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Rainforest conservation policy assessment: the case of the Atlantic Forest in Brazil

Avaliação de política de conservação de floresta tropical: o caso da Mata Atlântica no Brasil

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Tese apresentada ao Programa de Pós-Graduação em Economia do Departamento de Economia da Faculdade de Economia, Administração e Contabilidade da Universidade de São Paulo como requisito parcial para a obtenção do título de Doutor em Ciências

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Resumo

Ussami, K. A. (2022). Rainforest conservation policy assessment: the case of the Atlantic Forest in Brazil (Tese de Doutorado), Faculdade de Economia, Administração e Contabilidade, Universidade de São Paulo, São Paulo.

Esta tese avalia o impacto de uma política de conservação da vegetação nativa de forma quantitativa. Analisamos a Lei da Mata Atlântica, uma política de desmatamento zero lançada no Brasil em 2006 que afeta grandes áreas contendo tanto terras públicas quanto privadas, e avaliamos seus efeitos usando avanços recentes na abordagem de diferenças em diferenças. Encontramos um efeito positivo e significativo da lei sobre as florestas naturais. O aumento da cobertura florestal ocorre principalmente através do aumento no processo de recuperação, com recuperação líquida anual positiva mesmo na ausência de mudanças significativas nas perdas de cobertura após a lei. Tais efeitos positivos são observados imediatamente após aprovação da lei, com efeitos de antecipação de um a três anos, condizente com o momento em que o projeto de lei da Mata Atlântica foi aprovado na Câmara dos Deputados. O desmatamento antecipatório atrasou os benefícios líquidos da política na maior parte das regiões, sendo necessário em média 10 anos para que o aumento na cobertura florestal apresentasse resultados líquidos positivos. A análise de heterogeneidade mostra diferentes respostas a depender da região, com maiores efeitos vindos de municípios com menores estoques de florestas no baseline. Nossos resultados sugerem que a eficácia dessa lei foi baseada em um conjunto de iniciativas vinda de diferentes atores. Após a lei, as áreas tratadas tiveram um aumento na área dos municípios protegidos por Unidades de Conservação e um aumento da cobertura florestal natural em Unidades de Conservação pré-existentes à lei. Estimamos também um aumento relativo da cobertura florestal em propriedades privadas, cujos proprietários parecem ter cumprido a lei em grande medida, além de terem criado novas Unidades de Conservação particulares. O desmatamento antecipatório afetou tanto terras privadas como Unidades de Conservação, reduzindo os benefícios da política. Os governos municipais parecem ter aumentado seus gastos com gestão ambiental ao longo do tempo, mas esse aumento não foi significativamente diferente entre áreas tratadas e não tratadas. Nossas tentativas em explorar os mecanismos pelo lado do monitoramento e coação não foram conclusivas. A replicação para outros biomas pode ser limitada por características institucionais e pelo engajamento da sociedade civil.

Palavras-chave: Análise de Impacto, Conservação, Desmatamento, Fiscalização, Áreas Protegidas

Abstract

Ussami, K. A. (2022). Rainforest conservation policy assessment: the case of the Atlantic Forest in Brazil (Tese de Doutorado), Faculdade de Economia, Administração e Contabilidade, Universidade de São Paulo, São Paulo.

This dissertation assesses quantitatively the impact of a native vegetation conservation policy. We look at the Atlantic Forest Law (AFL), a zero deforestation policy launched in Brazil in 2006 that affects a huge area with both public and private lands, and evaluate its effects using recent advances in the difference-in-differences approach. We find a positive and significant effect of the AFL on the natural forest cover. Increases in forest cover occur mainly through the increase in the recovery process (allowing for native vegetation to naturally grow back or actively recovering it by planting seeds or seedlings), with positive annual net recovery even in the absence of significant changes in the forest loss process after the law. The increase in the natural forest cover and net recovery is observed immediately after the law's approval (in 2007), and society might have anticipated the AFL by increasing the deforestation one to three years prior to the law, which is consistent with the timing when the draft bill was approved in the Chamber of Deputies. This pre-emptive clearing delayed the net benefit from the policy in the majority of regions, taking an average of 10 years to the increase in forest cover to start producing net benefits. The analysis of heterogeneity showed that different regions responded differently to the policy, with higher effects coming from municipalities with less forests in the baseline. Our results suggest that the success of the AFL may be explained by a set of different strategies conducted by different stakeholders. Following the AFL, treated areas experienced an increase in the share of municipalities' territories protected by Conservation Units, and an increase in the native forest vegetation cover in pre-existing Conservation Units. We also estimate a relative increase in the natural forest cover in private properties, whose owners seem to have complied with the law to a large extent and created new private Conservation Units. Pre-emptive clearing in the few years before the law affected both private and Conservation Units area, avoiding higher benefits from the AFL protection. Municipal governments seemed to have increased their environmental management expenditures over time, but this increase was not significantly different between treated and untreated areas. Our attempt to explore the mechanisms from the monitoring and enforcement side was not conclusive. Replication to other biomes might be limited by institutional characteristics and by the engagement of civil society.

Keywords: Impact analysis, Conservation, Deforestation, Enforcement, Protected Areas

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Symbols, Acronyms and Abbreviations

ADI	Direct Action of Unconstitutionality (Portuguese acronym)
AF	Atlantic Forest
AFL	Atlantic Forest Law
ATT	Average Treatment effect on the Treated
BA	(Brazilian state of) Bahia
BNDES	Brazilian Development Bank
CEPF	Critical Ecossystem Partnership Fund
CNUC	National Register of Conservation Units
Datasus	Brazilian Unified Health System Data
DiD	difference-in-differences
EIN	Environmental Infraction Notices
EPA	Environmental Protection Area (APA, Área de Preservação Ambiental, for the Brazilian acronym)
FBDS	Brazilian Foundation for Sustainable Development
FUNAI	National Indian Foundation
GDP	Gross Domestic Product
IBAMA	Brazilian Institute of Environment and Renewable Natural Resources
IBGE	Brazilian Institute of Geography and Statistics
INCRA	National Institute for Colonization and Agrarian Reform
IUCN	International Union for Conservation of Nature
kha	Thousands of hectares
MCA	Minimum Comparable Areas (Portuguese acronym)
MG	(Brazilian state of) Minas Gerais
Mha	Millions of hectares
MMA	(Brazilian) Ministry of Environment
NGO	Non-Governmental Organization
PNRH	Private Natural Heritage Reserve (RPPN, Reserva Particular do Patrimônio Natural, for the Brazilian acronym)
PPCDAm	Action Plan for the Prevention and Control of Deforestation in the Legal Amazon
PPCerrado	Action Plan for the Prevention and Control of Deforestation and Fires in the Cerrado
Siconfi	Brazilian Public Sector Accounting and Tax Information System
SP	(Brazilian state of) Sao Paulo
TWFE	Two Way Fixed Effects

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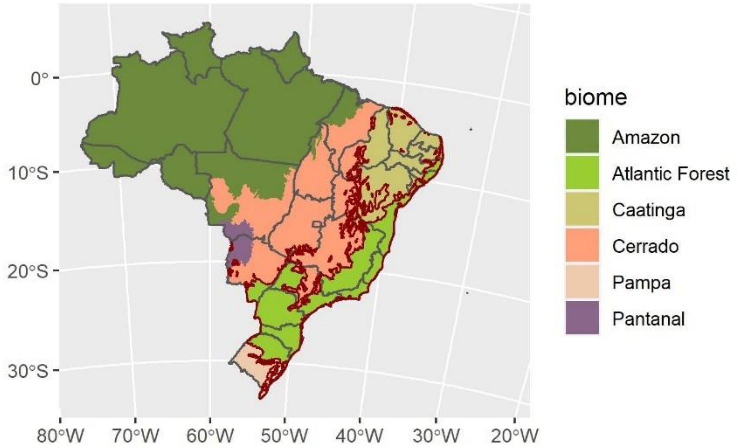
1 Introduction

The Atlantic Rainforest in Brazil used to be one of the greatest tropical forests in the Americas, originally covering around 112 Mha in highly heterogeneous regions, which supported high biodiversity and endemism. However, the native forest currently occupies only around 28% of its original area (Rezende et al., 2018), as a result of five centuries of strong human occupation (Dean, 1995). The Atlantic Forest biome accounts for only 13% of the Brazilian territory, but more than half of Brazilian cities are in this biome which is now home to 60% of the Brazilian population (including large cities such as Sao Paulo and Rio de Janeiro) and it is the region where 70% of the Brazilian GDP is produced.[1] This exceptional concentration of endemic species with a serious level of habitat loss has led the Atlantic Forest to be internationally recognized as a biodiversity hotspot for conservation priorities since the late 1980s (Norman Myers, 1988).

In Brazil, after a long negotiation process, the 2006 Federal Law No. 11,428, also known as the Atlantic Forest Law (AFL), established the formal framework to specifically protect the remaining Atlantic Forest with a zero deforestation policy. Both pristine and in-recovery vegetation are protected by this law, inside public or private properties. The area covered by the AFL includes native vegetation from different forest and non-forest formations and applies mainly to the Atlantic Forest biome (Figure 1), but also includes some fragments inside all biomes except for the Amazon biome.

[1] Based on municipal population and GDP estimates from IBGE, ref. 2019.

Figure 1 – Brazilian biomes. The red line indicates the boundary of the area where the Atlantic Forest Law (AFL) applies.



Data source: MMA

In the next sections, we focus on evaluating the effects of 2006's law, taking advantage of the fact that many states had municipalities that are either inside or outside the AFL-covered area and assessed the effect of this policy using a difference-in-differences approach controlling for state and other baseline covariates. Our study adds to the literature aiming to evaluate conservation policy instruments using robust causal inference approaches.[2] However, consolidated evidences are concentrated in protected areas such as national parks and analysis of other policy instruments shows variable and contrasting results motivating additional investigation of the existing evidence.[3] In this sense, our study contributes to the understanding of conservation policies that target lands that include those under private management.[4] In particular, the Brazilian policy for forest protection is a rare case among great exporters of agricultural products where private properties are required to set-aside land for biodiversity protection without any compensation[5] and could be used as a reference for forest protection in other developing countries. As far as we know, this is the first study to assess the effectiveness of the Atlantic Forest Law using causal inference methods, and our results may help guide

[2] More on this literature on section 3.
[3] See Miteva *et al.* (2012) for a review on different biodiversity policy instruments.
[4] Examples of conservation policies of this type are payments for ecosystem services, endangered species protection and restrictions from forest to non-forest conversion in private lands (the AFL type of policy).
[5] Chiavari & Lopes (2017) compares forest and land use policies on private lands among some of the world's top ten exporters of agricultural products: Argentina, Brazil, Canada, China, France Germany and USA. They focus on the Brazilian Forest Code, but the Atlantic Forest Law also affects private lands without any compensation.

future decisions related to the Atlantic Forest protection, as some controversial issues related to the AFL remain.[6]

We focus on the AFL effects on the natural forest cover and annual forest loss and recovery. We take advantage of the fact that many states had municipalities that are either inside or outside the AFL application area and assess the effect of this policy using a difference-in-differences approach controlling for state and other baseline covariates.

We find a positive and significant effect of the AFL on the natural forest cover. Increases in natural forest cover occur mainly through the increase in the recovery process (allowing for native vegetation to naturally grow back or actively recovering it by planting seeds or seedlings), with positive annual net recovery even in the absence of significant changes in the forest loss process after the law. The increase in the natural forest cover and net recovery is observed immediately after the law's approval (in 2007), and society might have anticipated the AFL by increasing the deforestation one to three years prior to the law, which is consistent with the timing when the draft bill was approved in the Chamber of Deputies. To check the robustness of our results, we consider the case where all municipalities in our sample that had less than 25% of natural forests cover in the baseline to strengthen the limitation of remaining forests stocks available to deforestation. We also check the variation in different types of farming land cover to reduce the possibility that our results are affected by variation in commodity prices.[7] Analysis of heterogeneity shows that municipalities with less forests in the baseline experienced a stronger effect from the AFL protection while municipalities with more forests in the baseline experienced a decrease in forests even after the law. We also looked at different states and apart from Minas Gerais, it seems that the pre-emptive clearing delayed the net benefit from the policy, taking an average of 10 years to the increase in forest cover to start producing net benefits. We also confirm that the effects of the AFL on the natural forest cover are similar to the reference specification inside private lands and even inside pre-existing Conservation Units,[8] with positive and significant results that loose their effect due to the pre-emptive

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[66] *e.g.*, a dispatch from the Ministry of Environment in 2020 recommended environmental entities to ignore part of the protection given by the AFL. The dispatch was revoked two months later but now the matter is to be evaluated by the Supreme Court. More details on section 2.

[7] The lack of effect coming from forest loss also contributes to the interpretation that our results are not driven by differences in commodity prices.

[8] Conservation Units are the Brazilian definition of protected areas such as national parks or forest reserves (Federal Law no. 9,985/2000, http://www.planalto.gov.br/ccivil_03/leis/l9985.htm). The Brazilian legislative and institutional framework for Conservation Units is compatible with the guidelines proposed by the International Union for Conservation of Nature (IUCN) (Pellizzaro, Hardt, Hardt, Hardt, & Sehli, 2015), which defined a protected area as "a clearly defined geographical space, recognised, dedicated and managed, through legal or other

clearing. We try to explore some mechanisms behind these results by looking at the frequency Environmental Infraction Notices (for state of Sao Pualo only due to data availability), at the Conservation Units cover evolution and at the municipal expenditures on environmental management. The results from monitoring and enforcement side (infraction notices) are not conclusive, and municipal expenditures are not significantly different between treated and control municipalities. Interestingly, the coverage by Conservation Units was positively affected by the AFL, in every category of Conservation Unit that we analyzed, including the category of private Conservation Units (Private Natural Heritage Reserve),[9] showing that the private sector also responded positively to the AFL by increasing its protected areas. We note, however, that our impact assessment cannot isolate the effects of the AFL from other initiatives aiming to protect the Atlantic Forest (such as the civil society engagement).

Our results suggest that the success of the AFL may be explained by a set of different strategies conducted by different stakeholders. Following the AFL, treated areas experienced an increase in the share of municipalities' territories protected by Conservation Units, and an increase in the native forest vegetation cover in pre-existing Conservation Units. We also estimate a relative increase in the natural forest cover in private properties, whose owners seem to have complied with the law to a large extent and created new private Conservation Units. Pre-emptive clearing in the few years before the law affected both private and Conservation Units area, avoiding higher benefits from the AFL protection. Municipal governments seemed to have increased their environmental management expenditures over time, but this increase was not significantly different between treated and untreated areas. Our attempt to explore the mechanisms from the command and control side was not conclusive.

The next section presents background regarding Atlantic Forest protection, including the Atlantic Forest Law in 2006 and related rules. Section 3 presents a literature review on the effects of protected areas on the natural cover. Section 4 presents the data and the adopted empirical strategy focusing on natural forests, section 5 shows the results from the main specification and section 0 reports our robustness checks. Section 7 presents four different heterogeneity analysis based on the remaining percentage of natural forest cover in the baseline, on states or groups of states, on private lands and on Conservation Units (the Brazilian

effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (IUCN, 2013).

[9] RPPN, Reserva Particular do Patrimônio Natural, for the Brazilian acronym

definition of protected areas such as national parks). In section 8 we complement the results by considering other types of natural vegetation (apart from forests) that are also protected by the AFL, and in section 9 we explore potential mechanisms behind the AF conservation. Section 10 concludes with some considerations on policy implications.

2 The Atlantic Forest protection: background

The differential treatment given to Atlantic Forest in legal instruments started with the Constitution of the Federative Republic of Brazil in 1988, which gave the Atlantic Forest the status of national heritage (Timeline in Figure 2).

In 1990, Federal Decree No. 99,547/1990 took the first steps to prohibit deforestation in Atlantic Forest. By that time, prohibition was limited to a smaller area covered by the dense ombrophilous forests mapped in the Brazilian Vegetation Map elaborated by the Brazilian Institute of Geography and Statistics in 1988.[10] Later, in 1993, Federal Decree No. 750/1993 increased the protection expanding the definition of Atlantic Forest to ombrophilous forests, seasonal forests, mangroves, "restinga" forests, altitude fields, inner swamps, and northeast forest enclaves. Federal Decree No. 750 also made it clear that both primary and secondary vegetation were protected.[11] However, the validity of these decrees was questioned with the argument that such prohibition required a Federal Law (Oliva, 2007).

The Federal Law finally came into effect in December 2006[12] and became known as the Atlantic Forest Law (AFL) increasing the legal certainty of the Atlantic Forest protection. After a long process that started in 1992 with the draft bill, it was approved in the Chamber of Deputies[13] in December 2003 and the Senate in February 2006 (these approval events in the Chamber of Deputies and in the Senate are used to define anticipation periods in our estimates).

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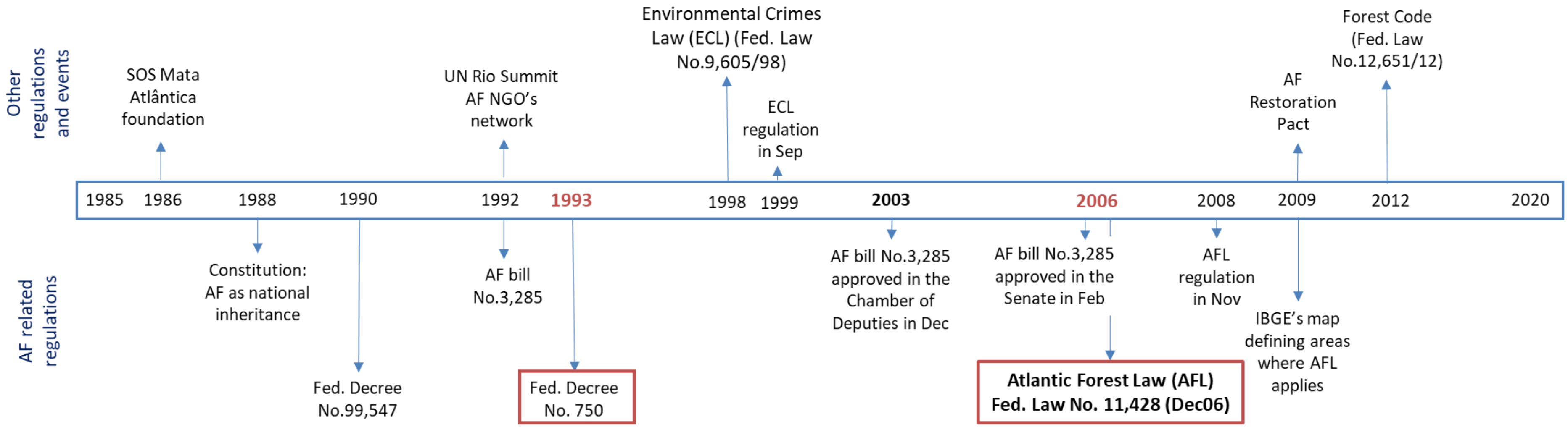
[10] Federal Ordinance/IBAMA No. 438/1989 defined the protected vegetation type.
[11] A primary vegetation is a vegetation that has never been logged and has developed following natural disturbances and under natural processes, regardless of its age. A secondary vegetation is a vegetation that has been logged and is recovering naturally or artificially (definitions adapted from the Convention on Biological Diversity, https://www.cbd.int/forest/definitions.shtml).
[12] Federal Law No. 11,428/2006.
[13] The Chamber of Deputies is composed of representatives of all Brazilian States and the Federal District, elected according to proportional electoral system (State's population). It is similar to the House of Representatives in the USA.

Figure 2 – Timeline with events related to native forests conservation in Brazil (above the line) and in Atlantic Forest (below the line)



Source: Own elaboration

The AFL defined that all remnants of native vegetation from the Atlantic Forest would be protected, including both primary and secondary vegetation, in advanced, medium, and initial stages of regeneration. In general, any cut, harvesting, or exploration of the native vegetation would only be allowed in activities or projects of public or social interest. The AFL also established that protection under its scope would apply to the different forest and non-forest formations, aligned with the previous definition of the Atlantic Forest used in Federal Decree No. 750/1993. The law was less restrictive than the previous decree (Varjabedian, 2010), but increased legal certainty concerning the prohibition of deforestation of the Atlantic Forest. It also contained many advances in the legal mechanisms of protection and regulation of uses of the Atlantic Forest (Oliva, 2007).[14] The AFL was regulated later in 2008 and the official map defining the area where this law applies was published in 2009, removing any possible doubts related to the geographical boundaries of the protection (red line in Figure 1).

Starting in the 1990s, other environment-related laws came into force in Brazil as a whole. These include the Environmental Crimes Law from 1998 and the Forest Code from 2012. The Forest Code requires that rural property owners keep a share of their property with native vegetation as a "Legal Reserve".[15] Similar to the AFL, this protection depends basically on the landowner's decision and the incentives they face based on monitoring and enforcement efforts by government agencies. Under the Forest Code, however, native vegetation that exceeds the minimum requirement can be legally removed (with licensing). In contrast, in the case of the Atlantic Forest, legal native vegetation removal is allowed only under special circumstances such as public/social interest.

The differential treatment given to the Atlantic Forest was not limited to legal instruments and included social mobilization, funding, and territorial management. The foundation of the non-governmental organization (NGO) SOS Mata Atlântica in 1986 is an example of such social mobilization. In 1992, a network of NGOs dedicated to the Atlantic Forest was created. Two years later the network had 118 affiliated NGOs and this number has increased to more than 250 in recent years.[16] In 2009, the Atlantic Forest Restoration Pact was created as a bottom-up movement, articulating and integrating different social actors to recover

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[14] See Oliva (2007) for a chart comparing the Atlantic Forest Law (Federal Law nº 11.428/2006) and the Federal Decree no. 750/1993.

[15] The Forest Code from 2012 is frequently referred as the Brazilian "new" Forest Code. The Legal Reserve requirement was part of the previous Brazilian Forest Code (from 1965) as well.

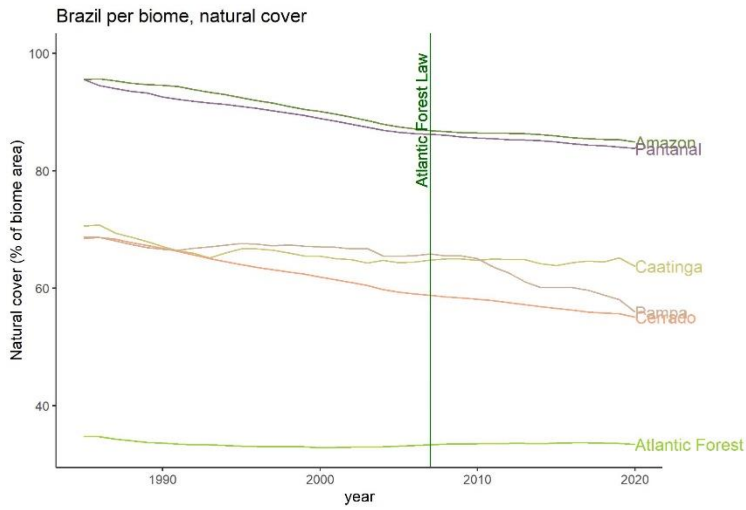
[16] http://rma.org.br/institucional/historia/

15 Mha by 2050.[17] This Pact also pledged 1 Mha to the 2020 Bonn Challenge,[18] a global goal to recover 150 Mha of degraded landscapes by 2020 and 350 Mha by 2030, launched by the Government of Germany and IUCN in 2011. From 2002 to 2011, civil society organizations from the Atlantic Forest received more than 10 million USD in grants from the Critical Ecossystem Partnership Fund (CEPF) in projects aiming to improve landscape management in this biodiversity hotspot.[19] From 2010 to 2017, the Brazilian Development Bank (BNDES, Portuguese acronym) has financed native vegetation recovery in the Atlantic Forest with non-refundable resources, motivated by the AFL (but not from any mandatory requirement by the law) (BNDES; UICN, 2015). Finally, 45% of the Brazilian Network of Biosphere Reserves are in the Atlantic Forest biome, while other biomes accounts for 10-20% each.[20] This network is internationally recognized as part of the World Network of Biosphere Reserves from UN's Man and the Biosphere Programme, a program focused on governance challenges of sustainable development.[21]

In Brazil, the focus on the protection of the Atlantic Forest to the detriment of other biomes was probably also motivated by its relative scarcity. In 1988, when the Brazilian Constitution defined the Atlantic Forest as a national heritage, there was less than 35% of the remaining natural cover in the Atlantic Forest, while in other biomes this percentage was more than 65% (Figure 3).[22]

[17] http://www.pactomataatlantica.org.br/
[18] https://www.bonnchallenge.org/pledges/brazils-atlantic-forest-restoration-pact
[19] The CEPF focus on world's biodiversity hotspots as described in Myers at al. (2000). In Brazil, Atlantic Forest and Cerrado are identified as a biodiversity hotspots, but civil society organizations from Cerrado biome only started to receive grants from CEPF after 2016 (Critical Ecosystem Partnership Fund, 2020).
[20] More information on the Brazilian network of biosphere reserves at https://reservasdabiosfera.org.br/a-rbrb/
[21] https://en.unesco.org/biosphere/about
[22] Different remote sensing data and interpretation techniques can lead to different results. In the Atlantic Forest in particular, images with higher resolution allow us to identify small fragments of native vegetation that were not accounted before. See Ribeiro et al. (2009) and Rezende et al. (2018) for a comparison.

