, fires and fires net of deforestation

	TAC			TAC			TAC		
	0			50			75		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
Short term									
	base								
Def	0.747	-0.007	0.931	0.053	-0.163	0.011	0.503	-0.239	0.002
Fires	0.000	-0.929	0.018	0.071	-0.784	0.002	0.002	-0.530	0.032
FiresCdef	0.000	-1.014	0.003	0.222	-0.620	0.006	0.023	-0.276	0.200
	LUT								
Def	0.001	0.011	0.797	0.000	-0.123	0.058	0.007	-0.133	0.032
Fires	0.000	-0.763	0.001	0.014	-0.722	0.002	0.000	-0.259	0.351
FiresCdef	0.000	-0.801	0.000	0.009	-0.635	0.001	0.000	-0.134	0.582
	no controls								
Def	0.770	0.003	0.971	0.099	-0.174	0.010	0.430	-0.251	0.001
Fires	0.002	-0.787	0.040	0.019	-0.799	0.001	0.000	-0.537	0.025
FiresCdef	0.008	-0.844	0.012	0.067	-0.632	0.003	0.002	-0.275	0.185
	no controls LUT								
Def	0.005	0.018	0.672	0.000	-0.133	0.052	0.002	-0.141	0.034
Fires	0.000	-0.604	0.009	0.002	-0.714	0.002	0.000	-0.260	0.358
FiresCdef	0.000	-0.637	0.002	0.001	-0.625	0.001	0.000	-0.126	0.606
Medium term									

	base								
Def	0.873	-0.004	0.967	0.087	-0.119	0.071	0.044	-0.202	0.007
Fires	0.000	-0.961	0.059	0.022	-0.805	0.008	0.000	-0.609	0.034
FiresCdef	0.001	-1.068	0.015	0.297	-0.695	0.009	0.000	-0.380	0.132
	LUT								
Def	0.873	-0.004	0.967	0.087	-0.119	0.071	0.044	-0.202	0.007
Fires	0.000	-0.961	0.059	0.022	-0.805	0.008	0.000	-0.609	0.034
FiresCdef	0.001	-1.068	0.015	0.297	-0.695	0.009	0.000	-0.380	0.132
	no controls LUT								
Def	0.881	0.011	0.897	0.166	-0.137	0.050	0.095	-0.223	0.004
Fires	0.004	-0.829	0.088	0.011	-0.809	0.006	0.000	-0.632	0.022
FiresCdef	0.013	-0.917	0.034	0.125	-0.692	0.008	0.000	-0.396	0.100
	No controls LUT								
Def	0.011	0.053	0.321	0.000	-0.102	0.158	0.004	-0.134	0.080
Fires	0.000	-0.530	0.104	0.003	-0.734	0.009	0.000	-0.444	0.212
FiresCdef	0.000	-0.621	0.033	0.002	-0.681	0.004	0.000	-0.320	0.297
Long term									
	Base								
Def	0.873	-0.029	0.779	0.087	-0.126	0.064	0.044	-0.205	0.007
Fires	0.000	-0.954	0.083	0.022	-0.829	0.012	0.000	-0.614	0.052
FiresCdef	0.001	-1.030	0.027	0.297	-0.712	0.014	0.000	-0.386	0.162
	LUT								
Def	0.003	0.049	0.328	0.000	-0.096	0.172	0.011	-0.146	0.056
Fires	0.000	-0.710	0.056	0.009	-0.828	0.008	0.000	-0.530	0.196
FiresCdef	0.000	-0.806	0.016	0.016	-0.768	0.004	0.000	-0.384	0.286
	No controls								
Def	0.881	-0.016	0.856	0.166	-0.149	0.039	0.095	-0.231	0.003
Fires	0.004	-0.865	0.096	0.011	-0.817	0.011	0.000	-0.672	0.027
FiresCdef	0.013	-0.935	0.042	0.125	-0.691	0.014	0.000	-0.436	0.098
	No controls LUT								
Def	0.011	0.032	0.564	0.000	-0.119	0.119	0.004	-0.166	0.047
Fires	0.000	-0.541	0.144	0.003	-0.795	0.010	0.000	-0.615	0.123
FiresCdef	0.000	-0.605	0.066	0.002	-0.728	0.006	0.000	-0.461	0.178

Table SI 20 Summary results TAC: deforestation, logging and logging net of deforestation

	TAC			TAC			TAC		
	0			50			75		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
Short term									
	base								
Def	0.747	-0.007	0.931	0.053	-0.163	0.011	0.503	-0.239	0.002
Logging	0.365	0.018	0.470	0.277	0.023	0.183	0.182	0.027	0.066
LoggingCdef	0.398	0.018	0.470	0.271	0.023	0.186	0.182	0.027	0.067