Figure 3 – Natural cover evolution per biome (as % of biome area), 1985-2020.



Data source: Mapbiomas collection 6.0

Other biomes or regions in Brazil were also declared as national heritage though. The Brazilian Amazon Forest, the Coastal hills ("Serra do Mar"), the Pantanal Mato-Grossense, and the Coastal Zone were all declared a national heritage in the same article of the Constitution that gave this status to the Atlantic Forest (art. 225, §4o). However, none of these other regions were the object of a law like the Atlantic Forest Law.

Apart from nationwide forest protection policies (such as Forest Code), the protection of the native vegetation from other biomes was done by other instruments, such as PPCDAm in the Amazon and PPCerrrado in the Cerrado. PPCDAm, the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon, started in 2004 and included integrated actions across different government institutions, novel procedures for monitoring/control/ territorial management, and rural credit conditional on the compliance with environmental regulations. PPCerrado, the Action Plan for the Prevention and Control of Deforestation and Fires in the Cerrado, started in 2010 and included actions on protected areas, monitoring, and control, sustainable products incentive, and environmental education. A particular case of the state of Sao Paulo is that State Law no. 13,550/2009 protected the remaining natural cover from the Cerrado biome in the state, practically equating the protection of the Cerrado with that of the Atlantic Forest.

Despite the evolution in the protection of the Atlantic Forest from the legal perspective, some controversial issues remain. A recent example was a dispatch from the Ministry of

Environment in 2020[23] recommending that environmental entities apply Forest Code regulations in consolidated areas in the Atlantic Forest, ignoring part of the protection given by the AFL. This dispatch was revoked two months later,[24] but the Federal Government asked the Supreme Court to evaluate the matter,[25] which has not been done yet.[26] These events illustrate the value of a clear understanding of the policy and its effectiveness to guide future policy decisions. In the next section, we review some studies that evaluated conservation policy instruments and show that the AFL-type of policy is rarely assessed. As far as we know, this is the first study to assess the effectiveness of the Atlantic Forest Law.

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[23] Dispatch no. 4,410/2020 (https://www.in.gov.br/web/dou/-/despacho-n-4.410/2020-251289803). See

[24] Dispatch no. 19,258/2020 (https://www.in.gov.br/en/web/dou/-/despacho-n-19.258/2020-mma-260081499)

[25] ADI (Direct Action of Unconstitutionality) no. 6446 from June 2020.

[26] See Technical note by the Brazilian Bar Association with comments on Dispatch no. 4,410/2020 (http://s.oab.org.br/arquivos/2020/05/370dbc42-7aec-4385-997e-abb7d59d8b8d.pdf). A Techincal note by Mapbiomas presents quantitative information related to the Dispatch no. 4,410/2020 (https://mapbiomas-br-site.s3.amazonaws.com/Nota%20T%C3%A9cnica/Nota_T%C3%A9cnica_Mata_Atl%C3%A2ntica__despacho_4.410_2020_do_MMA.pdf)

3 Literature review

Biodiversity policy instruments targeting areas under private management have variable and contrasting results. In a review by Miteva et al. (2012) focusing on developing countries, for example, impacts from payment for ecosystem services and decentralization seem to be very context-specific.

In Brazil, the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) might be the conservation program with more studies trying to evaluate its impact. The program started in 2004 and included many different actions, with overall positive and significant results. Assunção *et al*. (2015) estimate that PPCDAm reduced deforestation after controlling for commodity prices. Burgess et al. (2018) use a regression discontinuity design across national borders to assess PPCDAm effects on deforestation. Arima et al. (2014) and Assunção and Rocha (2019) look at a specific action in PPCDAm that targeted a few municipalities with a high deforestation rate and also find significant deforestation reduction using a difference-in-differences approach. Some policies created by decentralized governments in response to PPCDAm targeting also presented positive responses in reducing deforestation, but only after 4-5 years.[27] In contrast, poor enforcement combined with the banning of the harvest and trade of Brazilian mahogany (an endangered hardwood species), another conservation policy in the Brazilian Amazon (and unrelated to PPCDAm), actually increased extraction of the species it meant to protect (Chimeli & Boyd, 2010). Azevedo et al. (2017) use ordinary least squares regression models to evaluate a particular instrument of the Forest Code, the land registries (CAR), comparing registered and unregistered properties in the states of Pará and Mato Grosso. Their results show that these land registries' effects on reducing deforestation were limited to a temporary effect on small properties only, with no effect on medium and large properties.

In the Atlantic Forest region, Ruggiero et al. (2019) and Fiorini et al. (2020) assess different payments for ecosystem services programs using propensity score matching, and find positive but limited effects on the forest cover. The effects from the programs assessed by Ruggiero et al. relied on reforestation/regeneration (rather than reduced deforestation) and the

[27] Sills et al. (2015) use synthetic control method to assess the "green municipality" initiative from the municipality of Paragominas, one of the targeted municipalities from PPCDAm. Inspired by Paragominas case, the state of Pará launched a similar program that was assessed by Moz-Christofoletti; Pereda and Campanharo (2022) using regression discontinuity design across the borders of the state of Pará.

positive effects came slowly, 4-5 years after the programs started. In contrast, the program assessed by Fiorini et al. showed effects primarily in its first year, through reduced deforestation.

All of these studies, nevertheless, assess conservation policies with very different designs when compared to the case of the Atlantic Forest Law. The Australian case of the Vegetation Management Act (VMA) in a biodiversity hotspot analyzed by Simmons et al. (2018) seems to be the closest policy with an impact assessment. Under VMA, which passed in the year 2000, deforestation of old-growth remnant vegetation was prohibited for agriculture or pasture on private lands from Brigalow Belt South bioregion of Queensland, Australia. The authors use covariate matching to analyze the effectiveness of the VMA on deforestation rates over time using two counterfactual scenarios representing upper and lower estimates of policy impact. In the highest impact scenario, they estimate that the VMA significantly reduced the rate of deforestation but in the lowest scenario, ‘panic clearing’ before and after enactment of the VMA minimized the effect and may have marginally increased deforestation. Their assessment is limited by the lack of data on pre-intervention periods, and the frequent amendments to VMA turn this evaluation even more complex.

However, unlike the VMA, the AFL had fewer amendments, and data on pre-intervention periods are long enough for us to explore potential anticipation effects (panic clearing) and distinguish it from previous trends. Despite the importance of the Atlantic Forest region as the home for most of the Brazilian population and economic activity, to the best of our knowledge, this is the first study to use a causal inference strategy to estimate the impact of the AFL, the main protection policy for the AF biome. We use a difference-in-differences strategy as detailed in the next section.

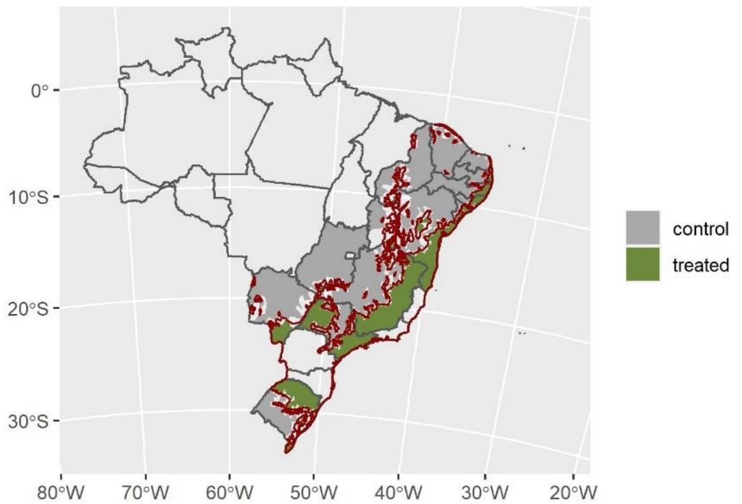
4 Data and empirical strategy

4.1 Data

We use municipality panel data from 1993 to 2020 (treatment starts at $t = 2007$) with land use and cover as a percentage of the municipality's total area from Project MapBiomas collection 6.0 data (Brazilian Annual Land Use and Land Cover Mapping Project).[28] This dataset is produced from the pixel-per-pixel classification of 30 m resolution Landsat satellite images, with 27 different land use and cover categories.[29]

Municipalities' data were aggregated in minimum comparable areas (MCA) to guarantee comparable regions over time using the updated version of MCAs from Ehrl (2017)[30] (MCA and municipalities will be used as synonyms henceforth). The treated (control) group consists of municipalities whose territory is at least 95% inside (outside) the AFL application area.[31] Only municipalities from states with both treated and control municipalities were kept in the database (Figure 4).[32]

Figure 4 – Treated and control MCAs. AFL application area boundary in red line.



[28] MapBiomas Project - is a multi-institutional initiative to generate annual land cover and use maps using automatic classification processes applied to satellite images. The complete description of the project can be found at http://mapbiomas.org

[29] See land use and land cover categories in Appendix 1.

[30] https://sites.google.com/site/philippehrl/research?authuser=0

[31] In the 13 states analyzed, there are 707 MCAs that have more than 5% and less than 95% inside the AFL application area and were removed from the MCA sample using this threshold. It was a reduction of 18% of our sample, that ended up with 3122 MCAs (1661 treated and 1461 untreated).

[32] Note that using this criterion, all municipalities from our sample are outside Legal Amazon.

The Atlantic Forest Law protects all types of vegetation related to the Atlantic Forest biome, which consists mainly of forests but also includes wetlands and grasslands. One pertinent concern is if the natural cover from municipalities located in control areas (*i.e.*, in other biomes) are good enough controls for the natural cover from the Atlantic Forest biome. Confounding effects might come from municipalities in untreated areas with a very different vegetation composition when compared to the Atlantic Forest (not only vegetation composition but also the determinants of this difference, such as soil type and precipitation). This is the case of the natural grasslands prevailing in the south of Brazil (in the Pampa biome) that can be used as natural pastures (*i.e.*, the land can be used for farming without removing the natural vegetation).[33] Besides, some land cover and change are easier to detect than others in satellite images,[34] which means that treated and untreated areas may be associated with different patterns of classification errors. Thus, we focus on natural *forest* cover as outcome to avoid these confounding effects.[35]

Figure 5 shows the trends in natural forest cover (as % of MCA area) in treated and control MCAs with vertical lines indicating the moment when the AF bill was first approved in the Chamber of Deputies (gray vertical line) and when the AFL finally came into force (green vertical line). Figure 5 (b) shows the same information, with natural forest cover as an index (1993=100). Natural forest cover in treated MCAs seems to revert the decreasing path around the period when the AFL was sanctioned (solid line) while in untreated MCAs, the natural forest cover trend is more erratic with interspersed periods of increasing and decreasing trends (dashed line).

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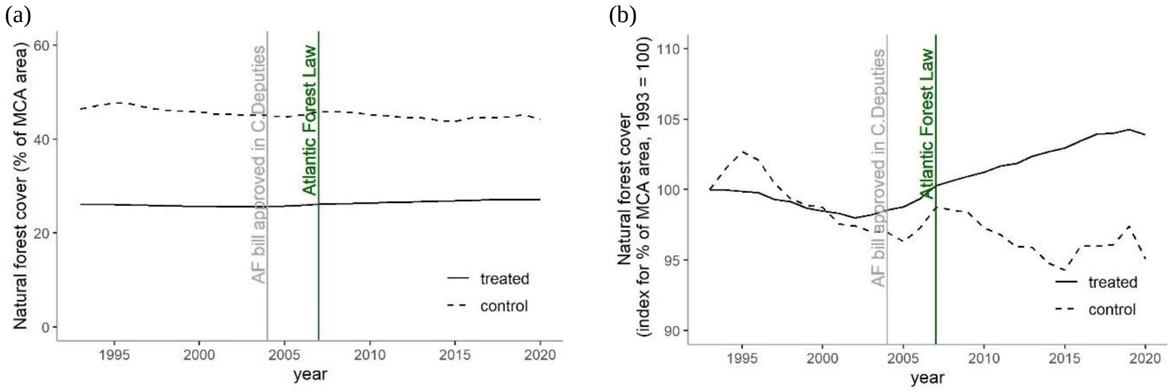
[33] In the Pampa's grasslands example, we can expect a negative bias reducing the forest protection effect of the AFL.

[34] For example, deforestation through clear-cutting leaves visible scars in the forest, which are easily detected in satellite images. This is one of the reasons why PRODES (the Brazilian Amazon Rainforest Monitoring Program by Satellite), a pioneer system focused on the Brazilian Amazon started monitoring deforestation by rapid clear-cuts. In contrast, progressive degradation is more difficult to detect (Almeida et al., 2021).

[35] Natural forest cover includes forest and savanna formations, mangrove and wooded restinga (category 1 in Mapbiomas classification). It excludes planted monoculture forests of exoctic species such as eucalyptus or pinus. See Appendix 1 for Mapbiomas collection 6 land use and cover categories.

Figure 5 – Natural forest cover evolution in treated and control AMCs, 1993-2020. (a) Natural forest cover as % of MCA area (b) Natural forest cover as index (% of MCA area, 1993= 100)



Another relevant concern relates to possible differential responses to commodity prices in treated and untreated areas.[36] In the difference-in-differences setup, an increase in prices of a specific crop that is predominantely cultivated in untreated areas but not in treated ones (soybean in Cerrado area, for instance) could lead to variation in deforestation that are not linked to the AFL at all. The same could happen even if both treated and untreated areas produce the commodity but are differently responsive to the variation in prices. So, in case of increase in cattle prices, if the untreated area is more responsive to these prices[37] than the treated areas, a relative decrease in forests in treated areas could have been caused by this increase in cattle prices that in turn have encouraged only farmers from untreated areas to increase pasture lands by deforesting.

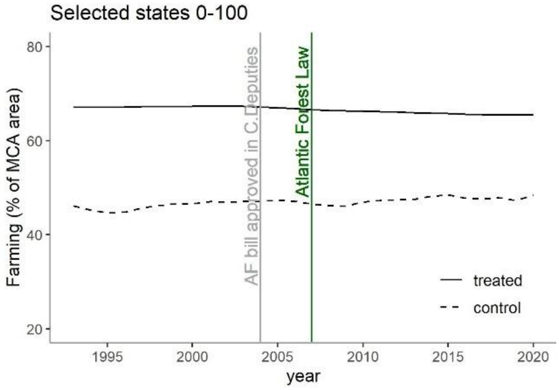
It does not seem to be the case for our sample municipalities. Farming cover are indeed increasing in control areas, as expected (Figure 6), but the evolution of disaggregated components of farming (pasture, crops, silviculture, and mosaic of crops and pasture) follow different patterns (Figure 7). For any increase in commodity prices that affects untreated areas differently, the effect in deforestation could be observed if we also observe a differencial increase in the correspondent land use cover. However, none of the plots from Figure 7 suggests a differential increase in these land use cover. In particular, pasture cover (the highest share in farming area) is relatively stable in control municipalities, reducing possible effects coming from variation in cattle prices (Figure 7 (a)). In turn, crops cover increases over time, but this increase appear to be the same in both treated and control municipalities (Figure 7 (b)).[38] For

[36] Assunção et al. (2015) demonstrated a positive and robust relationship between crop prices and deforestation and between lagged cattle prices and deforestation in the Brazilian Amazon.
[37] For reasons that are not related to the AFL protection, such as differences in productivity.
[38] This is confirmed in section 6.2 as robustness check.

silviculture (non native planted forests) and for mosaic of pasture and crops, treated municipalities showed a higher increase when compared to control ones (Figure 7 (c)). For all these disaggregated components of farming, the lack of differential increase in control areas relative to treated areas reduces possible effects coming from variation in commodity prices.

Figure 6 –Farming cover evolution in treated and control AMCs, 1993-2020. (a) Farming cover as % of MCA area (b) Farming cover as index (% of MCA area, 1993= 100)

(a)



(b)

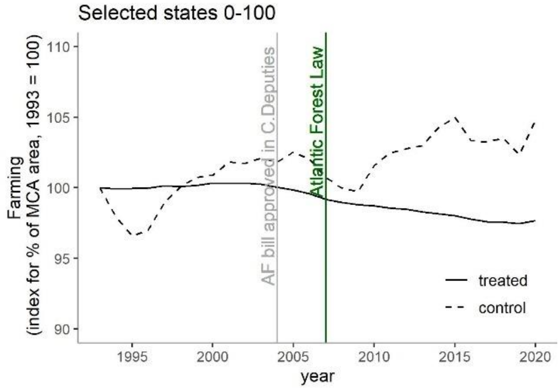
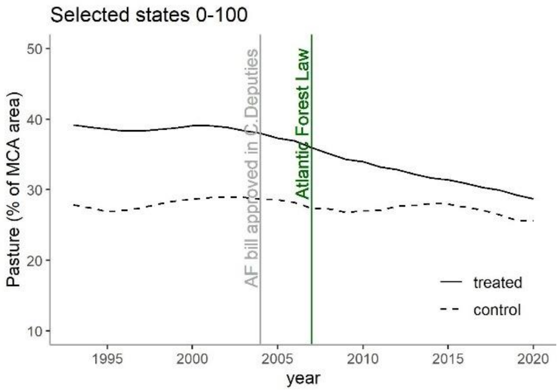
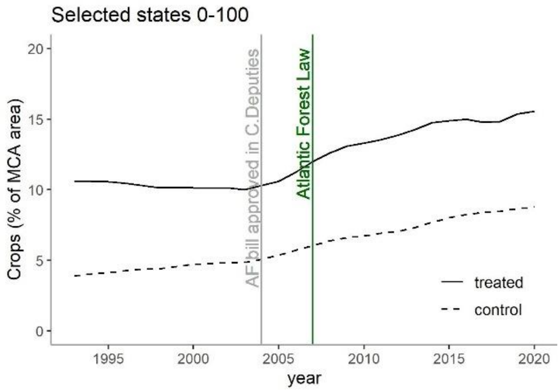


Figure 7 – Pasture, crops, silviculture and mosaic of pasture/crops cover evolution in treated and control AMCs, 1993-2020 (as % of AMC area)

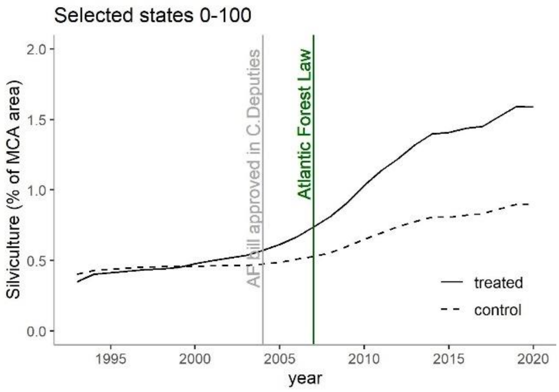
(a) Pasture cover



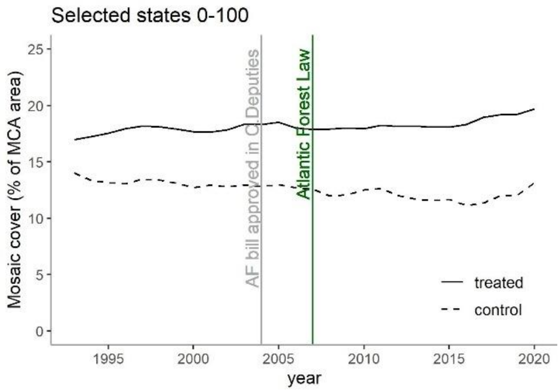
(b) Crops cover



(c) Non-native forest plantation (silviculture) cover



(d) Mosaic of pasture and crops



We complemented those data with socioeconomic municipal variables from the Brazilian Institute of Geography and Statistics - IBGE (GDP, GDP *per capita*, sectorial value-added, share of urban population) and from the Brazilian Unified Health System Data – Datasus (infant mortality rate - deaths per 1,000 live births). We also included data on Conservation Units coverage from the National Register of Conservation Units (CNUC, Portuguese acronym) from the Brazilian Ministry of Environment (MMA). In Table 1 we can compare the mean value for these observable characteristics in treated and control groups, highlighting the need to control for covariates in our empirical strategy.

Table 1 – Mean values for observable variables in treated and control municipalities

Variable	Treated	Control	Difference[1]
No. of MCAs	1,661	1,461	200
Area (ha)	38,323	111,906	-73,583***
Population in 2000 (hab)	34,456	20,992	13,464*
Share of urban population in 2000	62.7	57.0	5.7***
GDP in 2000 (R$ million)	295	100	195*
GDP per capita in 2000 (R$)	4,556	3,162	1,394***
Agriculture value added in 2000 (%)	22.5	23.0	-0.5
Industry value added in 2000 (%)	18.3	13.4	4.9***
Services value added in 2000 (%)	34.8	29.8	4.9***
Public sector value added in 2000 (%)	24.4	33.8	-9.4***
Infant mortality rate (per 1,000 live births), avg 1997-2004	21.8	21.3	0.5
Natural forest in 1985 (% of MCA area)	27.2	49.9	-22.6***
Conservation Units in 2006 (% of MCA area)	8.2	4.2	4.0***

[1] Welch test *p<0.1;** p<0.05; ***p<0.01

4.2 Empirical strategy

We use yearly municipality-level panel data to estimate the average treatment effect on the treated (ATT) of the AFL on the natural forest cover using a difference-in-differences (DiD) design. We consider that the treatment started in 2007 (the law is from December 2006), and test different specifications using zero to three years of anticipation periods (consistent with the timing when the draft bill was being approved in the Chamber of Deputies and then in the Senate). We restrict the analysis to the period 1993-2020, after Decree no. 750/1993, which took initial steps towards a differential treatment of the Atlantic Forest concerning land use conversion. As will be shown in our data, estimates from pre-2006 period show that it is reasonable to assume conditional parallel trends in this evaluation, even with the prior protection given by the decrees from 1993 and 1990.

We use the doubly robust estimator proposed by Sant'Anna & Zhao (2020), which is consistent if either a propensity score[39] or outcome regression[40] are correctly specified and the parallel trends assumption holds conditional on covariates. We use the "did" estimation package for R from Callaway & Sant'Anna (2020), with the doubly robust estimator implemented in the case of multiple periods. In the AFL context, once units are treated, they remain treated in the following periods and are compared to never treated units. Inference relies on simultaneous clustered bootstrapped standard errors at the municipality level and accounts for the autocorrelation of the data.

We first estimate the ATT for each pair of periods according to equation 1:

$$ATT(g,t,\delta) = E\left[\left(\frac{G_g}{E[G_g]} - \frac{\frac{p_g(X)C}{1-p_g(X)}}{E\left[\frac{p_g(X)C}{1-p_g(X)}\right]}\right)\left(Y_t - Y_{g-\delta-1} - E\left[Y_t - Y_{g-\delta-1}|X, C=1\right]\right)\right] \qquad (1)$$

Where $g = 2007$ and refers to the treatment starting date, $\delta = 0{,}1{,}2{,}3$ and refers to the anticipation periods and $t \in \{2, \dots, \tau - \delta\}$ is the period, after the treatment $(t \geq g - \delta)$. G_g is a binary variable that is equal to one if a unit is first treated in period g, C is a binary variable that is equal to one for units that do not participate in the treatment at any time period (never treated units), and p_g is a generalized propensity score. X is a vector of covariates and includes state dummies, the baseline outcome, and some other covariates in the baseline.

In Brazil, Federal, state, and municipal governments have shared responsibilities in legislative and executive actions related to the environment, so we allow for state heterogeneity by adding state dummies. Baseline natural forest cover (as % of MCA area, from the year 1985) is added as a covariate to account for the different likelihood of vegetation removal depending on the remaining stocks in natural forest cover. Other baseline covariates are also added to control for previous socioeconomic and conservation status (log of GDP in 2000, log of GDP per capita in 2000, the share of agriculture value added in 2000, the share of the urban population in 2000, the average infant mortality rate from period 1997-2004 and area covered by Conservation Units in 2000, as % of MCA area).

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[39] This is the DiD inverse probability weighted estimator proposed by Abadie (2005).
[40] This is the kernel-based DiD regression estimator proposed by Heckman et al. (1997)

We then aggregate them into an average using equation 2:

$$\theta_s(g) = \frac{1}{\tau - g + 1} \sum_{t=2}^{\tau} 1\{g \leq t\} ATT(g, t) \qquad (2)$$

There might be two sources of downward bias in our specification. The first one is the concurrent incentives to protect other control regions/biomes through other instruments,[41] such as executive programs and action plans (PPCerrado, for instance). The other possible source of bias follows from the fact that land cover removal pressure may be different in treated and untreated areas. It is commonly argued that environmental protection is frequently set in areas with low pressure for land use conversion (*i.e.* low opportunity costs) and that this differential pressure biases the estimated effects of the protection upward.[42] In the case of the Atlantic Forest Law, the protection was defined with the exact opposite reasoning once its geographic delimitation includes the most densely populated area in Brazil and concentrates 70% of the Brazilian GDP. In this sense, the AFL may be subject to additional downward bias when we compare the Atlantic Forest to other biomes.

Other two sources of upward bias of our estimates come from spillover effects: one from the AFL itself, and other that comes from another important protection policy in the Amazon region, the PPCDAm (as untreated areas for AFL are also untreated areas for PPCDAm). We partially tackle the latter issue by removing all municipalities from the Legal Amazon from our sample. We also proceed with a robustness check where our sample is restricted to municipalities with less than 25% of natural forest cover in the baseline, which means that remaining natural cover is scarce for both treated and control areas, reducing the possibility of spillover effects. Finally, we analyze the effects of the AFL on native vegetation by looking at the effects on stock outcomes (natural forest cover) and three flow outcomes (annual loss, recovery and net recovery). In particular, we consider that results from recovery are less prone to this bias because PPCDAm focuses on tackling deforestation of primary forests, whereas the AFL tries to protect primary and secondary vegetation, including the ones in an early stage of recovery (which in turn may lead to an increase in annual recovery).

[41] The AFL is a unique case of a law regulating the protection of remaining vegetation of one particular biome. Protection of native vegetation is generally given by regulations applied in all Brazilian territory (Forest Code gives a differential treatment to Legal Amazon though).
[42] Joppa and Pfaff (2011) and Pfaff et al. (2014) try to tackle this issue using matching when analyzing the impact of protected areas in the natural cover.

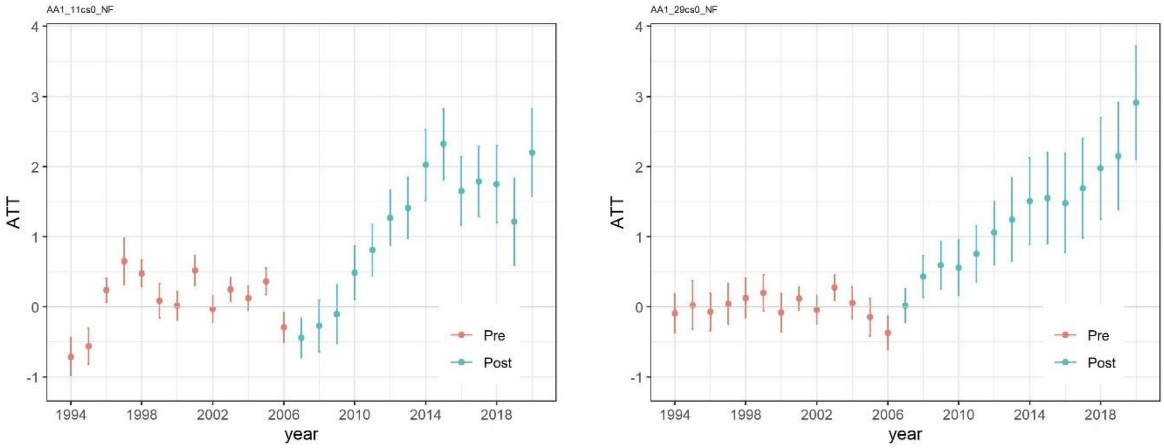
5 Results and discussion

5.1 Effects on natural forest cover

Figure 8 shows event studies under different assumptions about parallel trends. Figure 8 (a) assumes unconditional parallel trends whereas in Figure 8 (b), the parallel trends assumption holds after controlling for covariates. Even though there is no clear trend for the estimated coefficients prior to the AFL, the evidence in Figure 8 (a) may be suggestive of violation of the parallel trends assumption when no covariates are included in the estimation model. This result may suggest that a two-way fixed effects (TWFE) estimation strategy for differences in differences may not be adequate.[43] Figure 8 (b) presents estimates conditional on covariates and stronger evidence in favor of the parallel trends assumption.[44] The pre-treatment period coefficients contrast drastically to the post-treatment ones, and we can observe a consistent relative increase in the natural forest cover of the municipalities affected by the AFL.

Figure 8 – Atlantic Forest Law effects on the natural forest cover (as % of MCA area) with no anticipation. Cluster at the MCA level

(a) Unconditional parallel trends (b) Conditional parallel trends



Aggregate results using different identification strategies are shown in Table 2. Column (1) refers to the specification shown in Figure 8 (a). and column (4) to the one shown in Figure

[43] Note that differently from TWFE event study type graph, in Callaway & Sant'Anna (2020), the base period is different for post and pre-treatment. For pre-treatment periods, the base period is the period right before the current period. For post-treatment periods, the base period is the period immediately before treatment (when there is anticipation, it is before the period of anticipation).

[44] The coefficients from 2003 and 2006 are individually significantly different from zero in the pre-treatment period. Althouth we reject the null hypothesis that all coefficients in this period are zero, we do not detect any discernible pattern that could suggest violation of the parallel trends assumption.

8 (b). All specifications lead to a positive and significant effect of the AFL in municipalities' natural forest cover, and controlling for covariates produces slightly higher effects. The reference specification assumes conditional parallel trends after controlling for state dummies, baseline natural forest cover, and other baseline control variables (column 4), resulting in a 1.3 pp relative increase of natural forest cover in municipalities protected by the Atlantic Forest Law.

Table 2 - Aggregate effect of Atlantic Forest Law on the natural forest cover with no anticipation

	Selected states, 0-100 Dependent variable: nat. forest cover (% of MCA area)			
	(1)	(2)	(3)	(4)
ATT	1.149***	1.417***	1.364***	1.279***
	(0.124)	(0.107)	(0.104)	(0.167)
MCA cluster	✓	✓	✓	✓
State dummies		✓	✓	✓
Baseline nat. forest cover			✓	✓
Baseline control variables				✓
Anticipation periods	0	0	0	0
Baseline nat. forest cover in treated MCAs (2006)	25.91	25.91	25.91	25.91
Qty. of treated MCAs	1661	1661	1661	1661
Qty. of control MCAs	1461	1461	1461	1461

Note: * p < 0.1; ** p < 0.05; *** p < 0.01
Robust standard errors are in parenthesis

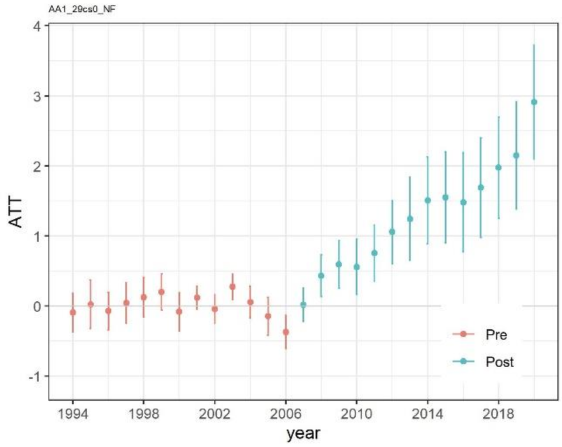
The results are robust to different anticipation periods (Table 3). Estimates from pre-treatment periods suggest one period of anticipation, and the most conservative specification assumes two years of anticipation, with 0.8 pp of relative increase of natural forest cover in treated municipalities. Two years of anticipation matches the moment when the draft bill of Atlantic Forest Law was being discussed in the Senate after its approval in the Chamber of Deputies. With two years of anticipation, natural forest cover consistently increases after a transitory decrease between 2005 and 2007 and after 2013, the natural forest cover in treated municipalities is estimated to be significantly higher than in untreated ones (Figure 9).

Table 3 - Aggregate effect of Atlantic Forest Law on the natural forest cover with different anticipation periods

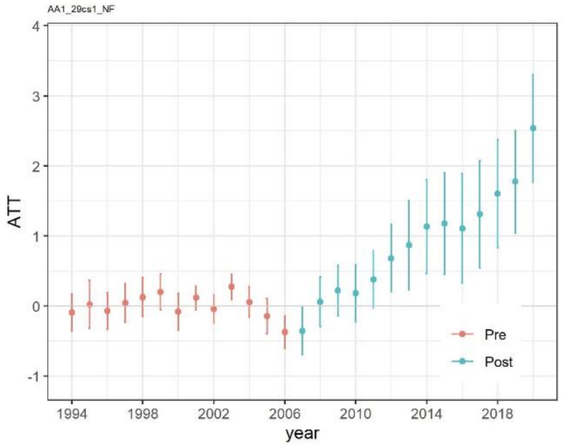
	Selected states, 0-100 Dependent variable: nat. forest cover (% of MCA area)			
	(1)	(2)	(3)	(4)
ATT	1.279***	0.905***	0.758***	0.814***
	(0.159)	(0.170)	(0.235)	(0.258)
MCA cluster	✓	✓	✓	✓
State dummies	✓	✓	✓	✓
Baseline nat. forest cover	✓	✓	✓	✓
Baseline control variables	✓	✓	✓	✓
Anticipation periods	0	1	2	3
Baseline nat. forest cover in treated MCAs (2006)	25.91	25.91	25.91	25.91
Qty. of treated MCAs	1661	1661	1661	1661
Qty. of control MCAs	1461	1461	1461	1461
Note:	* p < 0.1; ** p < 0.05; *** p < 0.01 Robust standard errors are in parenthesis			

Figure 9 – Atlantic Forest Law effects on the natural forest cover (as % of MCA area), different periods of anticipation. Conditional on state, natural forest cover and other covariates in the baseline. Cluster at the MCA level

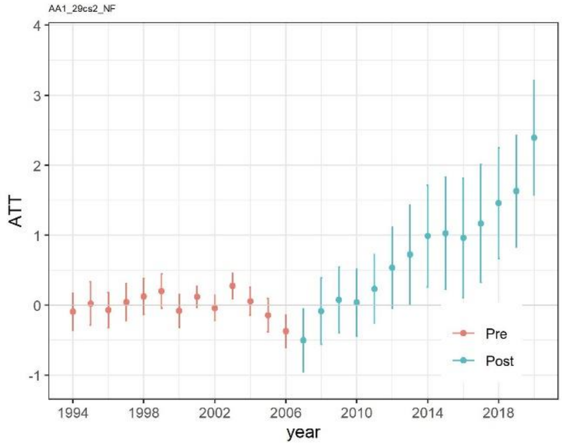
(a) No anticipation



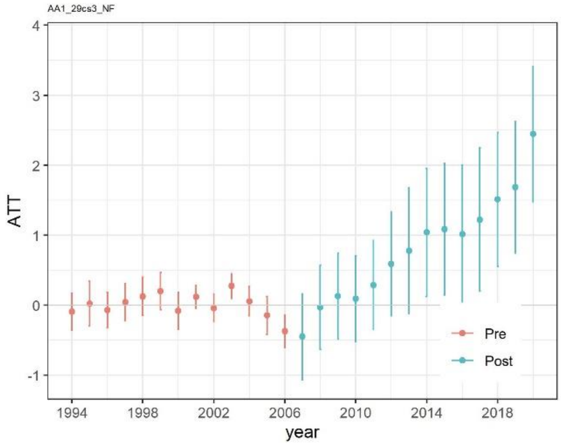
(b) 1 period of anticipation



(c) 2 periods of anticipation



(d) 3 periods of anticipation



5.2 Effects on net recovery

In this section, we explore results from flow variables. Net recovery (net difference among recovery and loss of natural forest cover) is normalized to reduce cross-sectional variation due to heterogeneity in municipality size.[45] We follow the procedure of Assunção et al. (2015), according to the following expression:

$$NNR_{it} = (ANR_{it} - \overline{ANR_{\iota}})/sd(ANR_i) \qquad \text{Equation (1)}$$

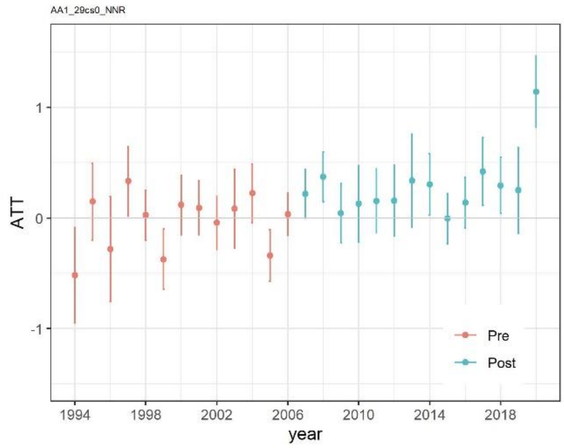
where NNR_{it} is the normalized net recovery in municipality i in period t; ANR_{it} is the annual net recovery in municipality i between period t and t-1 (in hectares), $\overline{ANR_{\iota}}$ and $sd(ANR_i)$ are the mean and standard deviation of the annual net recovery over the period 1993-2020.

The effects of the AFL on normalized net recovery are shown in Figure 10. Pre-treatment estimates seems to support parallel trends assumption with two anticipation periods. Aggregate results show no effects when these anticipation periods are taken into account (Table 4 (a)).

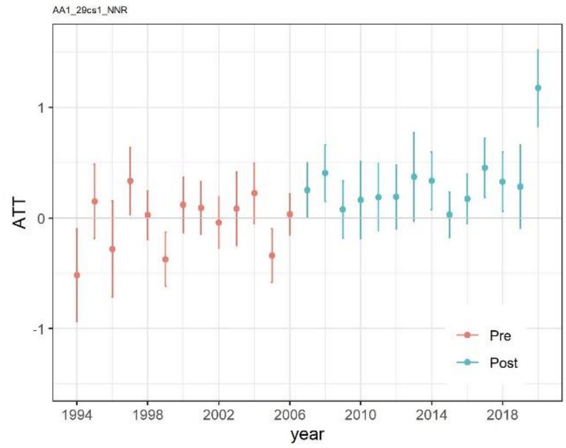
[45] See results for non-normalized net revegetation (as a % of the MCA area) in Appendix 2.

Figure 10 – Atlantic Forest Law effects on normalized net recovery for natural forests (as % of MCA area), different periods of anticipation. Conditional on state, natural forest cover and other covariates in the baseline. Cluster at the MCA level

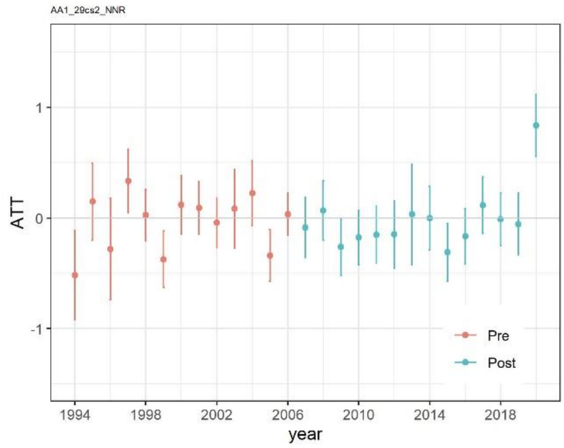
(a) No anticipation



(b) 1 period of anticipation



(c) 2 periods of anticipation



(d) 3 periods of anticipation

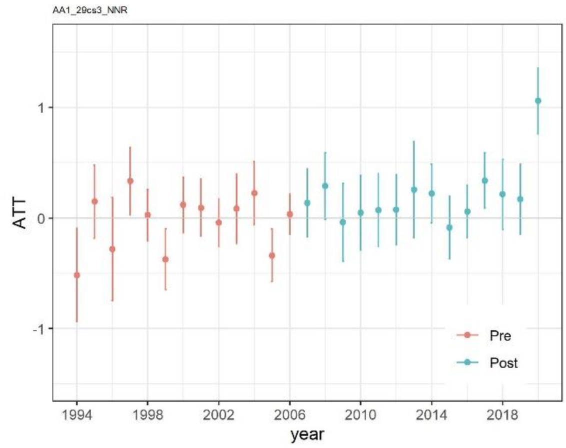


Table 4 - Aggregate effect of Atlantic Forest Law on normalized net recovery, loss and recovery of natural forest cover with different anticipation periods

Dependent variable	Selected states, 0-100			
	(1)	(2)	(3)	(4)
(a) Normalized net recovery of natural forests	0.282***	0.316***	-0.023	0.200**
	(0.074)	(0.071)	(0.064)	(0.074)
(b) Normalized loss of natural forests	0.021	-0.082	0.339***	0.025
	(0.053)	(0.058)	(0.065)	(0.060)
(c) Normalized recovery of natural forests	0.437***	0.406***	0.256***	0.357***
	(0.081)	(0.078)	(0.067)	(0.085)
MCA cluster	✓	✓	✓	✓
State dummies	✓	✓	✓	✓
Baseline nat. forest cover	✓	✓	✓	✓
Baseline control variables	✓	✓	✓	✓
Anticipation periods	0	1	2	3
Baseline nat. forest cover in treated MCAs (2006)	25.91	25.91	25.91	25.91
Qty. of treated MCAs	1661	1661	1661	1661
Qty. of control MCAs	1461	1461	1461	1461
Note:	* p < 0.1; ** p < 0.05; *** p < 0.01			
	Robust standard errors are in parenthesis			

In Figure 11 net recovery is disaggregated into forest loss and recovery. First, pre-treatment estimates from normalized recovery show stronger evidences for parallel trends, while the same estimates from normalized loss are more erractic. Pre-treatment estimates also suggest that the anticipation effects came mainly from an increase in forest loss (rather than a decrease in forest recovery) that started two years prior to the AFL (Figure 11 (a) and (b)), which is consistent to pre-emptive deforestation behaviour associated with policy changes (Simmons, Law, et al., 2018). There is no reason to expect any pre-emptive behaviour from the recovery side and our results confirm that there was no significant change in this outcome in the few years prior to the law. There is, however, a modest decrease in the recovery of natural forests two years before the AFL, which could be also explained by a pre-emptive clearing behaviour in regenerating[46] forests that prevented them to be detected as recovery.

Results from normalized recovery show a consistent increase in the annual recovery starting in the first year of AFL, with positive and significant coefficients for almost every year after the law in the case of no anticipation (all coefficients are positive, and 10 out of 14 are significant at 5%). The effects on recovery are reduced in the case of two years of anticipation (Figure 11 (d)), but the average effect is positive and significant for all cases of anticipation, including the two years' case (Table 4 (c)). Despite all these positive results from the recovery side, part of the effect in net recovery is neutralized with the increase in forest loss two years before the AFL (Figure 11 (c) and Table 4 (b)). This positive effect from the recovery side and the lack of effect from the loss side strengthen the idea that our sample municipalities is not suffering from the effects from variation in commodity prices. The effects on recovery may be odd at first because the AFL does not require active native vegetation recovery. One possibility is that native forests in the early stages of recovery (in situ) still classified as anthropic land use (in satellite images) immediately before the AFL was left to regenerate after the law and over the years it started to appear as natural forest cover in satellite images classification. Another possibility is an interaction between AFL and the Forest Code, which in turn requires that the landowners recover the deficit in native vegetation in Legal Reserves and APPs.

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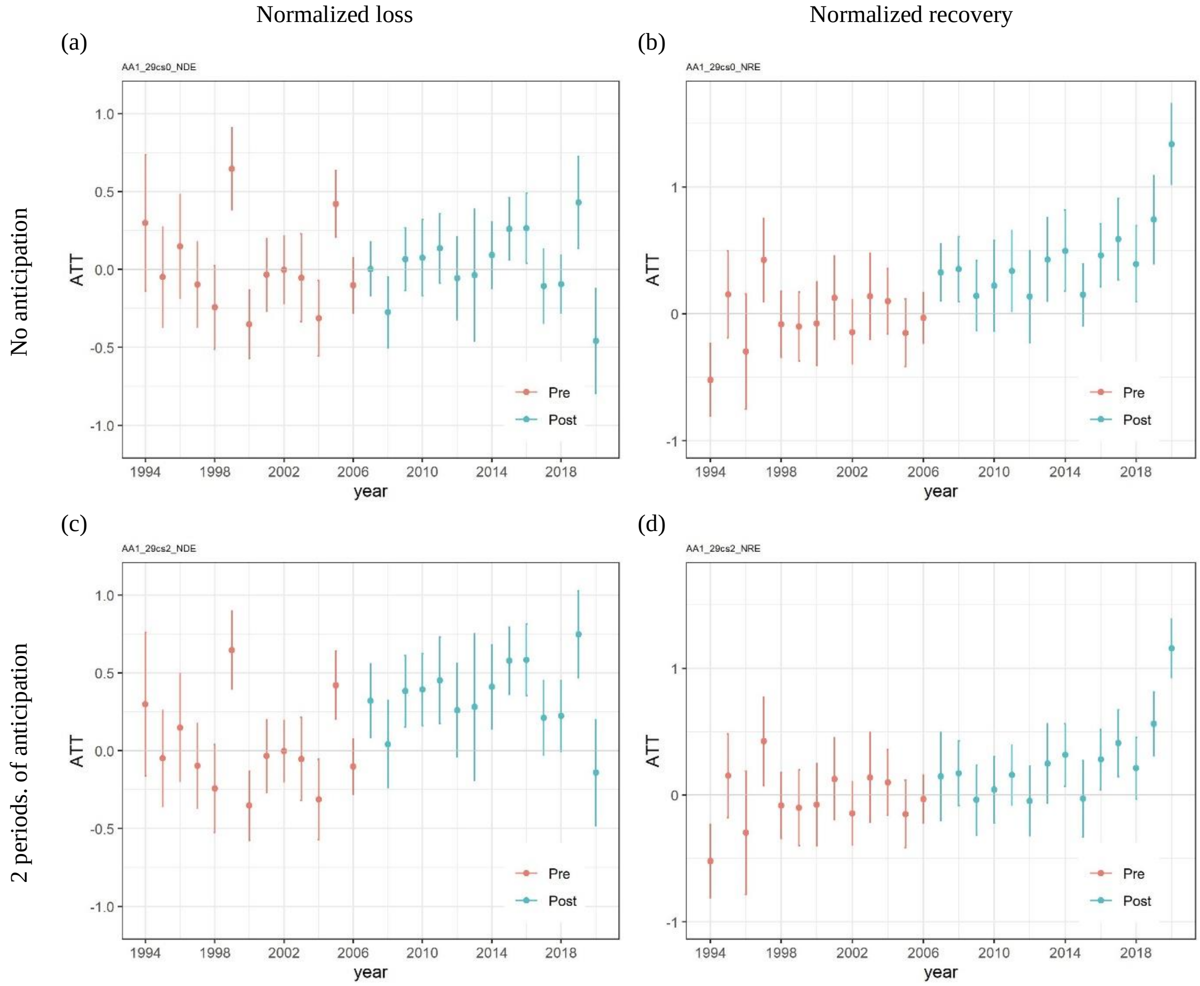
[46] Recall that the AFL also protects regenerating forests.