	LUT								
Def	0.001	0.011	0.797	0.000	-0.123	0.058	0.007	-0.133	0.032
Logging	0.689	0.002	0.913	0.017	0.021	0.104	0.145	0.008	0.545
LoggingCdef	0.614	0.001	0.922	0.016	0.021	0.105	0.144	0.008	0.549
	No controls								
Def	0.770	0.003	0.971	0.099	-0.174	0.010	0.430	-0.251	0.001
Logging	0.575	0.019	0.433	0.331	0.026	0.115	0.284	0.031	0.034
LoggingCdef	0.601	0.019	0.434	0.315	0.026	0.120	0.281	0.030	0.036
	No controls LUT								
Def	0.005	0.018	0.672	0.000	-0.133	0.052	0.002	-0.141	0.034
Logging	0.318	0.001	0.933	0.031	0.020	0.120	0.217	0.009	0.514
LoggingCdef	0.382	0.001	0.950	0.030	0.020	0.123	0.216	0.008	0.524
Medium term									
	base								
Def	0.873	-0.004	0.967	0.087	-0.119	0.071	0.044	-0.202	0.007
Logging	0.000	0.019	0.583	0.018	0.023	0.311	0.026	0.026	0.206
LoggingCdef	0.000	0.019	0.582	0.017	0.023	0.314	0.026	0.026	0.207
	LUT								
Def	0.003	0.055	0.276	0.000	-0.087	0.199	0.011	-0.117	0.093
Logging	0.000	0.004	0.841	0.029	0.024	0.205	0.140	0.004	0.807
LoggingCdef	0.000	0.003	0.889	0.028	0.024	0.207	0.140	0.004	0.810
	No controls								
Def	0.881	0.011	0.897	0.166	-0.137	0.050	0.095	-0.223	0.004
Logging	0.000	0.019	0.572	0.017	0.028	0.214	0.007	0.031	0.118
LoggingCdef	0.000	0.019	0.575	0.015	0.027	0.219	0.007	0.031	0.121
	No controls LUT								
Def	0.011	0.053	0.321	0.000	-0.102	0.158	0.004	-0.134	0.080
Logging	0.000	0.001	0.978	0.050	0.021	0.269	0.202	0.005	0.789
LoggingCdef	0.000	-0.001	0.978	0.049	0.021	0.272	0.199	0.005	0.796
Long term									
	base								
Def	0.873	-0.029	0.779	0.087	-0.126	0.064	0.044	-0.205	0.007
Logging	0.000	0.012	0.731	0.018	0.022	0.354	0.026	0.025	0.247
LoggingCdef	0.000	0.012	0.726	0.017	0.022	0.357	0.026	0.025	0.248
	LUT								
Def	0.003	0.049	0.328	0.000	-0.096	0.172	0.011	-0.146	0.056
Logging	0.000	0.002	0.934	0.029	0.026	0.208	0.140	0.003	0.866
LoggingCdef	0.000	0.001	0.976	0.028	0.026	0.210	0.140	0.003	0.869
	No controls								
Def	0.881	-0.016	0.856	0.166	-0.149	0.039	0.095	-0.231	0.003
Logging	0.000	0.011	0.755	0.017	0.027	0.250	0.007	0.032	0.143
LoggingCdef	0.000	0.011	0.752	0.015	0.027	0.255	0.007	0.032	0.146
	No controls LUT								
Def	0.011	0.032	0.564	0.000	-0.119	0.119	0.004	-0.166	0.047

Logging	0.000	-0.006	0.826	0.050	0.022	0.289	0.202	0.005	0.816
LoggingCdef	0.000	-0.006	0.796	0.049	0.022	0.292	0.199	0.005	0.824