Figure 11 – Atlantic Forest Law effects on normalized loss and recovery for natural forests. Conditional on state, natural forest cover and other covariates in the baseline. Cluster at the MCA level



6 Robustness check

6.1 Subsample: municipalities with less than 25% of natural forest cover in the baseline

One significant difference between municipalities in the Atlantic Forest and in other biomes is that a substantial portion of the Atlantic Forest's native vegetation was removed during the first half of the 20th century. In our reference specification, municipalities in the Atlantic Forest had an average of 25.9% of its remaining natural forest cover in 2006 and municipalities outside the Atlantic Forest still had an average of more than 45% in the same year,[47] which means that rural property owners from untreated areas still had plenty of remaining areas in their properties to convert[48] from native vegetation into farming.

In our previous exercises, we have used the baseline of natural forest cover in each municipality as a covariate to deal with this difference. In this section, we constrain our sample considering only MCAs with less than 25% of natural forest cover in the baseline year (1985).[49] Thus, with such a small percentage of remaining natural forest cover, possible differences related to the exploration of logging in native forests (which might be different in different biomes) are also reduced. This last point also tackles the possible bias coming from the common untreated area between AFL and protection policies in the Amazon region. With this subsampling procedure, the number of control and treated MCAs is reduced but control MCAs are closer to the Atlantic Forest (and further from Amazon region and its deforestation belt)

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[47] In 1985 (the first year covered by the Mapbiomas database), Atlantic Forest had less than 35% of its natural cover and other biomes had more than 65%.

[48] This land convertion could also be legal. The Brazilian Forest Code mandates that rural property owners keep at least 20% of their property area as a "Legal Reserve", an area where natural vegetation must be preserved (20% is the minimum percentage in all biomes except in the Brazilian Legal Amazon, where it increases to 80% in areas covered by forests and 35% in areas covered by savannah). Moreover, the Forest Code also defines that some areas, such as those around watercourses (springs, rivers, lakes, reservoirs), hilltops, and areas in high altitudes or with high declivity, are protected as Areas of Permanent Preservation (APP.) (The Brazilian Forest Code was updated in 2012 (Federal Law no. 12.651/2012). Before that, the Forest Code was defined by Federal Law no. 4,771/1965. Legal Reserve and APP protection are basically the same in both old and new Forest Codes). The remaining area is left to the farmer's production and he/she can legally remove the native vegetation as long as he/she gets the vegetation removal license, and the activity is not constrained by another type of protection policy (such as that governing national parks).

[49] 25% was defined based on the Forest Code, considering that 20% must be kept as Legal Reserve and as estimate of 8.5% as APP (On average, around 8.5% of a municipality area is protected as APP, according to the Brazilian Foundation for Sustainable Development data (FBDS). FBDS have mapped APP in 23 out of 27 Brazilian states. The percentage of estimated APP varies from 5 to 25% of the municipality area. States almost fully located in the Atlantic Forest biome (Rio de Janeiro, Espírito Santo, Paraná and Santa Catarina) are the ones with the higher share of APP (17%, 12%, 12% and 25%, respectively). Data retrieved from http://geo.fbds.org.br/). The remaining 71.5% of a typical rural property is left to the farmer's production.

(Figure 12). It is also worth noting that the trends of natural forest cover suggest a clearer difference between the path of treated and control MCAs after the AFL (Figure 13).

Figure 12 – Treated and control MCAs in robustness check (MCAs with less than 25% of natural forest cover in the baseline). AFL application area boundary in red line.

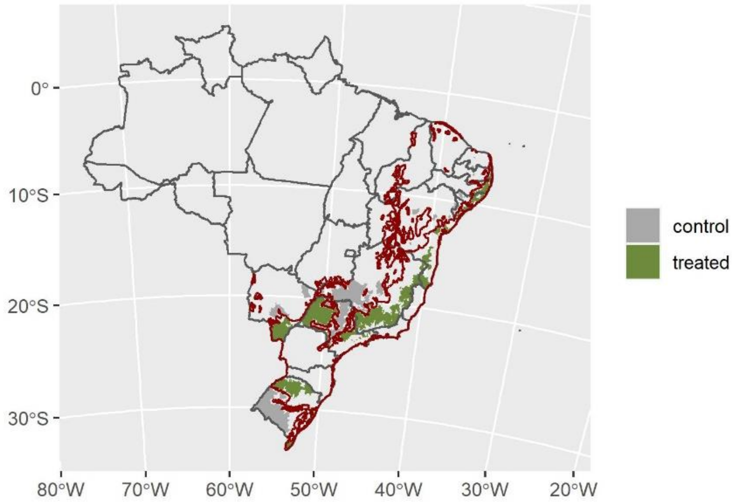
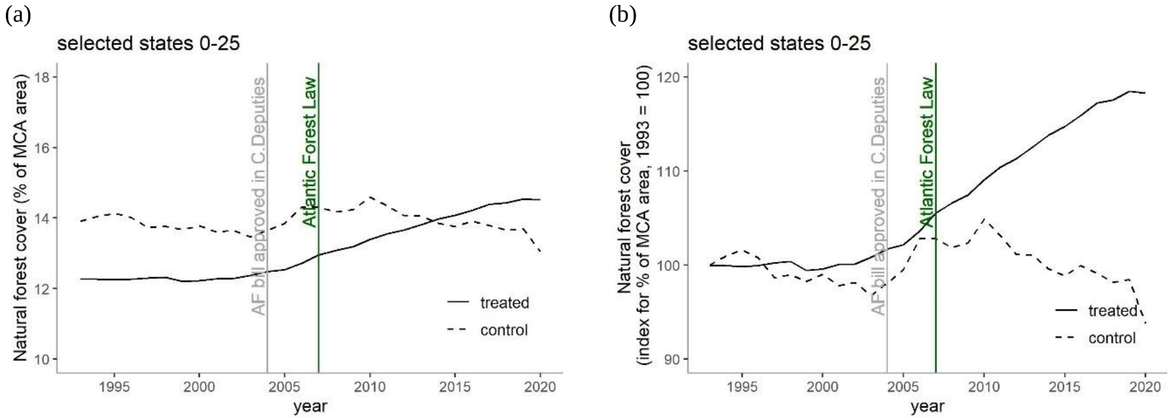


Figure 13 – Natural forest cover evolution in treated and control AMCs in robustness check (MCAs with less than 25% of natural forest cover in the baseline), 1993-2020. (a) Natural forest cover as % of MCA area (b) Natural forest cover as index (% of MCA area, 1993= 100)



The aggregate results for this sample are qualitatively the same as the reference specification from previous section (Table 5 and Figure 14). In section 7 we explore some heterogeneities using the same sampling procedure.

Table 5 - Aggregate effect of Atlantic Forest Law on the natural forest cover and on normalized net recovery, loss, and recovery for the subsample with less than 25% of natural forest cover in the baseline

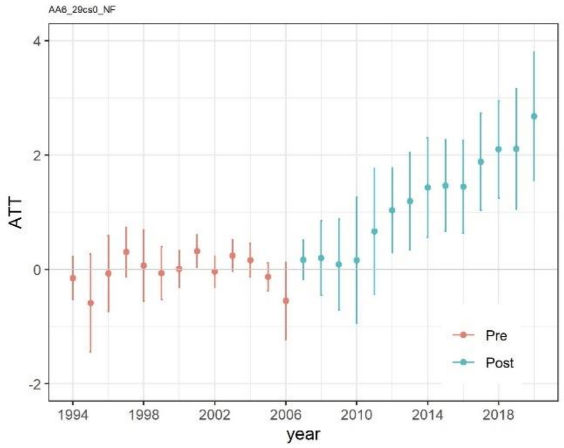
Dependent variable	Selected states, 0-100			
	(1)	(2)	(3)	(4)
(a) Natural forest cover	1.185***	0.634**	0.503*	0.662**
	(0.283)	(0.288)	(0.283)	(0.265)
(b) Normalized net recovery of natural forests	0.323**	0.382***	-0.027	0.362***
	(0.129)	(0.081)	(0.082)	(0.099)
(c) Normalized loss of natural forests	0.072	-0.057	0.364***	-0.137
	(0.080)	(0.069)	(0.079)	(0.084)
(d) Normalized recovery of natural forests	0.527***	0.552***	0.275***	0.457***
	(0.174)	(0.092)	(0.083)	(0.102)
MCA cluster	✓	✓	✓	✓
State dummies	✓	✓	✓	✓
Baseline nat. forest cover	✓	✓	✓	✓
Baseline control variables	✓	✓	✓	✓
Anticipation periods	0	1	2	3
Baseline nat. forest cover in treated MCAs (2006)	12.71	12.71	12.71	12.71
Qty. of treated MCAs	970	970	970	970
Qty. of control MCAs	259	259	259	259

Note: * p < 0.1; ** p < 0.05; *** p < 0.01

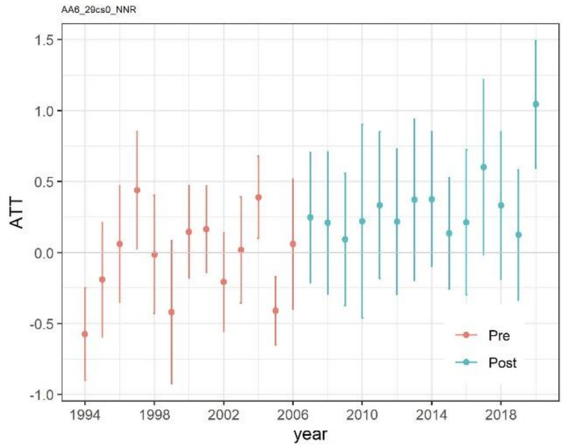
Robust standard errors are in parenthesis

Figure 14 – Atlantic Forest Law effects on the natural forest cover (as % of MCA area) and on normalized net recovery, loss, and recovery for the subsample with less than 25% of natural forest cover in the baseline, with no anticipation. Conditional on state, natural forest cover and other covariates in the baseline. Cluster at the MCA level

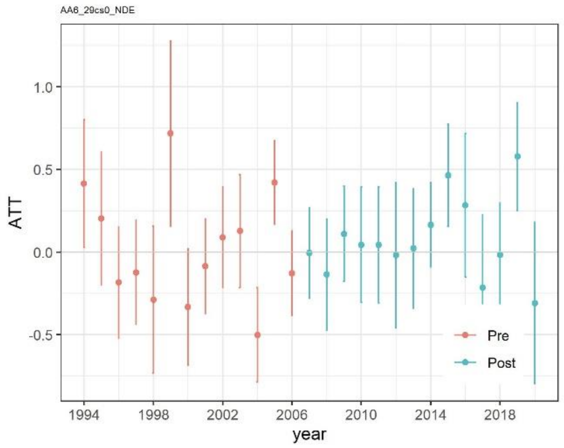
(a) Natural forets cover



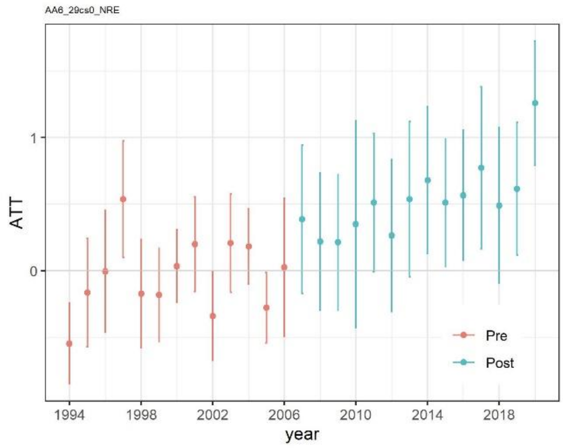
(b) Normalized net recovery of natural forests



(c) Normalized loss of natural forests



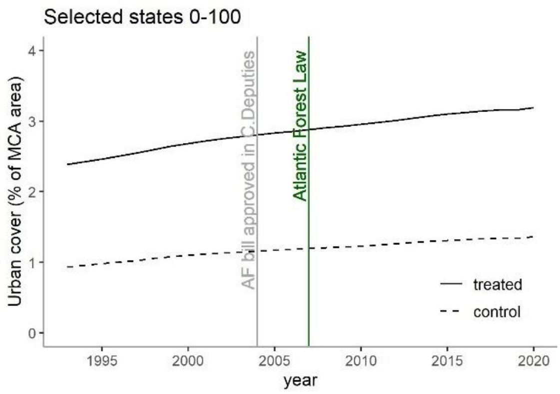
(d) Normalized recovery of natural forests



6.2 Effects on anthropic land cover

In this section, we further explore the impact of the AFL by estimating its effect on different anthropic land uses. We investigate the consequences of the AFL on farming land cover and its disaggregated components (pasture, crops, silviculture, and mosaic of crops and pasture), as well as urban land cover. Graphs of farming cover evolution (and its disaggregated components) were already shown in section 4.1 (Figures 6 and 7). Urban cover evolution are shown in Figure 15.

Figure 15 –Urban cover evolution in treated and control AMCs, 1993-2020 (as % of AMC area)



Observed effects on farming are negative and of a magnitude that is consistent with the positive effects for natural forest cover (reference specification). The estimates for farming also suggest an anticipation effects before the law (Table 6 (1) and Figure 16 (a)). We do not observe any significant aggregate effect for all other farming component in both cases of anticipation periods. This could be the result of land use substitution between different anthropic land cover, and the analysis of annual coefficients in Figure 16 show a negative trend for pasture cover, non-native forest plantation (silviculture), and urban cover (Figure 16, b,d,f). Satellite images show that urban areas are also associated with deforestation in the AFL area (SOS Mata Atlântica, 2022) (Figure 15), but our results suggest that these areas can also experience a reduction in urban cover following the AFL *relative to control areas*. Lastly, we do not observe any trend (or aggregate significant effect) for crops cover, reducing the chances that our sample municipalities are subject to variation in crop prices that lead to a differential effect in our treated and control areas. [50]

[50] See Appendix 3 for annual plots of estimated coefficients in the case of three periods of anticipation.

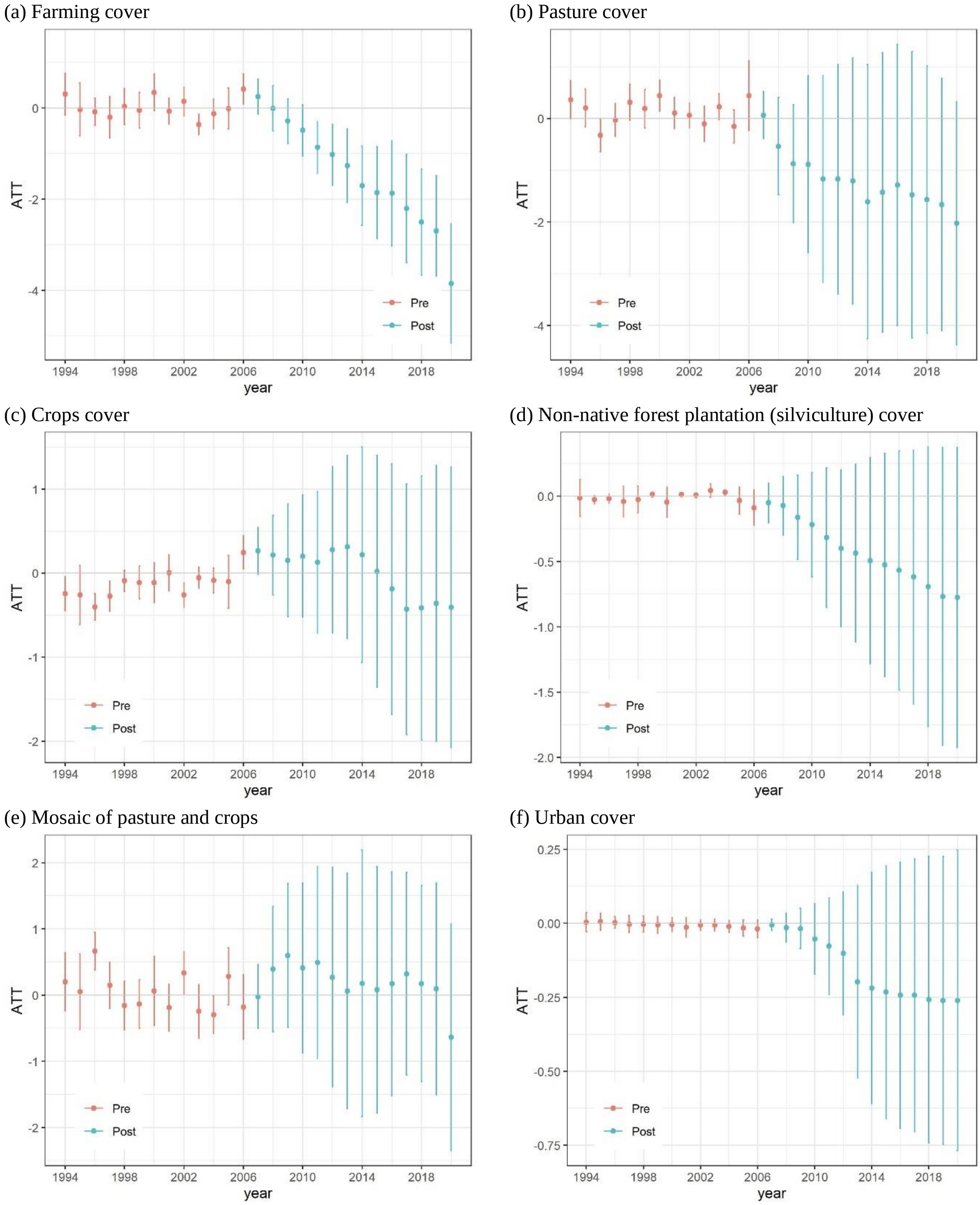
Table 6 - Aggregate effect of Atlantic Forest Law on different types of anthropic land cover

	Anticipation periods	Farming	Pasture	Crops	Silviculture	Mosaic pasture/ crops	Urban
		(1)	(2)	(3)	(4)	(5)	(6)
Effect on anthropic land cover	0	-1.454***	-1.202	0.000	-0.436	0.183	-0.156
		(0.231)	(0.762)	(0.390)	(0.273)	(0.488)	(0.136)
	3	-1.171***	-0.690	0.062	-0.529	-0.014	-0.201
		(0.382)	(1.107)	(0.443)	(0.378)	(0.613)	(0.155)
MCA cluster		✓	✓	✓	✓	✓	✓
State dummies		✓	✓	✓	✓	✓	✓
Baseline nat. cover		✓	✓	✓	✓	✓	✓
Baseline control variables		✓	✓	✓	✓	✓	✓
Baseline nat. cover in treated MCAs (2006)		30.12	30.12	30.12	30.12	30.12	30.12
Qty. of treated MCAs		1661	1661	1661	1661	1661	1661
Qty. of control MCAs		1461	1461	1461	1461	1461	1461

Note: * p < 0.1; ** p < 0.05; *** p < 0.01

Robust standard errors are in parenthesis

Figure 16 – Atlantic Forest Law effects on farming, pasture, crops, silviculture, mosaic of pasture/crops and urban cover (as % of MCA area), with no anticipation. Conditional on state, natural cover and other covariates in the baseline. Cluster at the MCA level



7 Analysis of heterogeneity

7.1 Effects in municipalities with different percentages of natural forest cover in the baseline

The percentage of remaining natural forest cover in the municipality can define the different possibilities concerning the removal or conservation of native vegetation. One remarkable difference in these possibilities is based on the Forest Code and how close the percentage of the remaining natural forest cover is to the minimum percentage to be protected as required by this law (Details in section 6.1). If one municipality has a high percentage of natural forest cover, it might be the case that rural property owners in this municipality can still legally change the land cover for farming (as long as they are not constrained by another protection law, such as the AFL). Another difference may be related to Conservation Units, the Brazilian term for protected areas such as national parks. In the Atlantic Forest, huge areas with continuous remaining natural forest cover are the ones with a set of connected and sometimes overlapping protected areas.

In this section, we disaggregate the results taking the natural forest cover in the baseline into account, and explore their heterogeneities. The disaggregation is done with the same sampling procedure used in section 6.1. We subset the MCAs according to the following criteria:

- Group 0-25: MCAs with 0-25% of natural forest cover in the baseline (1985);[51]
- Group 25-50: MCAs with 25-50% of natural forest cover in the baseline (1985);
- Group 50-75: MCAs with 50-75% of natural forest cover in the baseline (1985);
- Group 75-100: MCAs with 75-100% of natural forest cover in the baseline (1985).

Treated and control MCAs for each of these groups are shown in Figure 17. Only states with MCAs in both treated and untreated areas were kept in the groups, *i.e*, some MCA from the reference specification are not in any of the four groups.[52]

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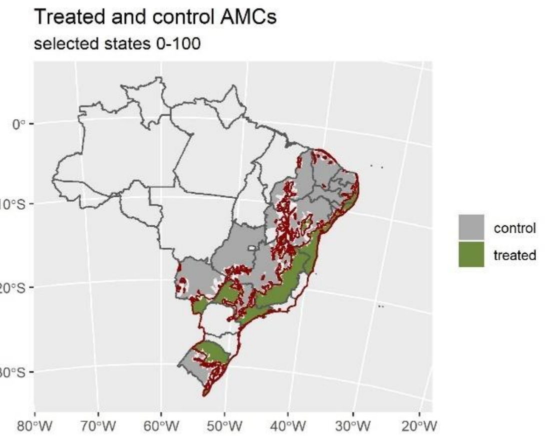
[51] This is the same saubsample from section 6.1.

[52] For example, in the state of Pernambuco in the northeast of Brazil, there are 23 MCAs with 75-100% of natural forest cover in the baseline in the control group, but none in the treated group. Thus, all MCAs from the state of Pernambuco were removed from Group 75-100.

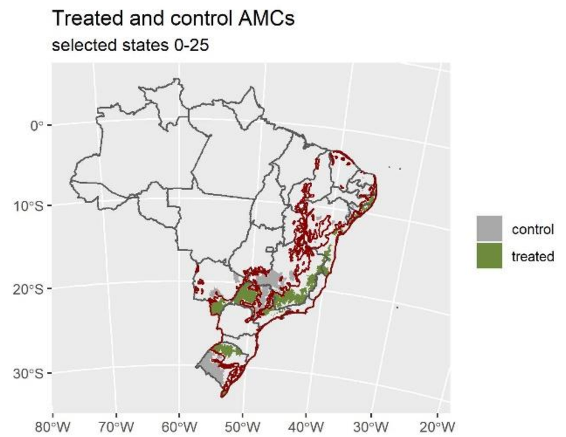
In Figure 18 we plot the natural cover evolution for treated and untreated MCAs for each of these groups. The plots reinforce the idea that the AFL effect was heterogeneous depending on the stock of remaining natural forest cover in the baseline. The trends for group 0-25 suggests a positive effect of the law, while MCAs from group 75-100 seem not to have been affected by tle law.

Figure 17 – Treated and control MCAs in the reference specification (0-100) and different groups

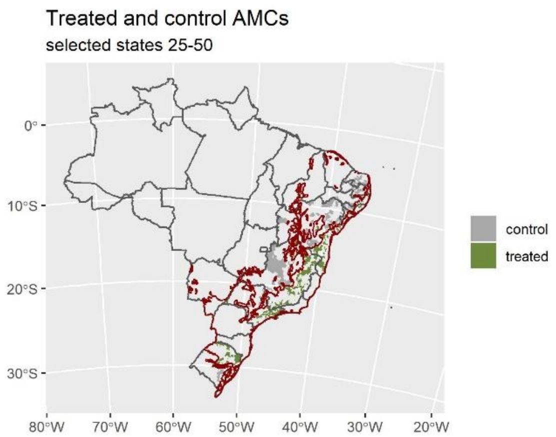
(a) 0-100



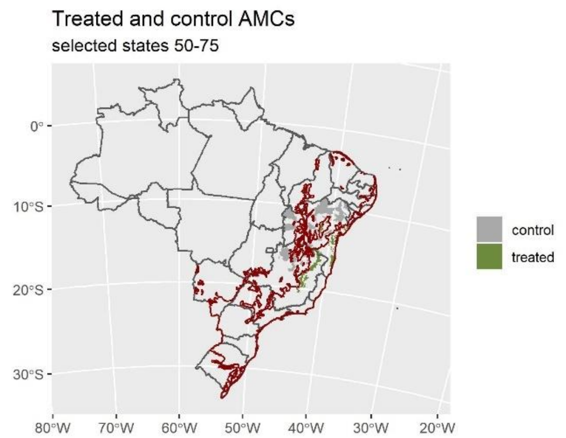
(b) 0-25



(c) 25-50



(d) 50-75



(e) 75-100

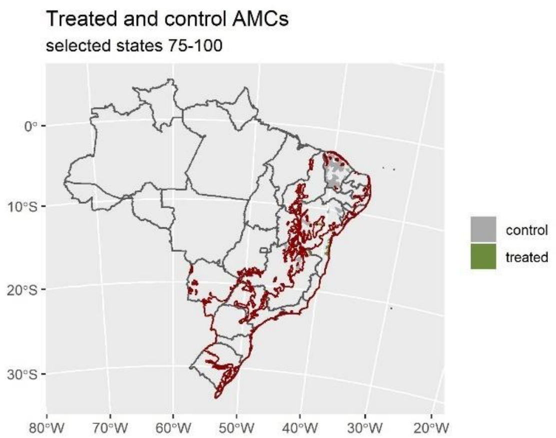
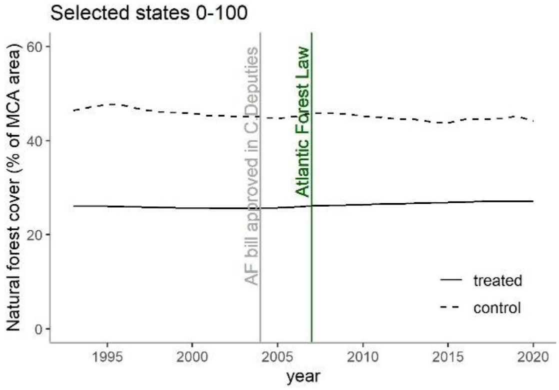
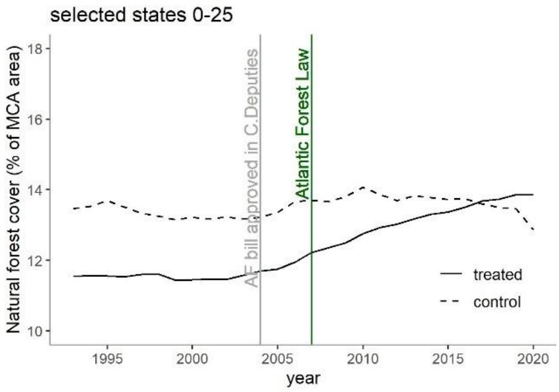


Figure 18 – Natural forest cover (as % of MCA area) evolution in treated and control MCAs for different groups, 1993-2020

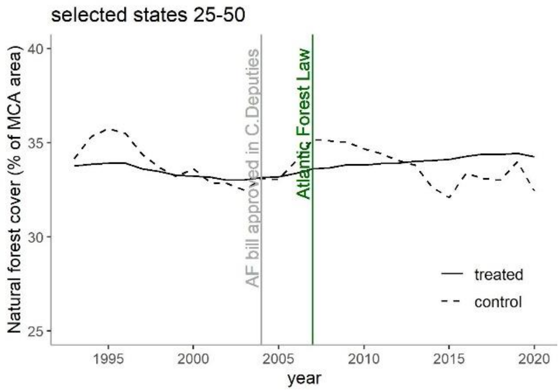
(a) 0-100



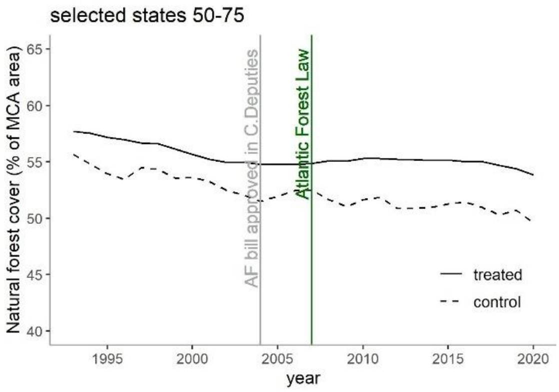
(b) 0-25



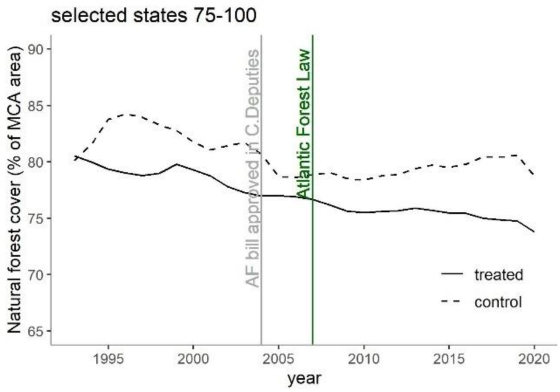
(c) 25-50



(d) 50-75



(e) 75-100



The estimates of different groups show that the observed aggregate effects on the natural forest cover in the reference specification came mainly from 0-25 group (Table 7, column (1)). Results from group 75-100 were in the opposite direction, with a significant reduction on natural forest cover after AFL (Table 7, column (4)). Groups 25-50 and 50-75 showed positive and significant effect of AFL on forest cover in the cases of no anticipation, but these results reduce with the increase in the anticipation periods (Table 7 (a)). Despite this fact, group 25-50 contributed to the aggregate effect on net recovery and recovery in the reference specification. Effects on the recovery side were more consistent than that on the deforestation side (see Appendix 3 for annual plots of flow variables).

Table 7 - Aggregate effect of Atlantic Forest Law on the natural forest cover and on normalized net recovery, loss, and recovery for different groups

Dependent variable	Anticipation periods	Selected states				
		0-25 (1)	25-50 (2)	50-75 (3)	75-100 (4)	Ref (5)
(a) Natural forest cover	0	1.185***	1.289***	2.141***	-1.765**	1.279***
		(0.283)	(0.368)	(0.589)	(0.859)	(0.159)
	1	0.634**	0.586*	1.530**	-2.481***	0.905***
		(0.288)	(0.287)	(0.631)	(0.702)	(0.170)
	2	0.503*	0.162	0.770	-2.163***	0.758***
		(0.283)	(0.357)	(0.696)	(0.728)	(0.235)
	3	0.662**	-0.067	0.663	-2.005***	0.814***
		(0.265)	(0.462)	(0.877)	(0.733)	(0.258)
(b) Normalized net recovery of natural forests	0	0.323**	0.586***	0.198	0.387	0.282***
		(0.129)	(0.190)	(0.227)	(0.280)	(0.074)
	1	0.382***	0.413***	0.361	-0.546	0.316***
		(0.081)	(0.140)	(0.284)	(0.350)	(0.071)
	2	-0.027	0.104	-0.382	-0.237	-0.023
		(0.082)	(0.169)	(0.363)	(0.284)	(0.064)
	3	0.362***	0.226**	-0.656***	-0.378	0.200**
		(0.099)	(0.097)	(0.168)	(0.284)	(0.074)
(c) Normalized loss of natural forests	0	0.072	-0.083	0.037	-0.051	0.021
		(0.080)	(0.118)	(0.206)	(0.303)	(0.053)
	1	-0.057	-0.199*	-0.343	0.321	-0.082
		(0.069)	(0.117)	(0.257)	(0.321)	(0.058)
	2	0.364***	0.159	0.294	0.337	0.339***
		(0.079)	(0.135)	(0.334)	(0.329)	(0.065)
	3	-0.137	-0.038	0.621***	0.791**	0.025
		(0.085)	(0.106)	(0.183)	(0.358)	(0.060)
(d) Normalized recovery of natural forests	0	0.527***	0.831***	0.446*	0.799**	0.437***
		(0.174)	(0.215)	(0.239)	(0.332)	(0.081)
	1	0.552***	0.523***	0.405	-0.526	0.406***
		(0.092)	(0.137)	(0.262)	(0.374)	(0.078)
	2	0.275***	0.350**	-0.181	-0.077	0.256***
		(0.083)	(0.179)	(0.226)	(0.201)	(0.067)
	3	0.457***	0.398***	-0.410**	-0.029	0.357***
		(0.102)	(0.107)	(0.193)	(0.186)	(0.085)
MCA cluster		✓	✓	✓	✓	✓
State dummies		✓	✓	✓	✓	✓
Baseline nat. forest cover		✓	✓	✓	✓	✓
Baseline control variables		✓	✓	✓		✓
Baseline nat. forest cover in treated MCAs (2006)		12.71	33.37	54.78	76.90	25.91
Qty. of treated MCAs		970	420	96	25	1661
Qty. of control MCAs		259	280	78	102	1461

Notes: * p < 0.1; ** p < 0.05; *** p < 0.01

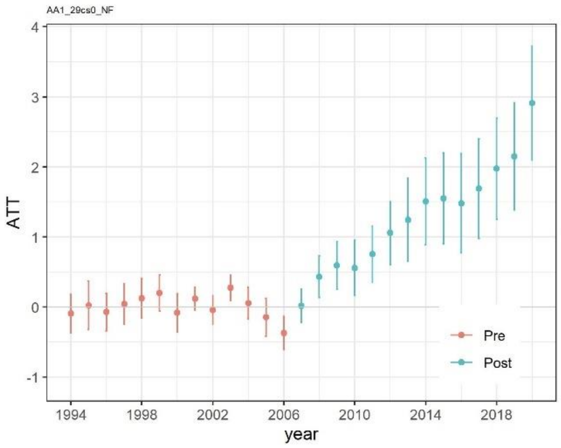
Robust standard errors are in parenthesis

Group 75-100 was not conditioned on other covariates in the baseline due to the small sample size

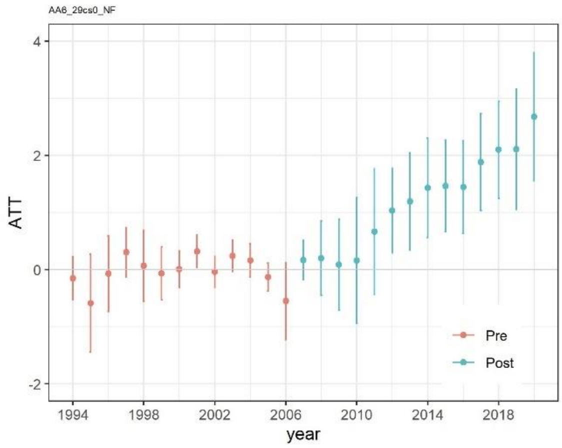
The 4 subsamples does not sum up to the reference specification (Ref) due to te lack of common support for states

Figure 19 – Atlantic Forest Law effects on the natural forest cover (as % of MCA area) for different groups, no anticipation. Conditional on state, natural forest cover and other covariates in the baseline[1]. Cluster at the MCA level

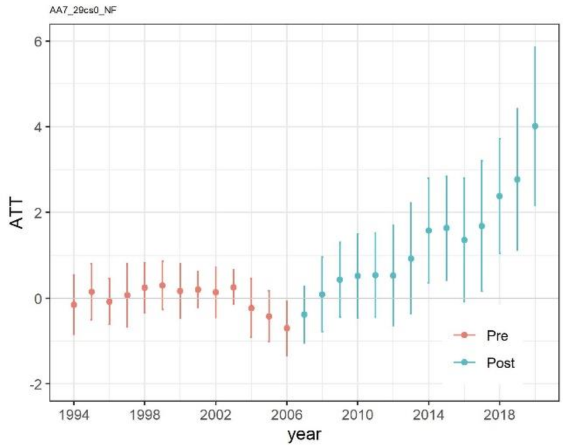
(a) 0-100



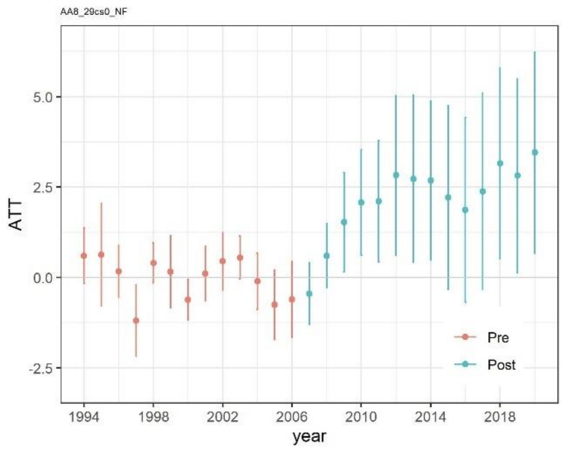
(b) 0-25



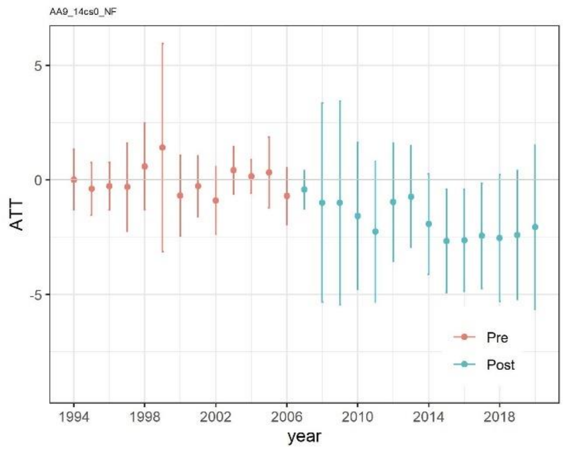
(c) 25-50



(d) 50-75



(e) 75-100



[1] Except for Group 75-100 which was conditional on state and natural forest cover in the baseline only (no other covariates in the baseline due to the small sample size)

7.2 Effects in different states

States may have additional regulations concerning native vegetation protection, as long as they are more restrictive than the federal regulation. Besides, much of the command-and-control actions related to environmental regulations fall under the responsibility of state governments. Thus, in this section, we subdivide our sample and reduce it to individual states or groups of states. We analyze individual results for the states of Sao Paulo (SP), Minas Gerais (MG) and Bahia (BA), as they are the states with relatively large number of treated and untreated municipalities. We additionally consider five other samples created by leaving different groups of states out of the reference sample containing all states (Figure 20):

- Ref-SP: MCAs from the reference set, except for MCAs in the state of Sao Paulo;
- Ref-MG: MCAs from the reference set, except for MCAs in the state of Minas Gerais;
- Ref-BA: MCAs from the reference set, except for MCAs in the state of Bahia;
- Ref–SP-MG: MCAs from the reference set, except for MCAs in the state of Sao Paulo and Minas Gerais;
- Ref–SP-MG-BA: MCAs from the reference set, except for MCAs in the state of Sao Paulo, Minas Gerais and Bahia;

Natural forest cover evolution for treated and untreated MCAs for each of these groups is shown in Figure 21. The case of the state of Sao Paulo is peculiar: it is the only state where the percentage of the MCA area with natural forest cover in treated municipalities (solid line) is above the percentage for untreated ones (dashed line).

The effects of the AFL on the natural forest cover were positive and significant for all these groups in the case of no anticipation. However, part of these effects are lost in the case of three periods of anticipation (Table 8 (a)). Among the single states analyzed, Minas Gerais (MG) is the only case where the AFL positively affected the forest cover regardless of these three anticipation periods (Table 8 (2a)), and removing Minas Gerais municipalities from the reference specification reduces the aggregate effect to zero in the remaining municipalities (Table 8 (8a)). Despite this fact, the event study estimates from the specification that excludes MG clearly show a pattern of gradual increase of the natural forest cover (Figure 22 (f)), and in the case of three years of anticipation we can see a positive and significant effect of the AFL from 2017 on (*i.e,* it took 10 years for forests stock to recover from the pre-emptive clearing in the three years prior to the law).[53]

Apparently, the pre-emptive clearing during the few years before the AFL avoided a net benefit from the policy in the majority of regions. For instance, in the case of three anticipation periods in the state of Sao Paulo (Table 8 (1)), the significant reduction in deforestation and the significant increase in recovery (and consequently a significant increase in net recovery) were not enough to result in aggregate positive effect in the stock variable (forest cover). These results from flow variables for the state of Sao Paulo are surprising considering that since 2009 there is a specific law in this state protecting the natural cover in untreated areas (State Law no. 13,550/2009).

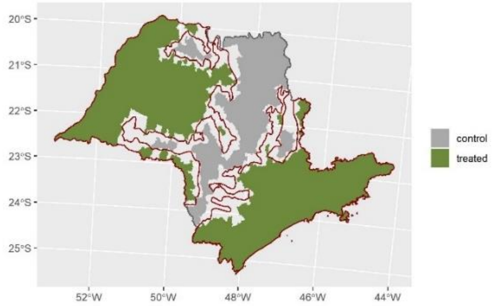
Results from flow variables from Minas Gerais and Bahia are less clear, sometimes with a significant increase in forest loss after the AFL (Table 8 (2) and (3)). Results for MCAs located in other states except for these three (SP, MG and BA) (Table 8 (11)) are more similar to the case of the state of SP, where the pre-emptive clearing reduced the effect on forest cover despite all the results from flow variables.

Finally, it is worth noting that the positive effect on recovery are sustained in almost every group (except for the states of MG and BA), reinforcing the idea that the AFL was more effective on the recovery side than on the loss side (see Appendix 3 for annual plots of flow variables).

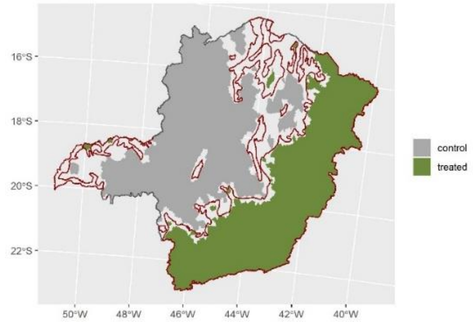
[53] See event study graphs with three periods of anticipation in Appendix 4.

Figure 20 – Treated and control MCAs in different groups of states

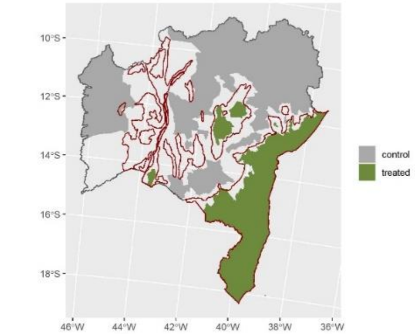
(a) SP: Sao Paulo



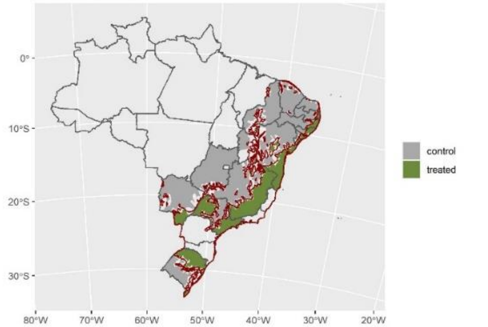
(b) MG: Minas Gerais



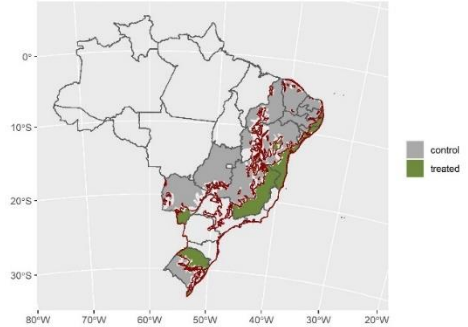
(c) BA: Bahia



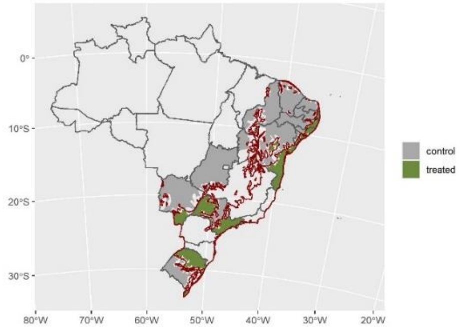
(d) Reference



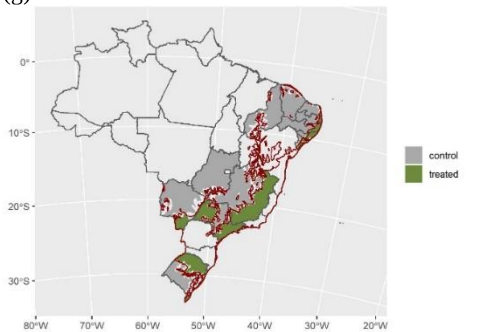
(e) Ref-SP



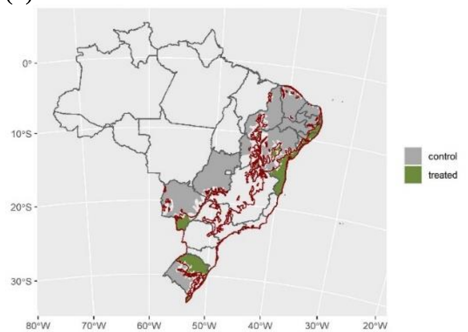
(f) Ref-MG



(g) Ref-BA



(h) Ref-SP-MG



(i) Ref-SP-MG-BA

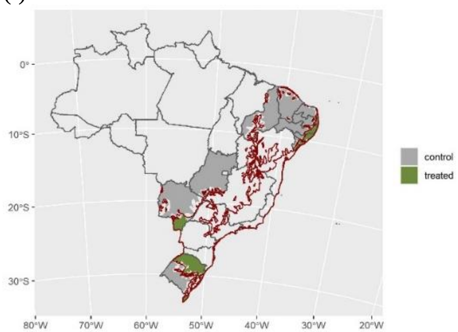
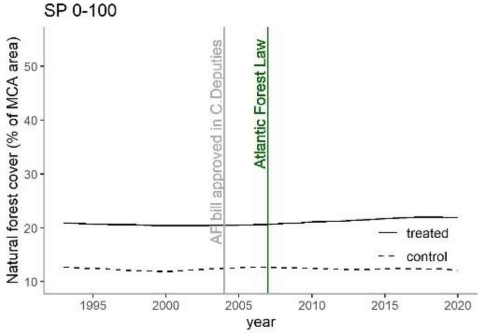
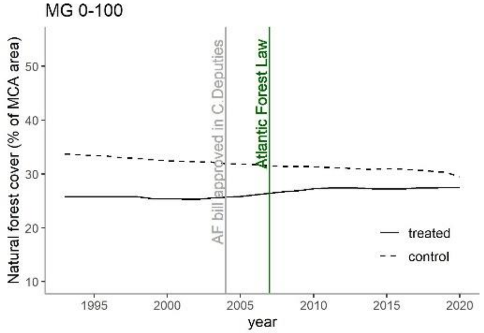


Figure 21 – Natural forest cover (as % of MCA area) evolution in treated and control MCAs for different groups of states, 1993-2020