Table SI 21 Summary results TAC: deforestation of intact and degraded forests

	TAC			TAC			TAC		
	0			50			75		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
Short term									
	base								
Def int for	0.759	-0.020	0.721	0.449	-0.099	0.036	0.982	-0.157	0.008
Def deg for	0.351	0.570	0.088	0.000	-0.140	0.585	0.000	-0.577	0.024
	LUT								
Def int for	0.004	0.004	0.902	0.000	-0.080	0.110	0.202	-0.085	0.088
Def deg for	0.000	0.153	0.428	0.000	-0.285	0.320	0.000	-0.679	0.008
	No controls								
Def int for	0.801	-0.012	0.836	0.447	-0.114	0.027	0.944	-0.167	0.006
Def deg for	0.331	0.524	0.037	0.001	-0.074	0.765	0.000	-0.601	0.018
	No controls LUT								
Def int for	0.007	0.004	0.914	0.001	-0.095	0.077	0.272	-0.093	0.084
Def deg for	0.004	0.300	0.072	0.000	-0.260	0.347	0.000	-0.724	0.003
Medium term									
	base								
Def int for	0.871	-0.009	0.903	0.610	-0.072	0.175	0.000	-0.139	0.026
Def deg for	0.480	0.593	0.116	0.001	-0.098	0.679	0.000	-0.570	0.019
	LUT								
Def int for	0.009	0.047	0.240	0.000	-0.048	0.371	0.060	-0.070	0.234
Def deg for	0.000	0.282	0.186	0.000	-0.195	0.465	0.000	-0.664	0.008
	No controls								
Def int for	0.907	-0.004	0.953	0.606	-0.101	0.091	0.004	-0.167	0.012
Def deg for	0.410	0.607	0.015	0.001	-0.009	0.968	0.000	-0.539	0.022
	No controls LUT								
Def int for	0.017	0.036	0.440	0.001	-0.076	0.207	0.272	-0.092	0.161
Def deg for	0.001	0.452	0.007	0.000	-0.138	0.577	0.000	-0.648	0.005
Long term									
	base								
Def int for	0.871	-0.030	0.690	0.610	-0.083	0.146	0.000	-0.148	0.022
Def deg for	0.480	0.473	0.259	0.001	-0.119	0.607	0.000	-0.722	0.003
	LUT								
Def int for	0.009	0.037	0.320	0.000	-0.060	0.293	0.060	-0.094	0.144
Def deg for	0.000	0.291	0.187	0.000	-0.137	0.595	0.000	-0.857	0.001
	No controls								
Def int for	0.907	-0.028	0.713	0.606	-0.115	0.071	0.004	-0.180	0.010

Def deg for	0.410	0.522	0.042	0.001	-0.042	0.840	0.000	-0.702	0.002
	No controls LUT								
Def int for	0.017	0.021	0.663	0.001	-0.094	0.148	0.272	-0.120	0.097
Def deg for	0.001	0.363	0.015	0.000	-0.134	0.575	0.000	-0.862	0.001

ii. Soy Moratorium

Following Gollnow, Cammelli, Carlson and Garrett (41) we restricted the sample of analysis to municipalities that produced soy throughout the study period because SoyM market share would have been artificially absent at other locations. We conduct the analysis at one single threshold, 50%, because the market share values are very skewed at the extremes. The three sub columns report the p-value of the placebo F test for parallel trends, the estimated average treatment effect and its p-value. Results are aggregated for a different number of periods pre and post treatment: Short=3 periods; Medium=5 periods; Long=10 periods

Table SI 22 Summary results SoyM: Deforestation, degradation and degradation net of deforestation

	SoyM			SoyM			SoyM		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
	Short term			Medium term			Long term		
	base			base			base		
Def	0.493	-0.636	0.017	0.151	-0.818	0.008	0.054	-1.023	0.006
Deg	0.255	-0.527	0.062	0.603	-0.743	0.066	0.815	-1.238	0.004
Deg C def	0.192	-0.150	0.554	0.416	-0.161	0.593	0.837	-0.325	0.398
	LUT			LUT			LUT		
Def	0.452	-0.896	0.010	0.614	-1.019	0.006	0.005	-1.146	0.004
Deg	0.090	-0.569	0.138	0.120	-0.426	0.284	0.024	-0.886	0.028
Deg C def	0.058	-0.039	0.892	0.086	0.203	0.503	0.030	-0.077	0.829
	no control			no control			no control		
Def	0.235	-0.328	0.228	0.023	-0.439	0.144	0.354	-0.648	0.065
Deg	0.434	0.086	0.749	0.053	0.043	0.859	0.000	-0.183	0.497
Deg C def	0.954	0.342	0.130	0.453	0.392	0.053	0.636	0.494	0.116
	no control LUT			no control LUT			no control LUT		
Def	0.939	-0.609	0.028	0.383	-0.731	0.017	0.203	-0.933	0.007
Deg	0.572	0.095	0.726	0.812	0.177	0.576	0.969	-0.085	0.832
Deg C def	0.379	0.506	0.046	0.983	0.565	0.066	0.772	0.509	0.228

Table SI 23 Summary results SoyM: Deforestation, fires and fires net of deforestation

	Short term			Medium term			Long term		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
	base			base			base		
Def	0.493	-0.636	0.017	0.151	-0.818	0.008	0.054	-1.023	0.006
Fires	0.731	-2.050	0.098	0.996	-2.079	0.128	0.731	-2.221	0.221