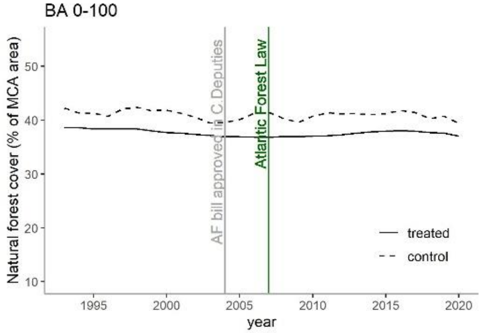
(a) SP: Sao Paulo



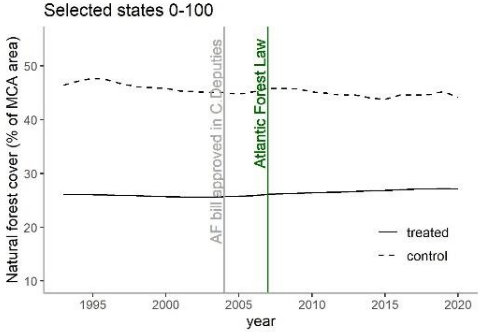
(b) MG: Minas Gerais



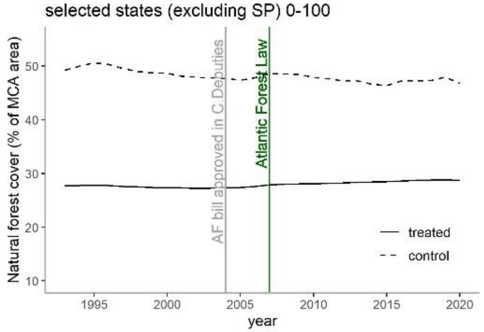
(c) BA: Bahia



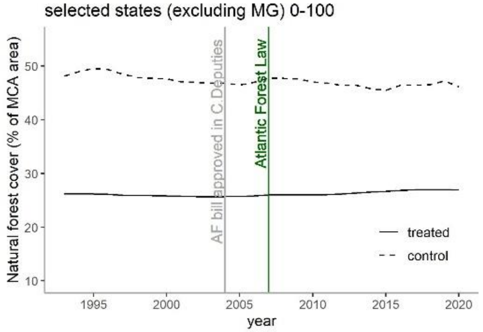
(d) Reference



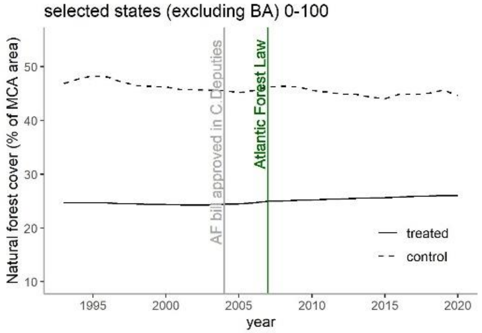
(e) Ref-SP



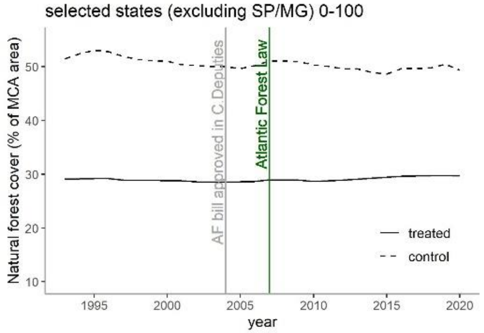
(f) Ref-MG



(g) Ref-BA



(h) Ref-SP-MG



(i) Ref-SP-MG-BA

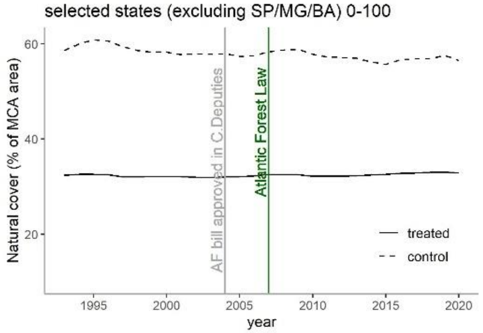


Table 8 - Aggregate effect of Atlantic Forest Law on the natural forest cover, net recovery, loss and recovery of natural forests for different groups of states

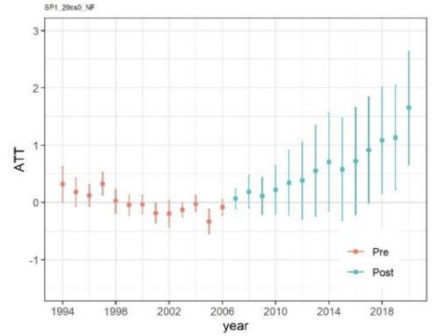
Dependent variable	Anticipation periods	Selected states								
		SP	MG	BA	Reference	Ref-SP	Ref-MG	Ref-BA	Ref-SP-MG	Ref-SP-MG-BA
		(1)	(2)	(3)	(6)	(7)	(8)	(9)	(10)	(11)
(a) Natural forest cover	0	0.617***	1.688***	1.490**	1.279***	1.351***	1.384***	1.294***	1.771***	1.870***
		(0.232)	(0.250)	(0.569)	(0.159)	(0.167)	(0.157)	(0.149)	(0.406)	(0.422)
	3	0.175	2.454***	-0.791	0.814***	0.755***	-0.101	1.131***	-2.026	-0.587
		(0.260)	(0.309)	(0.569)	(0.258)	(0.273)	(0.283)	(0.264)	(1.338)	(0.646)
(b) Normalized net recovery of natural forests	0	0.265**	-0.033	0.550***	0.282***	0.266***	0.384***	0.195**	1.177**	0.720*
		(0.115)	(0.278)	(0.197)	(0.074)	(0.078)	(0.136)	(0.081)	(0.525)	(0.369)
	3	0.554***	-0.194	-0.116	0.200**	0.147	0.454***	0.255***	0.514***	0.598***
		(0.119)	(0.126)	(0.143)	(0.074)	(0.099)	(0.083)	(0.089)	(0.134)	(0.182)
(c) Normalized loss of natural forests	0	-0.085	0.488**	-0.159	0.021	0.039	-0.016	0.096	-0.190	-0.105
		(0.105)	(0.192)	(0.193)	(0.053)	(0.066)	(0.069)	(0.068)	(0.181)	(0.149)
	3	-0.354***	0.478***	0.340***	0.025	0.120	-0.199***	-0.064	-0.199*	-0.288*
		(0.121)	(0.103)	(0.127)	(0.060)	(0.080)	(0.074)	(0.067)	(0.120)	(0.161)
(d) Normalized recovery of natural forests	0	0.212	0.285	0.793***	0.437***	0.444***	0.557***	0.360***	1.502**	0.943**
		(0.133)	(0.273)	(0.165)	(0.081)	(0.078)	(0.149)	(0.085)	(0.607)	(0.418)
	3	0.612***	0.113	0.168	0.357***	0.332***	0.571***	0.375***	0.587***	0.657***
		(0.159)	(0.140)	(0.135)	(0.085)	(0.091)	(0.082)	(0.096)	(0.128)	(0.180)
MCA cluster		✓	✓	✓	✓	✓	✓	✓	✓	✓
State dummies					✓	✓	✓	✓	✓	✓
Baseline nat. forest cover		✓	✓	✓	✓	✓	✓	✓	✓	✓
Baseline control variables		✓	✓	✓	✓	✓	✓	✓	✓	✓
Baseline nat. forest cover in treated MCAs (2006)		20.58	26.13	36.84	25.91	27.60	25.81	24.71	28.68	26.29
Qty. of treated MCAs		399	535	165	1661	1262	1126	1496	727	562
Qty. of control MCAs		111	172	127	1461	1350	1289	1334	1178	1051

Note: * p < 0.1; ** p < 0.05; *** p < 0.01

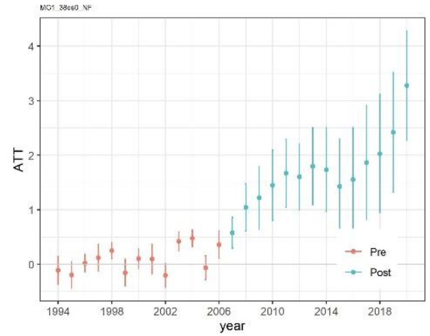
Robust standard errors are in parenthesis

Figure 22 – Atlantic Forest Law effects on the natural forest cover (as % of MCA area) for different groups of states, no anticipation. Conditional on natural forest cover and other covariates in the baseline. Estimates from groups of states also include state dummies. Cluster at the MCA level

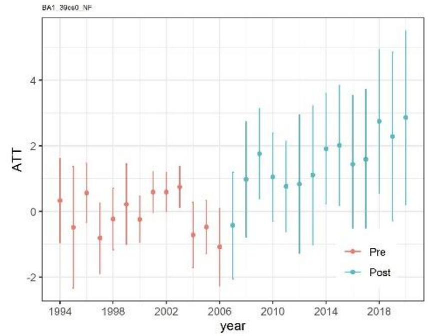
(a) SP: Sao Paulo



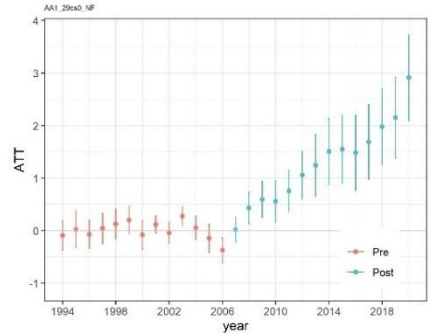
(b) MG: Minas Gerais



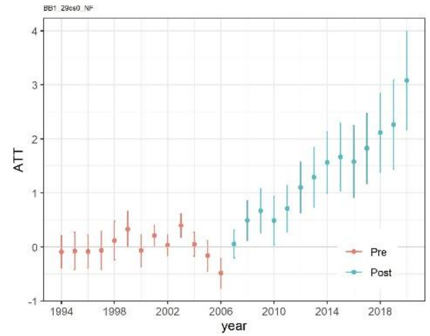
(c) BA: Bahia



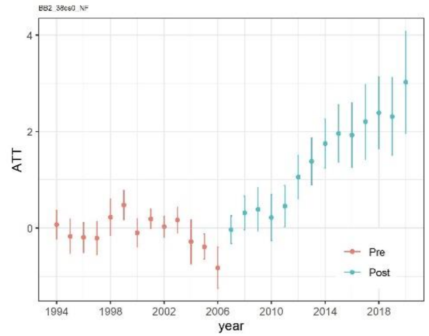
(d) Reference



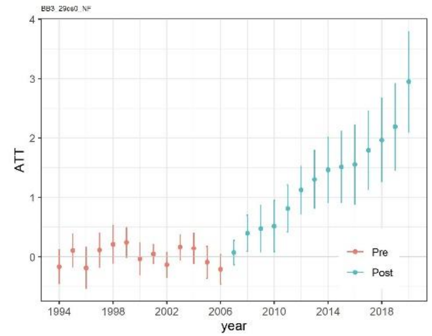
(e) Ref-SP



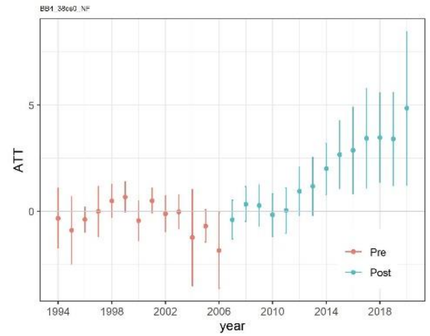
(f) Ref-MG



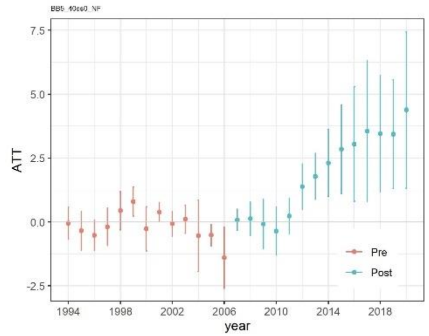
(i) Ref-BA



(j) Ref-SP-MG



(k) Ref-SP-MG-BA



7.3 Effects inside private lands

We now explore the effects on the natural forest cover in private lands by removing the information from part of municipalities' territories defined as any of these four land categories:

- Conservation Units (all categories[54], data from the National Register of Conservation Units (CNUC, Portuguese acronym),
- Indigenous lands (data from the National Indian Foundation, FUNAI),
- Quilombola areas[55] (data from National Institute for Colonization and Agrarian Reform, INCRA), and
- Rural settlements (data from National Institute for Colonization and Agrarian Reform, INCRA).

We then assess the effect of AFL on the natural forest cover in the remaining area of each MCA, which is consisted mainly of private lands,[56] and compare it with the reference scenario from section 5.[57] This area defined as private lands in each MCA was built in such a way that the stock of private lands was kept static over time considering the most recent information on these land categories, *i.e.*, any piece of territory that was ever defined in one of the four land categories was removed from the MCA, including those that were delimited in recent years.[58] That means that territories with characteristics that would define a Conservation Unit in the year 2010, for instance, would already be dropped off from the MCA territory in 1985.

The evolution of natural forest cover in these private lands followed a path like the one in the reference scenario, except for a difference in the level (natural forest cover in private lands is at a lower level since we ignore the cover in part of municipalities' territory) (Figure 23).

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[54] In Brazil, there are 12 different categories of Conservation Units in the National System of Natures Conservation Units, with different objectives, size, location and management approaches. Some categories of Conservation Units include private lands, but they were also removed from the private lands definition in this section. See more information on Conservation Units in Appendix 5.

[55] settlements first established by escaped slaves.

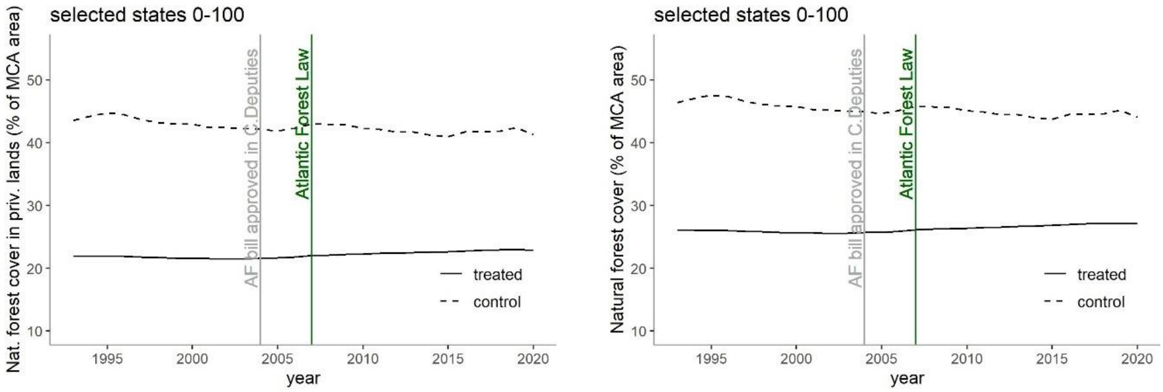
[56] In fact it can be a mix of private and public lands as it still includes urban areas, but the effect of these public lands in urban areas are expected to be low.

[57] The effect was reestimated using the same MCA sample from private lands (some few MCAs are totally covered by these four land categories.

[58] Conservation Units database retrieved in 2021, Indigenous lands, quilombola lands and rural settlements database retrieved in 2022.

Figure 23 – Natural forest cover (as % of MCA area) evolution in treated and control MCAs for different groups, 1993-2020

(a) Private lands[1] (b) Reference



[1] Excludes Conservation Units, Indigenous Lands, Quilombola Lands, and Rural Settlements

Data source: Mapbiomas collection 6

Aggregate estimated effects on natural forest cover from private lands were positive and significant and accounted for 82-87% of the estimated effect from the reference specification depending on the anticipation period case (Table 9 (a)). Net recovery was also positive and significant in these areas but the effect is close to zero in the case of three periods of anticipation (Table 9, line (b)). A similar pattern is also observed in event studies estimates (Figures 24 and 25).

Table 9 - Aggregate effect of Atlantic Forest Law on natural forest cover and normalized net recovery of natural foests in private lands and reference specification

Dependent variable	Anticipation periods	Private lands[1]	Reference
		(1)	(2)
(a) Natural forest cover	0	1.124***	1.291***
		(0.119)	(0.177)
	3	0.748***	0.915***
		(0.185)	(0.306)
(b) Normalized net recovery of natural forests	0	0.254***	0.239***
		(0.073)	(0.061)
	3	0.172	0.216***
		(0.151)	(0.076)
MCA cluster		✓	✓
State dummies		✓	✓
Baseline nat. forest cover		✓	✓
Baseline control variables		✓	✓
Baseline dependent stock variable in treated MCAs (2006)		21.80	25.89
Qty. of treated MCAs		1652	1652
Qty. of control MCAs		1455	1455

Note: * p < 0.1; ** p < 0.05; *** p < 0.01

Robust standard errors are in parenthesis

Figure 24 – Atlantic Forest Law effects on natural forest cover in treated and control MCAs in private lands and in reference specification, no anticipation and three periods of anticipation.

Private lands (excludes Conservation Units, Indigenous Lands, Quilombola Lands, and Rural Settlements)

Reference

No anticipation

3 periods of anticipation

(a) (b) (c) (d)

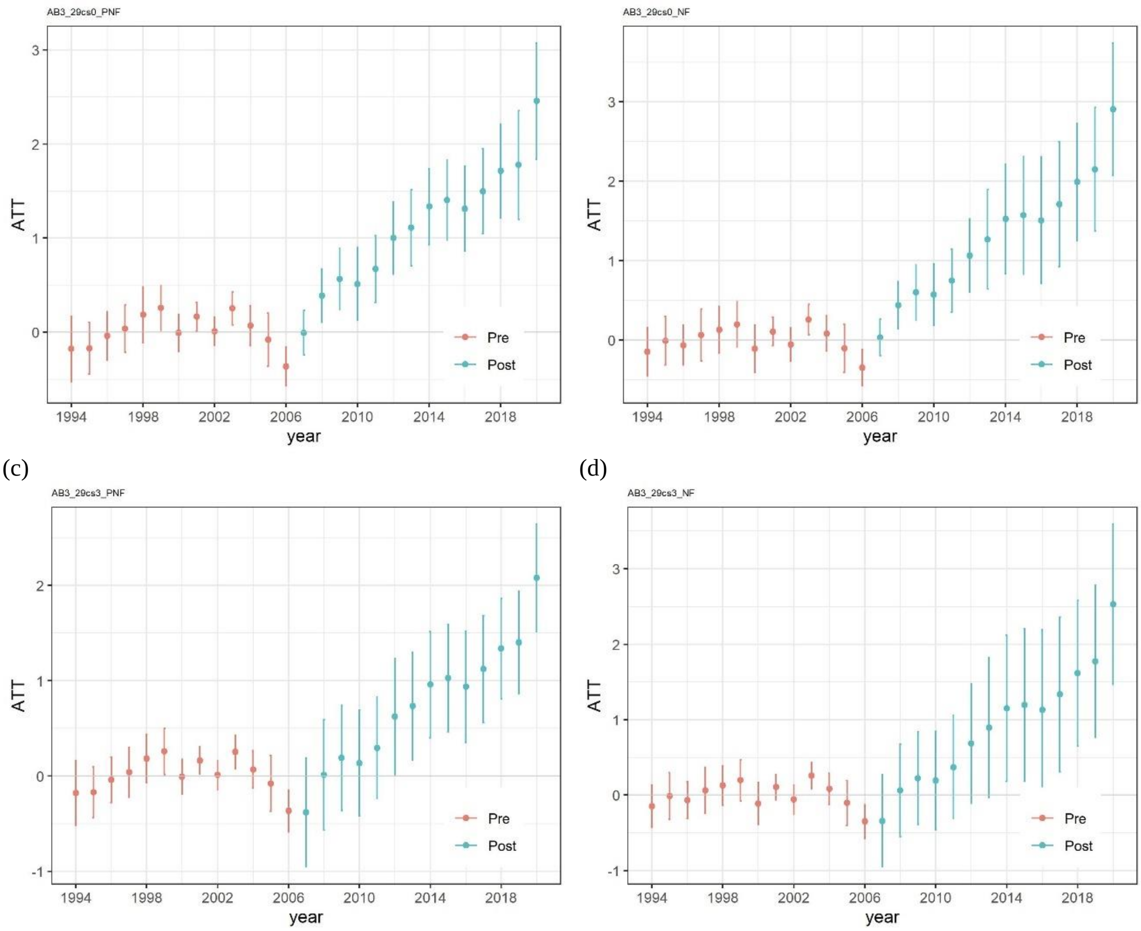
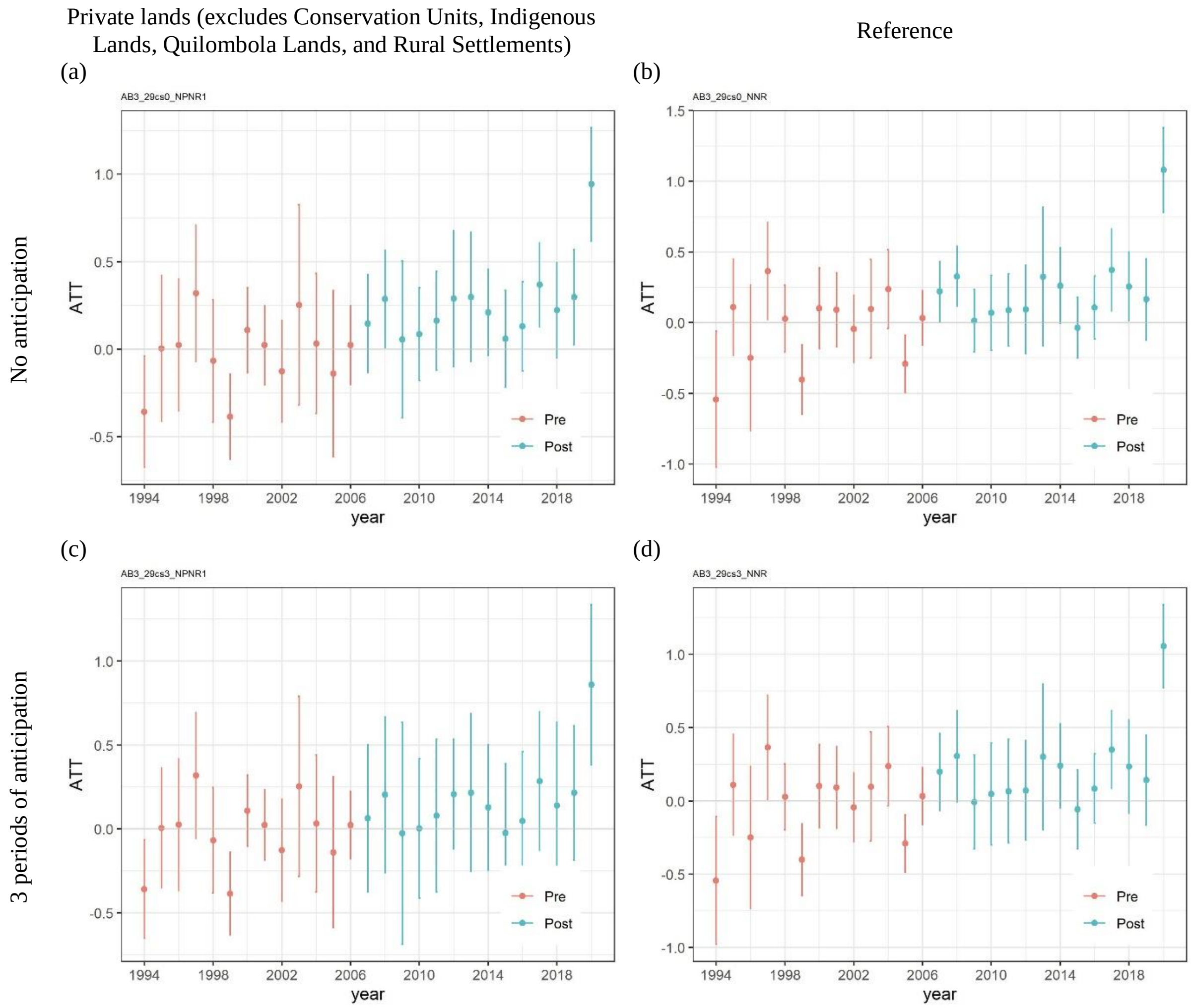


Figure 25 – Atlantic Forest Law effects on normalized net recovery in treated and control MCAs in (a) private lands and in (b) reference specification. No anticipation in the upper line and three period of anticipation in the bottom line



7.4 Effects inside Conservation Units

We complement the analysis from the previous section by looking at part of land categories that were excluded from private lands, focusing on the portion of municipalities with pre-existing Conservation Units when the AFL came out. We repeat the difference-in-differences exercise keeping only the information on natural forest cover from the part of municipalities' territories defined as Conservation Units in the period preceding the AFL (up to 2006, removing overlapping ones). Therefore, treated and control MCAs in this section consist only of MCAs that had Conservation Units defined in their territory before 2007.

Different governance restrictions for protected areas lead to different results (Ferraro et al., 2013; Pfaff, Robalino, Lima, Sandoval, & Herrera, 2014), so we aggregate these

Conservation Units into two different groups: the first one consider all categories of Conservation Units (Figure 26 (a)) and the second one excludes two categories of Conservation Units: Environmental Protection Area (EPA) and Private Natural Heritage Reserve (PNHR) (Figure 26 (b)). EPA is a category that combines one of the lowest protection degrees (category V according to IUCN classification) to extensive areas of private and public properties, and therefore, EPA coverage alone is higher than the sum of all other categories together. PNHR is a category exclusive to private properties and whose delimitation is indicated by the landowner, usually limited to small areas.[59]

Figure 26 – Treated and control MCAs. AFL application area boundary in red line.

(a) All categories of Conservation Units (b) Except EPA and PNHR

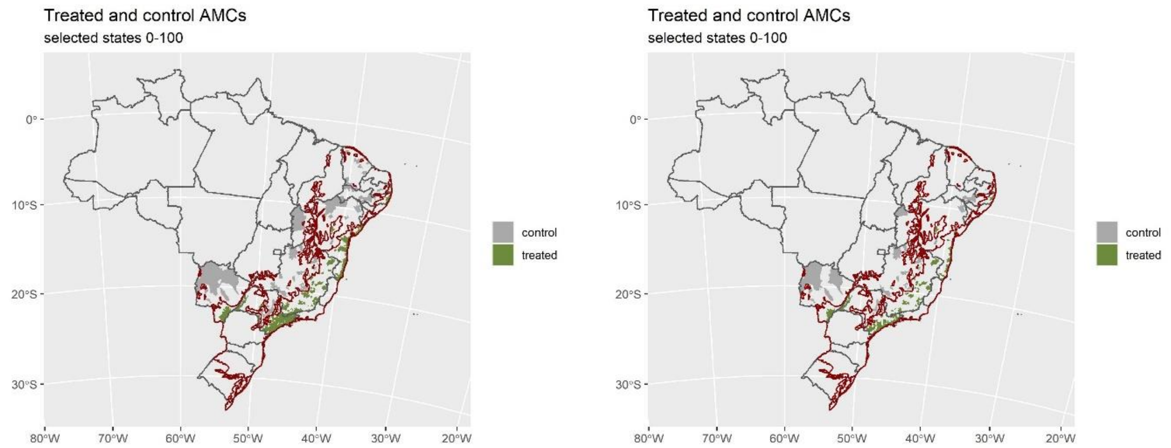


Figure 27 shows the natural cover evolution inside these Conservation Units in the sample municipalities. The column from the left side is dedicated to the municipalities with any category of Conservation Unit and the right side to the group without EPAs and PNHRs. In the first line (Figure 27 (a) and (b)), the natural forest cover inside these Conservation Units are shown as a % of the Conservation Unit area inside the MCA. In the second line, (Figure 27 (c) and (d)), the natural forest cover inside these Conservation Units are shown as a % of the MCA area. As expected, the group without EPAs and PNHRs have a higher percentage of forest protection but covers a smaller portion of the MCA territory. Finally, the third line of Figure 27 shows the reference specification filtering to the same sample municipalities. [60]

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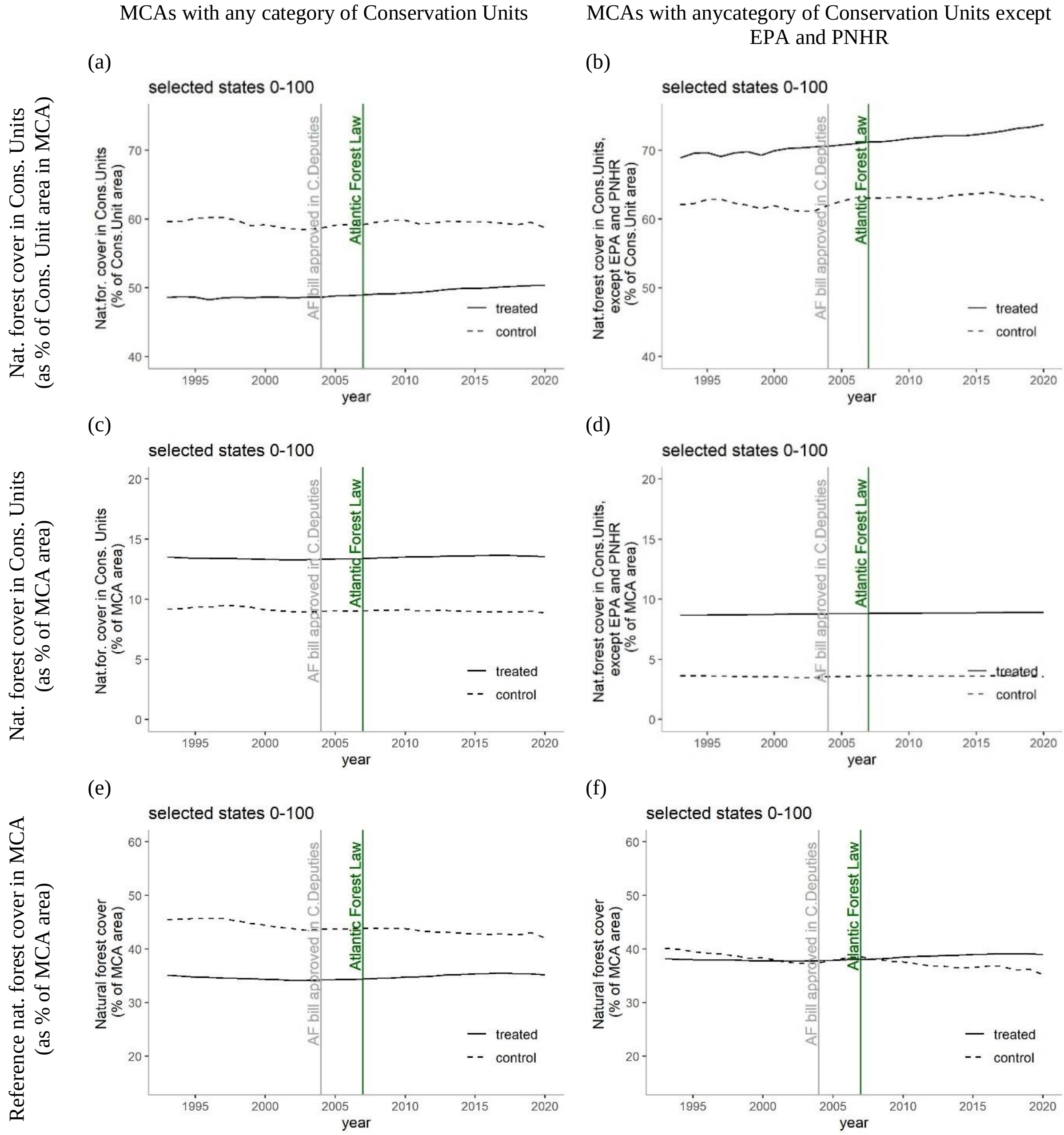
[59] See Appendix 5 for more details on Conservation Units categories in Brazil.
[60] We do not compare the results directly to the reference specification from section 5 because treated and control MCAs in this exercise are restricted to MCAs that have Conservation Units in their territory (up to 2006).

Figure 27 – Natural forest cover evolution in treated and control MCAs with pre-existing Conservation Units in 2006, 1993-2020



Data source: Mapbiomas collection 6

Our results for the group with that considers all categories of Conservation Units are similar to the reference specification case: with no anticipation, results are positive and significant for natural forest cover and for net recovery, but these positive results are probably counterbalanced with the pre-emptive clearing once they are close to zero when we take three periods of anticipation into account (Table 10, columns (1) and (3)). The result from column (2) loses some precision but the effect is still positive and marginally significant. More importantly, the comparison of columns (2) and (3) shows that almost 18.5% (0.272/1.469) of the increase in the natural forest cover in MCAs with previous Conservation Units could be assigned to the effect inside the Conservation Unit itself.

Results for natural forest cover inside all categories of Conservation Unis except EPAs and PNHRs are also positive and (marginally) significant in the case of no anticipation, but net recovery is positive and significant even in the case of three periods of anticipation. The contribution of the Conservation Units to the overall natural forest cover inside these municipalities is much smaller when compared to the case of all categories (less than 2%) probably due to the smaller coverage of this sample of Conservation Units in the municipality area. Surprisingly, the result is still positive and marginally significant.

The effect inside pre-existing Conservation Units seems to have started mainly after 2011 (Figure 28 (a) and (b)) while positive effects on the total natural cover in MCAs seem to have started immediately after the AFL (Figure 28 (d) ad (f)).[61]

[61] See yearly results from net recovery in Appendix 4.

Table 10 - Aggregate effect of Atlantic Forest Law on natural forest cover in pre-existing Conservation Units and reference specification

Dependent variable	Anticipation periods	MCAs with any category of Conservation Units			MCAs with any category of Conservation Units except EPA and PNHR[1]		
		Nat. cover in Conservation Units		Reference: nat. forest cover in MCA	Nat. cover in Conservation Units		Reference: nat. forest cover in MCA
		(1)	(2)	(3)	(4)	(5)	(6)
		(% of Cons. Unit area in MCA)	(% of MCA area)	(% of MCA area)	(% of Cons. Unit area in MCA)	(% of MCA area)	(% of MCA area)
(a) Natural forest cover	0	1.277***	0.272*	1.469***	1.053*	0.036*	2.208***
		(0.371)	(0.161)	(0.246)	(0.577)	(0.020)	(0.353)
	3	0.051	0.191	0.579*	-0.598	-0.011	0.623
		(0.518)	(0.184)	(0.323)	(0.695)	(0.059)	(0.452)
(b) Normalized net recovery of natural forests	0	0.450***	-[2]	0.446***	0.401**	-[2]	0.723**
		(0.124)	-	(0.119)	(0.204)	-	(0.306)
	3	0.001	-[2]	0.109	0.449**	-[2]	0.344
		(0.093)	-	(0.118)	(0.185)	-	(0.220)
MCA cluster		✓	✓	✓	✓	✓	✓
State dummies		✓	✓	✓	✓	✓	✓
Baseline nat. forest cover		✓	✓	✓	✓	✓	✓
Baseline control variables		✓	✓	✓	✓	✓	✓
Baseline dependent stock variable in treated MCAs (2006)		48.87	13.37	34.30	70.97	8.81	37.99
Qty. of treated MCAs		416	416	416	185	185	185
Qty. of control MCAs		164	164	164	72	72	72

Note:

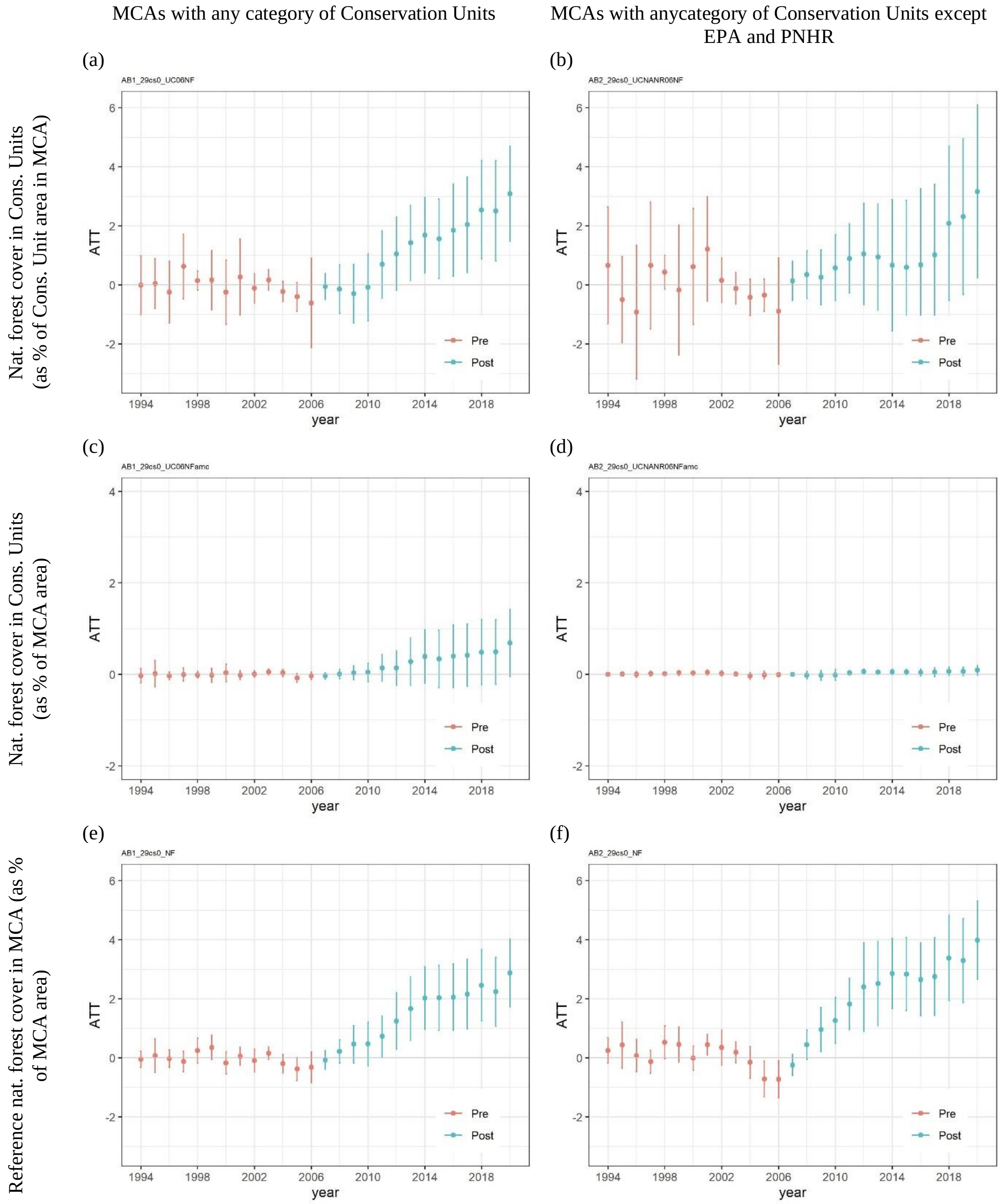
* p < 0.1; ** p < 0.05; *** p < 0.01

Robust standard errors are in parenthesis

[1]EPA: Area of Environmental Protection; PNHR: Private Natural Heritage Reserve

[2] Normalized net recovery of columns (1) and (2) are the same (analogously, for columns (4) and (5) as well)

Figure 28 – Atlantic Forest Law effects on natural forest cover in pre-existing Conservation Units, no anticipation. Conditional on state, natural forest cover and other covariates in the baseline. Cluster at the MCA level.



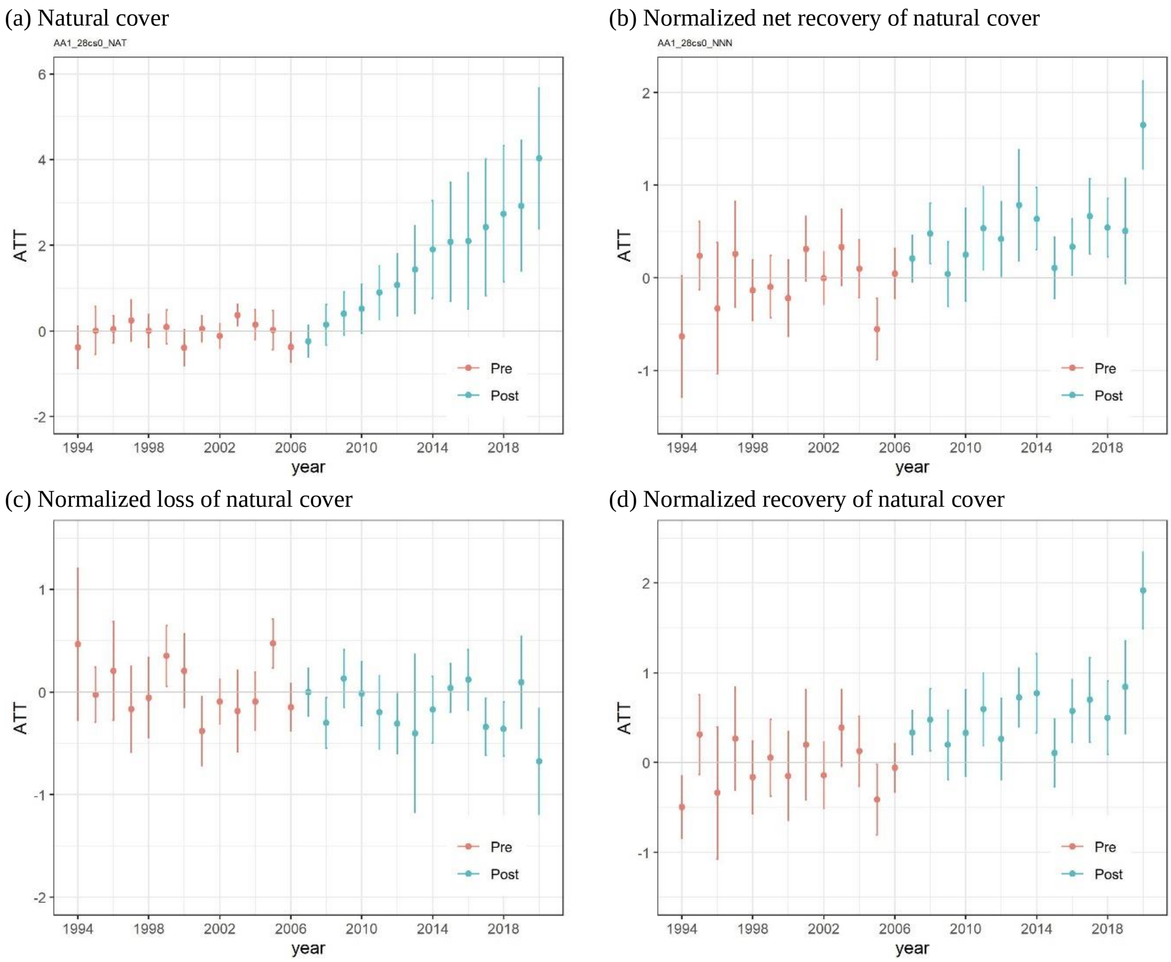
8 Complementary analysis

8.1 Effects on natural cover

In the reference specification, we focused on natural *forest* cover to avoid any confounding effect coming from differences on vegetation composition. However, the Atlantic Forest Law protects all types of vegetation related to the Atlantic Forest biome, including wetlands and grasslands.

Thus, in this section, we complement the analysis using all types of natural cover as the outcome.[62] Figure 29 shows that the overall effect of the AFL on the natural cover is very similar to that observed for natural forest cover, also suggesting anticipation effects.

Figure 29 – Atlantic Forest Law effects on the natural cover (as % of MCA area), different periods of anticipation. Conditional on state, natural cover and other covariates in the baseline. Cluster at the MCA level



(a) Natural cover

(b) Normalized net recovery of natural cover

(c) Normalized loss of natural cover

(d) Normalized recovery of natural cover

[62] See graphs of natural cover evolution in Appendix 6.

Aggregate effects are positive and significant for all anticipation periods, and higher than those estimated for natural forest cover (as expected, since natural forest cover is a subsample of natural cover) (Table 11). Results from normalized flow variables show that the recovery were positively affected by the AFL regardless of anticipation periods.

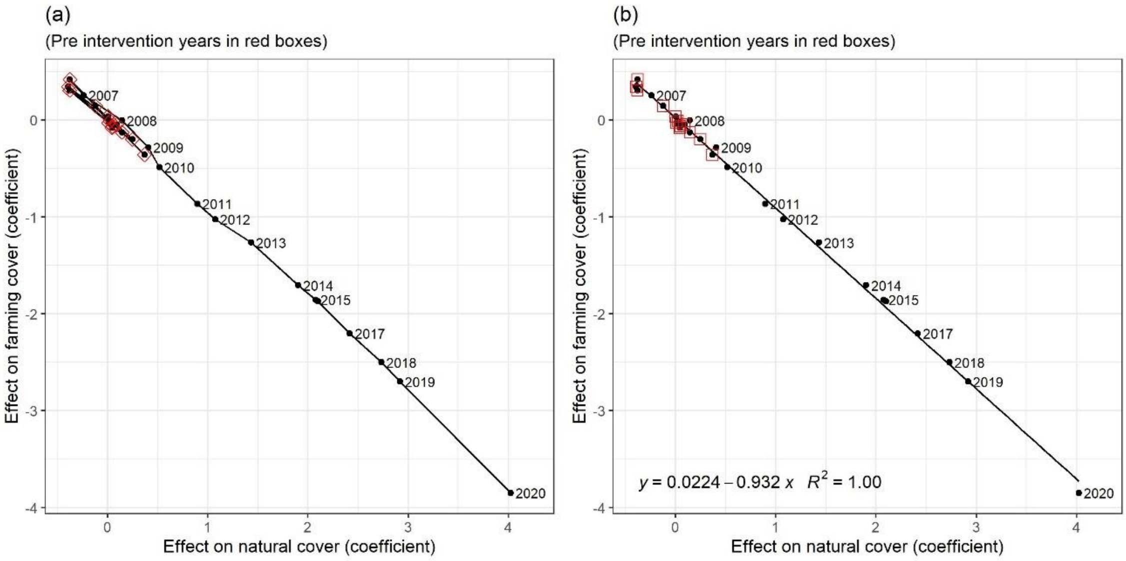
Table 11 - Aggregate effect of Atlantic Forest Law on natural cover, normalized net recovery, loss and recovery, with different anticipation periods

Dependent variable	Natural cover			
	(1)	(2)	(3)	(4)
(a) Natural cover	1.601***	1.225***	1.250***	1.396***
	(0.311)	(0.368)	(0.447)	(0.499)
(b) Normalized net recovery for natural cover	0.509***	0.554***	0.000	0.098
	(0.112)	(0.070)	(0.096)	(0.090)
(c) Normalized loss for natural cover	-0.170**	-0.317***	0.156*	0.064
	(0.066)	(0.056)	(0.085)	(0.073)
(d) Normalized recovery for natural cover	0.595***	0.535***	0.122	0.247*
	(0.123)	(0.093)	(0.102)	(0.120)
MCA cluster	✓	✓	✓	✓
State dummies	✓	✓	✓	✓
Baseline nat. cover	✓	✓	✓	✓
Baseline control variables	✓	✓	✓	✓
Anticipation periods	0	1	2	3
Baseline nat. cover in treated MCAs (2006)	30.12	30.12	30.12	30.12
Qty. of treated MCAs	1661	1661	1661	1661
Qty. of control MCAs	1461	1461	1461	1461
Note:	* p < 0.1; ** p < 0.05; *** p < 0.01			
	Robust standard errors are in parenthesis			

In Figure 30 we plot the coefficients for the effects on the natural cover against the coefficients for farming estimated on section 6.2 to help us gaining further insight into the changes in land use spurred by the AFL. In panel (a), the coefficients are connected in chronological order to enlighten the dynamics of the estimated effects on land cover, and in panel (b), a regression line is added. First, the line in Figure 30 (a) shows that the relative reduction in farming in treated municipalities occurred as the natural cover in these areas was increasing. The farming reduction effect is almost of the same magnitude as the increase in natural cover (Figure 30 (b), angular coefficient = -0.93 and $R^2 = 1.00$), showing that the increase in natural cover occurred at the expense of farming cover in areas protected by AFL.[63]

[63] Coefficients on the natural cover plotted against coefficients of other categories of anthropic land uses are shown in Appendix 6.