Fires C def	0.106	-0.959	0.227	0.120	-0.312	0.731	0.244	0.375	0.778
	LUT			LUT			LUT		
Def	0.452	-0.896	0.010	0.614	-1.019	0.006	0.005	-1.146	0.004
Fires	0.710	-2.437	0.060	0.533	-2.460	0.088	0.093	-2.781	0.125
Fires C def	0.408	-1.494	0.126	0.553	-0.903	0.394	0.039	-0.588	0.632
	No controls			no controls			No controls		
Def	0.235	-0.328	0.228	0.023	-0.439	0.144	0.354	-0.648	0.065
Fires	0.352	-1.359	0.298	0.133	-1.796	0.213	0.407	-2.844	0.119
Fires C def	0.393	-0.706	0.401	0.365	-0.713	0.422	0.401	-1.141	0.333
	No controls LUT			No control LUT			No controls LUT		
Def	0.939	-0.609	0.028	0.383	-0.731	0.017	0.203	-0.933	0.007
Fires	0.636	-1.926	0.138	0.879	-2.547	0.082	0.603	-3.951	0.039
Fires C def	0.359	-1.186	0.224	0.118	-1.348	0.183	0.299	-2.048	0.152

Table SI 24 Summary results SoyM: Deforestation, logging and logging net of deforestation

	Short term			Medium term			Long term		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
	base			base			base		
Def	0.493	-0.636	0.017	0.151	-0.818	0.008	0.054	-1.023	0.006
Logging	0.648	-0.038	0.328	0.268	-0.030	0.559	0.069	-0.071	0.291
Logging C def	0.563	-0.032	0.460	0.527	-0.003	0.962	0.203	-0.016	0.831
	LUT			LUT			LUT		
Def	0.452	-0.896	0.010	0.614	-1.019	0.006	0.005	-1.146	0.004
Logging	0.212	-0.100	0.067	0.240	-0.065	0.273	0.836	-0.103	0.173
Logging C def	0.130	-0.107	0.061	0.373	-0.071	0.243	0.918	-0.070	0.368
	No controls			No controls			No controls		
Def	0.235	-0.328	0.228	0.023	-0.439	0.144	0.354	-0.648	0.065
Logging	0.875	-0.035	0.305	0.492	-0.040	0.284	0.476	-0.078	0.100
Logging C def	0.579	-0.038	0.276	0.897	-0.027	0.506	0.497	-0.036	0.510
	No controls LUT			No controls LUT			No controls LUT		
Def	0.939	-0.609	0.028	0.383	-0.731	0.017	0.354	-0.648	0.065
Logging	0.270	-0.022	0.539	0.421	-0.034	0.405	0.476	-0.078	0.100
Logging C def	0.477	-0.039	0.325	0.501	-0.059	0.190	0.497	-0.036	0.510

Table SI 25 Summary results SoyM: deforestation of intact and degraded forests

	SoyM			SoyM			SoyM		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
	Short term			Medium term			long term		
	base			base			base		
Def int for	0.637	-0.479	0.008	0.204	-0.618	0.005	0.066	-0.782	0.003

Def deg for	0.807	-1.996	0.034	0.325	-2.448	0.016	0.433	-3.058	0.014
	LUT			LUT			LUT		
Def int for	0.347	-0.630	0.020	0.526	-0.740	0.009	0.008	-0.847	0.006
Def deg for	0.919	-2.569	0.024	0.528	-2.986	0.012	0.020	-3.401	0.010
	No controls			No controls			No controls		
Def int for	0.249	-0.210	0.251	0.035	-0.284	0.160	0.313	-0.440	0.059
Def deg for	0.405	-1.330	0.147	0.056	-1.618	0.107	0.549	-2.262	0.065
	No controls LUT			No controls LUT			No controls LUT		
Def int for	0.705	-0.397	0.035	0.542	-0.475	0.023	0.235	-0.635	0.006
Def deg for	0.831	-2.093	0.023	0.352	-2.384	0.016	0.268	-2.924	0.013

iii. PM

Following Assunção and Rocha (38), we did not control for logging (a potential channel of impact) nor fines (which are the main mechanism behind the impact of the program) and we build the counterfactual based on second order municipalities, as positive spillovers were found to first order neighbors. Tables reports results for the PM program against all municipalities in the sample, against first and against second order neighbors of the treated municipalities. The three sub columns report the p-value of the placebo F test for parallel trends, the estimated average treatment effect and its p-value. Results are aggregated for a different number of periods pre and post treatment: Short=3 periods; Medium=5 periods; Long=10 periods

Table SI 26 Summary results Priority municipalities: Deforestation, degradation and degradation net of deforestation

	PM			PM			PM		
Threshold	whole sample			1st order neighbors			2nd order neighbors		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
Short term									
	base								
def	0.842	-0.079	0.455	0.513	-0.079	0.456	0.510	-0.074	0.546
deg	0.705	0.005	0.963	0.744	0.038	0.749	0.891	0.726	0.038
degCdef	0.996	0.014	0.904	0.947	0.050	0.686	0.377	0.734	0.059
	LUT								
def	0.833	-0.141	0.172	0.525	-0.158	0.110	0.116	-0.416	0.035
deg	0.998	-0.029	0.788	0.206	-0.033	0.789	0.824	-0.460	0.437
degCdef	0.821	-0.040	0.714	0.335	-0.019	0.885	0.421	0.649	0.274
	no control								
def	0.230	-0.098	0.377	0.374	-0.013	0.914	0.118	-0.149	0.190
deg	0.128	-0.005	0.961	0.277	0.021	0.855	0.166	0.184	0.370
degCdef	0.905	0.005	0.964	0.608	0.019	0.870	0.041	0.285	0.222

	no control LUT								
def	0.433	-0.160	0.099	0.740	-0.134	0.191	0.205	-0.226	0.167
deg	0.955	-0.007	0.950	0.629	0.024	0.860	0.364	0.524	0.107
degCdef	0.488	-0.010	0.930	0.505	0.040	0.776	0.596	0.993	0.026
Medium term									
	base								
def	0.301	-0.074	0.505	0.093	-0.067	0.551	0.626	-0.134	0.269
deg	0.619	-0.022	0.841	0.753	0.031	0.791	0.905	0.596	0.057
degCdef	0.677	0.016	0.882	0.818	0.055	0.630	0.309	0.757	0.043
	LUT								
def	0.710	-0.129	0.231	0.088	-0.128	0.217	0.105	-0.350	0.017
deg	0.929	-0.091	0.396	0.202	-0.065	0.576	0.378	0.099	0.751
degCdef	0.945	-0.052	0.597	0.317	-0.032	0.788	0.557	1.061	0.005
	No controls								
def	0.638	-0.081	0.479	0.463	-0.004	0.973	0.481	-0.171	0.137
deg	0.400	-0.032	0.774	0.352	0.016	0.888	0.347	0.109	0.580
degCdef	0.678	0.009	0.926	0.497	0.016	0.879	0.016	0.250	0.226
	No controls LUT								
def	0.405	-0.145	0.168	0.317	-0.106	0.329	0.971	-0.249	0.140
deg	0.672	-0.066	0.533	0.644	-0.016	0.896	0.240	0.415	0.233
degCdef	0.431	-0.014	0.893	0.523	0.023	0.854	0.969	1.053	0.013
Long term									
	base								
def	0.991	-0.032	0.792	0.606	-0.029	0.812	0.029	-0.190	0.151
deg	0.930	-0.177	0.147	0.426	-0.206	0.166	0.920	0.024	0.938
degCdef	0.595	-0.120	0.277	0.606	-0.172	0.228	0.519	0.098	0.795
	LUT								
def	0.163	-0.100	0.396	0.833	-0.086	0.451	0.044	-0.322	0.024
deg	0.836	-0.198	0.114	0.303	-0.165	0.182	0.419	-0.244	0.397
degCdef	0.354	-0.109	0.290	0.190	-0.083	0.477	0.417	0.495	0.122
	No controls								
def	0.390	-0.046	0.696	0.838	0.014	0.916	0.028	-0.206	0.089
deg	0.395	-0.138	0.199	0.918	-0.200	0.179	0.888	-0.482	0.002
degCdef	0.338	-0.116	0.271	0.843	-0.198	0.176	0.933	-0.383	0.009
	No controls LUT								
def	0.240	-0.103	0.365	0.940	-0.066	0.584	0.193	-0.289	0.055
deg	0.184	-0.185	0.142	0.422	-0.132	0.304	0.238	-0.347	0.151
degCdef	0.051	-0.087	0.424	0.224	-0.050	0.673	0.023	0.368	0.142

Table SI 27 Summary results Priority municipalities: Deforestation, fires and fires net of deforestation

	PM			PM			PM		
	whole sample			1st order neighbors			2nd order neighbors		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
Short term									
	base								
def	0.842	-0.079	0.455	0.513	-0.079	0.456	0.510	-0.074	0.546
fires	0.691	-0.411	0.286	0.777	-0.491	0.223	0.277	-0.529	0.170
firesCdef	0.606	-0.419	0.290	0.612	-0.495	0.238	0.647	-0.387	0.379
	LUT								
def	0.833	-0.141	0.172	0.525	-0.158	0.110	0.116	-0.416	0.035
fires	0.627	-0.659	0.125	0.996	-0.610	0.182	0.045	-0.353	0.409
firesCdef	0.968	-0.543	0.235	0.837	-0.666	0.167	0.110	-0.553	0.336
	No controls								
def	0.230	-0.098	0.377	0.374	-0.013	0.914	0.118	-0.149	0.190
fires	0.497	-0.388	0.292	0.681	-0.231	0.559	0.383	-0.499	0.165
firesCdef	0.449	-0.354	0.332	0.529	-0.202	0.604	0.591	-0.288	0.432
	No controls LUT								
def	0.433	-0.160	0.099	0.740	-0.134	0.191	0.205	-0.226	0.167
fires	0.724	-0.807	0.054	0.682	-0.597	0.183	0.307	-0.625	0.137
firesCdef	0.946	-0.600	0.177	0.981	-0.624	0.189	0.418	0.001	0.999
Medium term									
	base								
def	0.301	-0.074	0.505	0.093	-0.067	0.551	0.626	-0.134	0.269
fires	0.467	-0.765	0.081	0.408	-0.825	0.065	0.719	-1.147	0.007
firesCdef	0.517	-0.726	0.098	0.540	-0.773	0.090	0.809	-0.817	0.053
	LUT								
def	0.710	-0.129	0.231	0.088	-0.128	0.217	0.105	-0.350	0.017
fires	0.475	-0.955	0.066	0.188	-0.943	0.063	0.879	-1.077	0.033
firesCdef	0.236	-0.860	0.091	0.122	-0.914	0.080	0.107	-0.980	0.097
	No controls								
def	0.638	-0.081	0.479	0.463	-0.004	0.973	0.481	-0.171	0.137
fires	0.549	-0.711	0.100	0.552	-0.518	0.252	0.889	-1.029	0.015
firesCdef	0.702	-0.646	0.116	0.779	-0.481	0.267	0.834	-0.710	0.063
	No controls LUT								
def	0.405	-0.145	0.168	0.317	-0.106	0.329	0.971	-0.249	0.140
fires	0.474	-1.095	0.033	0.362	-0.925	0.063	0.516	-1.271	0.016
firesCdef	0.210	-0.898	0.069	0.186	-0.866	0.093	0.218	-0.389	0.457
Long term									
	base								
def	0.991	-0.032	0.792	0.606	-0.029	0.812	0.029	-0.190	0.151
fires	0.837	-0.583	0.245	0.877	-0.718	0.155	0.266	-1.162	0.012
firesCdef	0.678	-0.485	0.318	0.769	-0.596	0.237	0.693	-0.470	0.292

	LUT								
def	0.163	-0.100	0.396	0.833	-0.086	0.451	0.044	-0.322	0.024
fires	0.367	-0.829	0.165	0.673	-0.822	0.151	0.273	-1.061	0.039
firesCdef	0.841	-0.673	0.238	0.382	-0.700	0.227	0.086	-0.379	0.482
	No controls								
def	0.390	-0.046	0.696	0.838	0.014	0.916	0.028	-0.206	0.089
fires	0.710	-0.588	0.218	0.361	-0.398	0.427	0.814	-1.053	0.024
firesCdef	0.911	-0.483	0.268	0.799	-0.342	0.460	0.559	-0.657	0.100
	LUT								
def	0.240	-0.103	0.365	0.940	-0.066	0.584	0.193	-0.289	0.055
fires	0.673	-0.958	0.096	0.744	-0.806	0.140	0.601	-1.251	0.023
firesCdef	0.575	-0.720	0.182	0.336	-0.654	0.244	0.093	-0.153	0.763

Table SI 28 Summary results Priority municipalities: Deforestation, logging and logging net of deforestation

	PM			PM			PM		
	whole sample			1st order neighbors			2nd order neighbors		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
Short term									
	base								
def	0.842	-0.079	0.455	0.513	-0.079	0.456	0.510	-0.074	0.546
logging	0.705	0.000	0.975	0.756	0.004	0.817	0.965	0.042	0.076
loggingCdef	0.719	0.002	0.872	0.757	0.007	0.711	0.964	0.038	0.122
	LUT								
def	0.538	-0.117	0.269	0.891	-0.166	0.116	0.969	-0.143	0.231
logging	0.546	-0.009	0.499	0.644	-0.016	0.305	0.740	-0.006	0.866
loggingCdef	0.543	-0.009	0.533	0.589	-0.013	0.440	0.808	-0.044	0.203
	No controls								
def	0.230	-0.098	0.377	0.374	-0.013	0.914	0.118	-0.149	0.190
logging	0.620	-0.003	0.841	0.488	-0.006	0.713	0.841	0.004	0.795
loggingCdef	0.625	-0.002	0.911	0.460	-0.005	0.769	0.515	-0.005	0.747
	No controls LUT								
def	0.146	-0.184	0.091	0.249	-0.170	0.123	0.248	-0.156	0.139
logging	0.640	-0.002	0.871	0.474	-0.003	0.833	0.831	0.014	0.354
loggingCdef	0.584	-0.005	0.702	0.408	-0.005	0.788	0.599	-0.073	0.066
Medium term									
	base								
def	0.301	-0.074	0.505	0.093	-0.067	0.551	0.626	-0.134	0.269
logging	0.588	0.004	0.860	0.670	0.007	0.780	0.983	0.043	0.121
loggingCdef	0.556	0.006	0.758	0.650	0.012	0.668	0.916	0.026	0.389
	LUT								
def	0.778	-0.091	0.414	0.450	-0.131	0.234	0.950	-0.242	0.045
logging	0.691	-0.017	0.374	0.757	-0.030	0.174	0.477	0.011	0.718

loggingCdef	0.642	-0.016	0.398	0.788	-0.024	0.291	0.742	-0.038	0.247
	No controls								
def	0.638	-0.081	0.479	0.463	-0.004	0.973	0.481	-0.171	0.137
logging	0.778	-0.001	0.968	0.969	-0.005	0.843	0.504	-0.001	0.971
loggingCdef	0.769	0.001	0.977	0.920	-0.003	0.919	0.859	-0.018	0.478
	No controls LUT								
def	0.565	-0.159	0.162	0.519	-0.144	0.206	0.719	-0.177	0.114
logging	0.731	-0.002	0.897	0.978	-0.008	0.743	0.362	0.011	0.610
loggingCdef	0.727	-0.008	0.660	0.965	-0.009	0.724	0.687	-0.104	0.093
Long term									
	base								
def	0.991	-0.032	0.792	0.606	-0.029	0.812	0.029	-0.190	0.151
logging	0.131	0.004	0.857	0.412	0.007	0.823	0.122	0.027	0.394
loggingCdef	0.088	0.009	0.696	0.343	0.014	0.672	0.221	0.015	0.710
	LUT								
def	0.406	-0.070	0.560	0.747	-0.096	0.419	0.881	-0.298	0.020
logging	0.279	-0.033	0.135	0.780	-0.054	0.060	0.090	-0.024	0.526
loggingCdef	0.202	-0.031	0.149	0.730	-0.046	0.112	0.329	0.036	0.387
	No controls								
def	0.390	-0.046	0.696	0.838	0.014	0.916	0.028	-0.206	0.089
logging	0.149	0.000	0.991	0.546	-0.003	0.918	0.047	-0.026	0.524
loggingCdef	0.163	0.004	0.862	0.553	0.002	0.956	0.434	-0.042	0.293
	No controls LUT								
def	0.360	-0.114	0.331	0.530	-0.104	0.381	0.036	-0.172	0.151
logging	0.122	-0.007	0.702	0.363	-0.022	0.481	0.026	0.004	0.901
loggingCdef	0.120	-0.016	0.438	0.378	-0.024	0.491	0.426	-0.126	0.307

Table SI 29 Summary results Priority municipalities: Deforestation of intact and degraded forest

	PM			PM			PM		
	whole sample			1st order neighbors			2nd order neighbors		
	pretr p	estimates	est p	pretr p	estimates	est p	pretr p	estimates	est p
Short term									
	base								
def int for	0.707	-0.098	0.290	0.703	-0.091	0.338	0.540	-0.096	0.364
def deg for	0.241	-0.311	0.537	0.307	-0.337	0.489	0.457	-0.601	0.295
	LUT								
def int for	0.619	-0.151	0.096	0.527	-0.171	0.054	0.033	-0.339	0.015
def deg for	0.708	-1.237	0.056	0.515	-0.304	0.538	0.893	-1.197	0.069
	No controls								
def int for	0.132	-0.125	0.211	0.196	-0.043	0.688	0.103	-0.129	0.246
def deg for	0.067	-0.134	0.785	0.077	-0.169	0.740	0.039	-0.715	0.153
	No controls LUT								
def int for	0.645	-0.170	0.045	0.951	-0.150	0.094	0.326	-0.184	0.166

def deg for	0.309	-1.373	0.025	0.178	-0.223	0.670	0.027	-1.225	0.078
Medium term									
	base								
def int for	0.524	-0.080	0.429	0.169	-0.069	0.501	0.795	-0.138	0.208
def deg for	0.163	-0.442	0.338	0.126	-0.426	0.352	0.196	-0.858	0.128
	LUT								
def int for	0.751	-0.132	0.177	0.160	-0.139	0.144	0.224	-0.272	0.015
def deg for	0.967	-1.243	0.041	0.151	-0.356	0.433	0.002	-1.486	0.019
	No controls								
def int for	0.766	-0.105	0.325	0.618	-0.025	0.827	0.764	-0.137	0.230
def deg for	0.572	-0.250	0.598	0.437	-0.255	0.610	0.956	-0.919	0.057
	No controls LUT								
def int for	0.422	-0.148	0.111	0.284	-0.119	0.222	0.706	-0.182	0.202
def deg for	0.823	-1.371	0.020	0.475	-0.281	0.570	0.357	-1.508	0.034
Long term									
	base								
def int for	0.683	-0.050	0.653	0.427	-0.038	0.735	0.248	-0.171	0.134
def deg for	0.011	-0.443	0.352	0.118	-0.432	0.363	0.100	-1.121	0.067
	LUT								
def int for	0.443	-0.112	0.290	0.988	-0.103	0.315	0.092	-0.267	0.024
def deg for	0.004	-1.166	0.060	0.475	-0.371	0.442	0.000	-1.670	0.010
	No controls								
def int for	0.566	-0.072	0.506	0.610	-0.011	0.925	0.119	-0.150	0.163
def deg for	0.054	-0.305	0.530	0.134	-0.304	0.557	0.001	-1.188	0.019
	No controls LUT								
def int for	0.513	-0.109	0.283	0.742	-0.080	0.450	0.440	-0.193	0.127
def deg for	0.001	-1.304	0.029	0.398	-0.300	0.564	0.001	-1.811	0.010

g. Size of cattle suppliers by supply chain linkages

To explain the different impact between TAC and G4 on deforestation and degradation, we used data from Levy (63) to test how property size varied by supply chain segment (G4, TAC, other). Property polygons from CAR were matched with publicly available GTA records from the state of Pará for the years 2014 to 2020. GTA records were obtained from the Agricultural Defense Agency of Pará website (64) while CAR records were obtained in 2021 and included all properties registered up until that date, unless deregistration occurred (65). 41% of GTAs were linkable to a CAR, providing a sample of 56,233 properties that was determined to be representative of the overall supply chain structure by Levy (63). Supply chain segment was determined based on the predominant meatpacker type the property supplied over the study period.

Figure SI 5 presents K-density estimates of the distribution of property size by supply chain linkages. If evidence how G4 suppliers are generally larger than TAC suppliers, both direct and indirect. Mann-Whitney and t-test of difference in distribution and means (Table SI 30) reveal that all groups are different at p<0.000.

Figure SI 5 K-density estimate of properties log of area by supply chain linkage

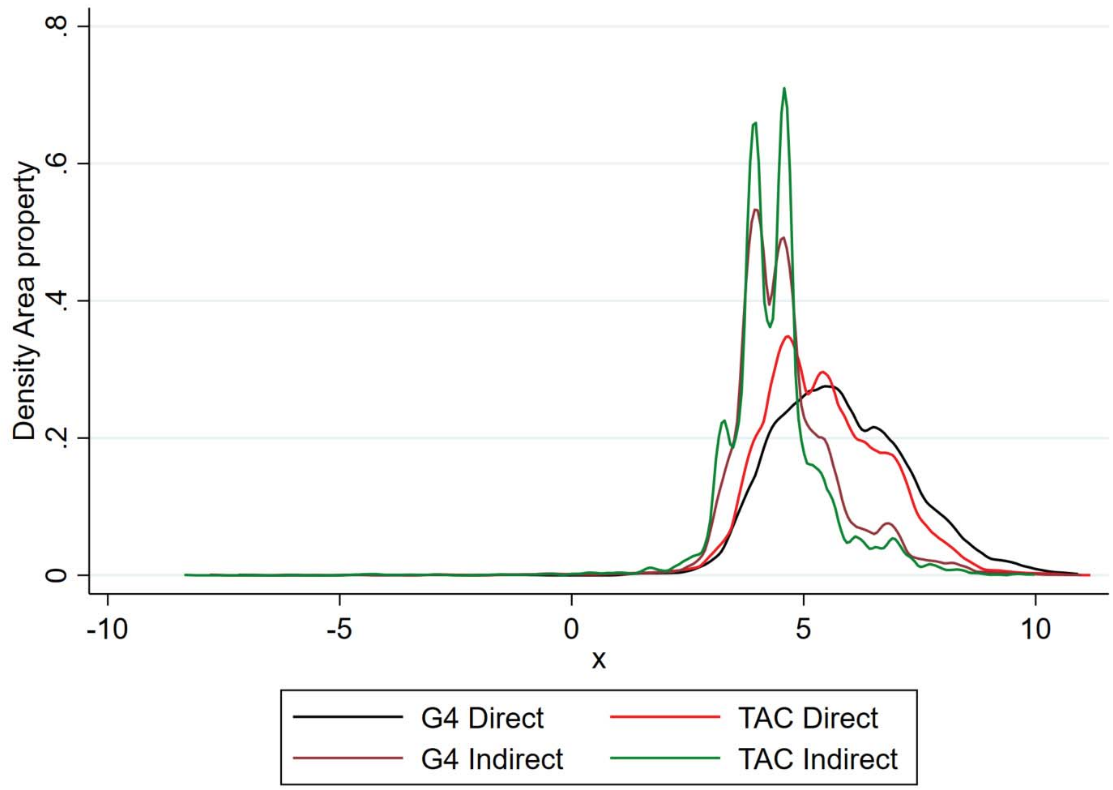


Table SI 30 summary statistics about property area by supply chain linkage

	mean	sd	N
TAC direct	614.4659	1925.004	5920
TAC indirect	191.0065	693.4429	7232
G4 direct	1064.387	2987.575	2352
G4 indirect	301.9213	1412.618	5915

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