Figure 30 – Coefficients of estimated effects of AFL on the natural cover (as % of MCA area) against the coefficients of estimated effects of AFL on farming cover (as % of MCA area). No anticipation, conditional on state, natural cover and other covariates in the baseline, cluster at the MCA level. Panel (a) shows the effects dynamics and panel (b) shows the correlation between the estimated effects.



9 Exploring some mechanisms

In this section, we explore some mechanisms that may have helped the Atlantic Forest Law (AFL) to have the estimated impact on the natural forest cover as discussed in the previous sections by looking at the frequency of environmental infraction notices, the area proected as Conservation Units and the municipal government expenditures on environmental management.

9.1 Monitoring and enforcement (state of Sao Paulo)

We first explore the monitoring and law enforcement mechanisms by looking at the Environmental Infraction Notices (EIN) frequency, as law enforcement is expected to play a pivotal role in the effectiveness of restriction-based conservation policies. This seems to be the case for Brazil: some studies have shown that monitoring and law enforcement were the main drivers for the reduction of deforestation in the Amazon (Assunção & Rocha, 2019; Burgess et al., 2018). With the increase in the legal certainty of the protection by the law, environmental monitoring and enforcement may have increased in treated areas, leading to an increase in the frequency of environmental infraction notices (EIN).[64] Alternatively, if society anticipated the increased enforcement and reduced environmental infractions by protecting the native vegetation, the outcome could be a reduction in EIN frequency in treated areas. These events can also change dynamically as economic agents learn about the new monitoring and enforcement environment. In this sense, there might be a temporary increase in monitoring (and in EIN frequency) followed by a reduction in EIN frequency due to law enforcement. Disentangling all the endogeneities related to this topic is a challenge that we are not dealing with in this section. Our contribution here resides on documenting the differencial effect on enforcement that could increase our understanding of the observed effect on forest cover on the previous sections.

In Brazil, the stewardship of the environment falls under the jurisdiction of the three tiers of government, with Federal, state, and municipal governments exercising both legislative and executive powers.[65] In particular, the licensing and inspection of vegetation suppression

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[64] In cases of additional environmental restrictions, treated areas could experience an increase in this frequency even with the same monitoring effort. This is not the case of AFL because there was a previous restrinction set by the Federal Decree no. 750 from 1993.

[65] Shared mandate among federal entities was partially regulated by the Complementary Law nº 140/2011. Neves (2016) argues that the Complementary Law nº 140/2011 focused mainly on environmental permitting and inspecting, dealing with the actions for environmental control of each level of government as distinct and separate

and management is generally the duty of state entities',[66] and each state has its own system of monitoring and control. In this section, our analysis is therefore restricted to the state of Sao Paulo because it was the only state with a relatively large number of municipalities in treated and control areas that provided easy public access to the entire database of environmental infraction notices. [67]

We have used the EIN drawn up by the Environmental Military Police from the state of Sao Paulo (data from Datageo Environmental Spatial Data Infrastructure) from the State Secretary of Infrastructure and the Environment (SP).[68]

Figure 31 (a) shows the evolution of all types of state EINs in the state of Sao Paulo and in Figure 31 (b), only the EINs related to flora are plotted. In both cases, treated areas experience more EINs when compared to untreated ones. Flora-related EIN frequency is a relevant share of the state's total EIN frequency. In Figure 31 (c) and (d) we present the trends in natural forest cover and in normalized loss of forests in the state of Sao Paulo for reference.

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entities. In this sense, the Complementary Law did not advance in building governance arrangements for coordinated mechanisms and vertical and horizontal cooperation systems to support the joint responsibilities in a scenario with disparate capabilities between subnational entities.

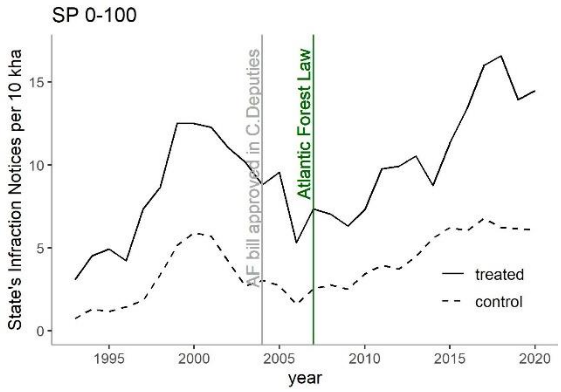
[66] Federal entities may also license and inspect vegetation suppression in case it is located inside Federal Conservation Units or when it is linked to the implementation of an enterprise that requires Federal environmental licensing (enterprises with significant environmental impact or related to some specific activities, such as petroleum). Municipal entities may also license and inspect vegetation suppression in case it is linked to the implementation of an enterprise that requires municipal environmental licensing (local environmental impacts, mainly in urban areas. i.e: gas stations). See Bim (2015) for environment related legislative and administrative competence in the Brazilian federalism.

[67] It is possible to consult *individual* notices/process in other states though. We have also explored IBAMA's Federal environmental infraction notices frequency and the effect of the AFL was not significantly different from zero. This result is expected due to the smaller share of responsibility to Federal government in cases of vegetation suppression. See Appendix 7 for these results.

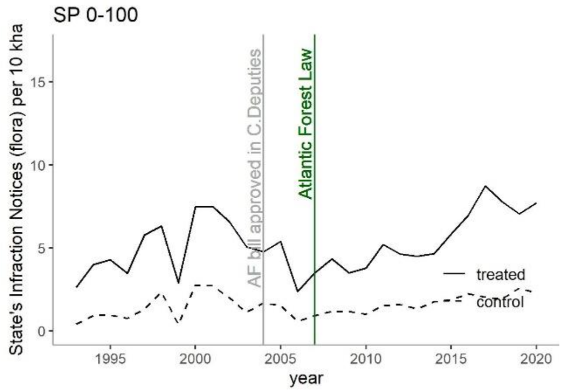
[68] http://datageo.ambiente.sp.gov.br/app/?ctx=DATAGEO#

Figure 31 – Federal and State's environmental infraction notices frequency (quantity per 10kha) evolution in treated and control MCAs in the state of Sao Paulo, 1985-2020

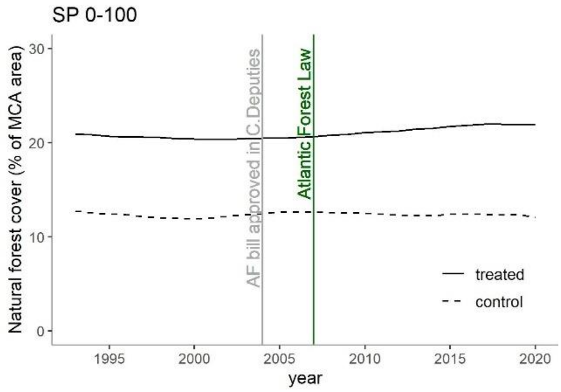
(a) State's EIN



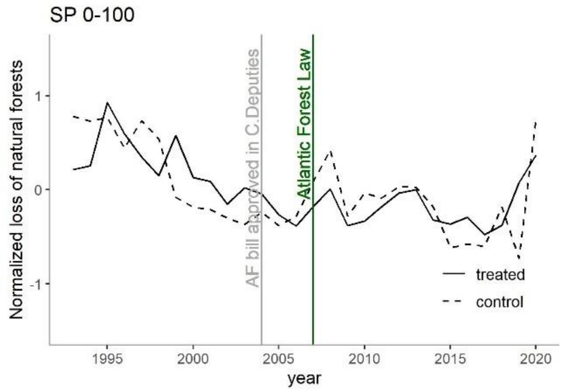
(b) State's EIN related to flora



(c) Natural forest cover



(d) Normalized loss of natural forests



Aggregate effects on the state's total EIN and state's EIN related to flora are positive and significant for the case of no anticipation, but these effects are not distinguishable from zero when taking three periods of anticipation into account (Table 12, columns (1) and (2)). It is also worth noting that the annual coefficients estimated for flora related EIN (Figure 32 (b)) increases over time, even after the state law from 2009 that started protecting the natural cover in untreated areas.[69] Interestingly, in the case of no anticipation, forest loss reduction is not precisely estimated, suggesting that an increase in the frequency of EIN was necessary to avoid an increase in deforestation. In contrast, in the case of three periods of anticipation, our results show that despite any difference in the frequency of EIN, deforestation was significantly reduced after the law, suggesting changes in deforesting behaviour regardless of any differential effort from command-and-control side. Taken together, these results are insufficient to suggest any kind of mechanism from the monitoring and enforcement side to help us understanding the

[69] State Law no. 13,550/2009 that protects Cerrado vegetation.

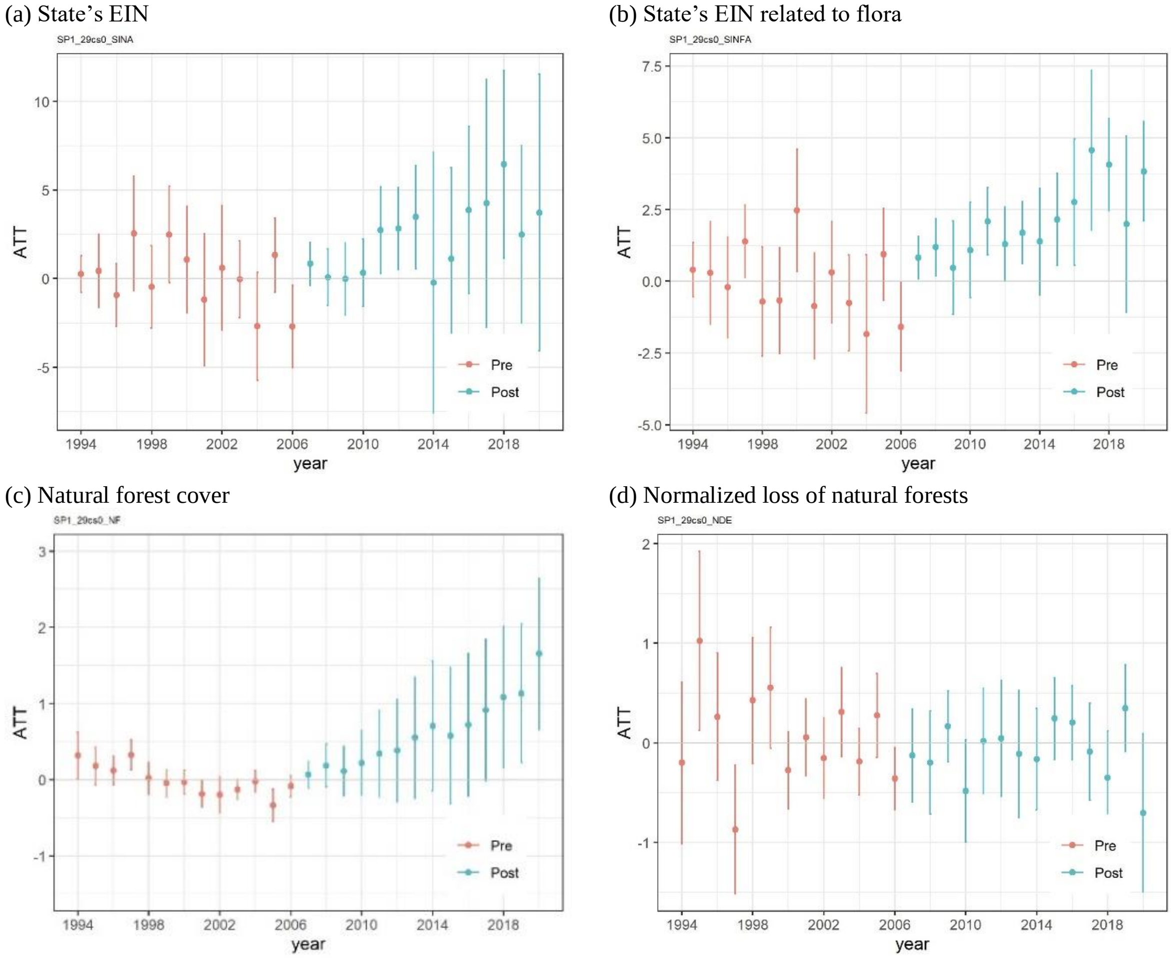
positive effect of AFL on forests. Future studies with data from states of Minas Gerais or Bahia could enrich the analysis.

Table 12 - Aggregate effect of Atlantic Forest Law on Federal and State's environmental infraction notices frequency (quantity per 10 kha) in the state of Sao Paulo

	Anticipation periods	Frequency of EIN (quantity per 10 kha)		Natural forests	
		State's EIN	Flora related State's EIN	Cover (% MCA area)	Normalized loss
		(1)	(2)	(3)	(4)
ATT	0	2.281**	2.100***	0.617***	-0.085
		(0.900)	(0.369)	(0.232)	(0.105)
	1	-0.413	0.512	0.534**	-0.443***
		(0.888)	(0.487)	(0.233)	(0.139)
	2	0.916	1.451*	0.198	-0.168
		(1.006)	(0.817)	(0.247)	(0.122)
	3	-1.770	-0.386	0.175	-0.354***
		(1.083)	(0.449)	(0.260)	(0.121)
MCA cluster		✓	✓	✓	✓
State dummies					
Baseline nat. Forest cover		✓	✓	✓	✓
Baseline control variables		✓	✓	✓	✓
Baseline outcome variable in treated MCAs (2006)		5.32	2.39	20.58	
Qty. of treated MCAs		399	399	399	399
Qty. of control MCAs		111	111	111	111

Note: * p < 0.1; ** p < 0.05; *** p < 0.01
Robust standard errors are in parenthesis

Figure 32 – Atlantic Forest Law effects on state's environmental infraction notices frequency (quantity per 10kha) in the state of Sao Paulo, with no anticipation and one period of anticipation. Total State's EIN (a, c) and only flora related State's EIN (b, d). Conditional on natural cover and other covariates in the baseline. Cluster at the MCA level



9.2 Creation of new Conservation Units

In this section, we use Conservation Units data to assess whether the Atlantic Forest Law affected the creation of new protected areas, be they from public or private initiatives. The role of protected areas in conserving species and ecosystems is internationally recognized, with many studies confirming their effectiveness in reducing deforestation.[70]

The creation of new protected areas can be part of wider environmental policies that explicitly define them as an instrument, such as the case of the global initiative in the Convention on Biological Diversity from 2010, which defined a target of having at least 17%

[70] The effects are heterogeneous though. See review by Miteva et al. (2012).

of terrestrial and inland water areas as protected areas by 2020,[71] or the case of the centralized and coordinated actions to fight deforestation in the Amazon (Mello & Artaxo, 2017). Apart from that, the creation of new Conservation Units can also occur indirectly in response to other incentives, such as the ecological intergovernmental fiscal transfer, as shown by Ruggiero *et al*. (2022).

We use municipality panel data from 1993[72] to 2020 (treatment starts at $t = 2007$) with Conservation Units from the National Register of Conservation Units (CNUC, Portuguese acronym) from the Brazilian Ministry of Environment (MMA).[73]

We aggregate these Conservation Units in four different groups of categories[74] for calculating the coverage of Conservation Units in MCAs (coverage as a % of MCA area), removing overlays. The first group consists of all 12 categories of Conservation Units. The second consists of all categories except Environmental Protection Area (EPAs) and Private Natural Heritage Reserve (PNHR). Environmental Protection Area (EPAs) and Private Natural Heritage Reserve (PNHR) are analyzed separately as the third and the forth group. We use the same MCAs sample from the reference specification.

Our specification still have two sources of downward bias. The first one comes from the concurrent incentives to create Conservation Units in other control regions/biomes through other instruments,[75] such as executive programs and action plans (PPCerrado had specific actions targeting the increase of Conservation Units coverage to 17% of the biome). The other possible source of bias follows from the fact that protected areas such as Conservation Units is frequently set in areas with low pressure for land use conversion (*i.e*. low opportunity costs).

Figure 33 shows the trends in the coverage of different groups of Conservation Units (as % of MCA area) in treated and control MCAs with vertical lines indicating the timing of AFL and other related events. In general, Conservation Units protect a larger share of the

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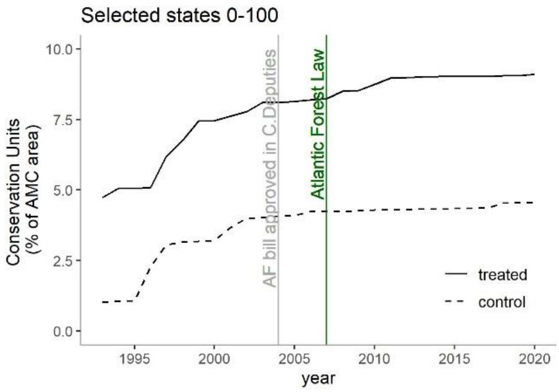
[71] Aichi Biodiversity Target, target 11 (https://www.cbd.int/sp/targets/)
[72] Except for the case of Conservation Units from the PNHR category. In our sample MCA, PNHR appear for the first time in 1990 in a control MCA, and in 1994 in a treated one. Pre-treatment data has reduced to 1997-2006 in order to keep common support for all covariates.
[73] http://mapas.mma.gov.br/i3geo/datadownload.htm
[74] See Appendix 5 for more details on Conservation Units categories
[75] The AFL is a unique case of a law regulating the protection of remaining vegetation of one particular biome. Protection of native vegetation is generally given by regulations applied in all Brazilian territory (Forest Code gives a differential treatment to Legal Amazon though).

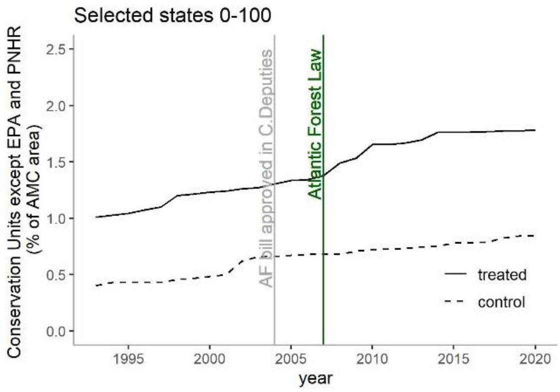
municipalities' territory in treated areas (solid line) and the municipality area protected by Conservation Units increases over time.

Figure 33 – Conservation Units area evolution (as % of MCA area) in treated and control MCAs, 1993-2020

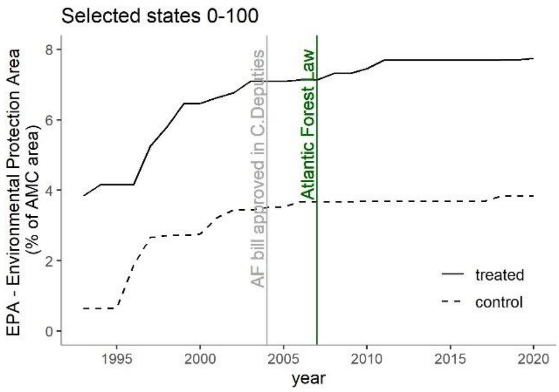
(a) All categories of Conservation Units



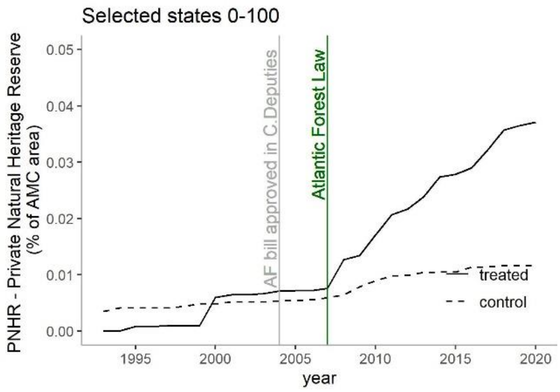
(b) Except Environmental Protection Area (EPA) and Private Natural Heritage Reserve (PNHR)



(c) Environmental Protection Area (EPA) only



(d) Private Natural Heritage Reserve (PNHR) only



The estimated aggregate results show that the AFL had a positive and significant effect on the Conservation Units coverage in treated MCAs, regardless of the groups of categories (Table 13). Figure 34

Figure 34 does not suggest any anticipation effect (as expected) and shows that estimated effects on all categories of Conservation Units are very similar to the effects on the EPA category (Area of Environmental Protection), which is not surprising due to the greater size of this type of Conservation Unit. For these groups, the positive effect disappears after 2018, as new Conservation Units are also created in control areas (Figure 34 (a) and (c)). The Private Natural Heritage Reserve (PNHR) coverage was also positively affected by the law, suggesting active participation of civil society in the protection of the Atlantic Forest (Table 13, column 4 and Figure 34 (d)). Removing EPA and PNHR from the Conservation Units did not affect qualitatively the results (Table 13, column 2).

We find that Conservation Units coverage was positively affected by the AFL, in every group of Conservation Units that we analyzed.[76] One interesting feature of this result is that positive effects were also observed in private Conservation Units, showing that the private sector also responded positively to the AFL by increasing its protected areas. It is worth noting that the creation of new PNHR is not differencially encouraged in the Atlantic Forest through economic incentives such as tax reduction. Also, our impact assessment cannot isolate the effects of the AFL from other initiatives aiming to protect the Atlantic Forest (such as the civil society engagement). In the case of new PNHR, civil society organizations may have played an important role for the observed results.

[76] An additional robustness check excluding Municipal Conservation Units was also performed to deal with possible imbalances in the registry of this category of Conservation Unit in our database. Our concern was that there are many Municipal Conservation Units that are not registered in the CNUC yet. A report by SOS Mata Atlântica shows that 24% of protected areas in the Atlantic Forest are protected by Municipal Conservation Units, however only 25.6% of these Municipal Conservation Units are registered in the CNUC (SOS Mata Atlântica, 2019). Unfortunately, there is no systematic database with all Municipal Conservation Units. The results were qualitatively the same and are shown in Appendix 8.

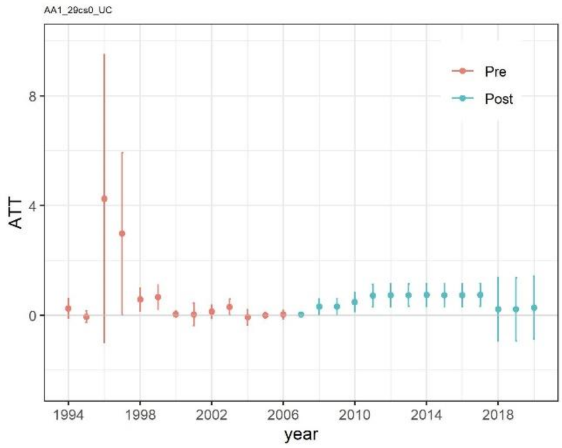
Table 13 - Aggregate effect of Atlantic Forest Law on Conservation Units coverage (as % of MCA area) for different groups of categories of Conservation Units

	Dependent variable: Conservation Units (% of MCA area)			
	(1) All	(2) Except EPA and PNHR	(3) EPA	(4) PNHR
ATT	0.499***	0.266***	0.329**	0.015**
	(0.172)	(0.075)	(0.143)	(0.006)
MCA cluster	✓	✓	✓	✓
State dummies	✓	✓	✓	✓
Baseline Conservation Units	✓	✓	✓	✓
Baseline control variables	✓	✓	✓	✓
Anticipation periods	0	0	0	0
Baseline Conservation Units coverage in treated MCAs (2006)	8.19	1.34	7.14	0.007
Qty. of treated MCAs	1661	1661	1661	1661
Qty. of control MCAs	1461	1461	1461	1461

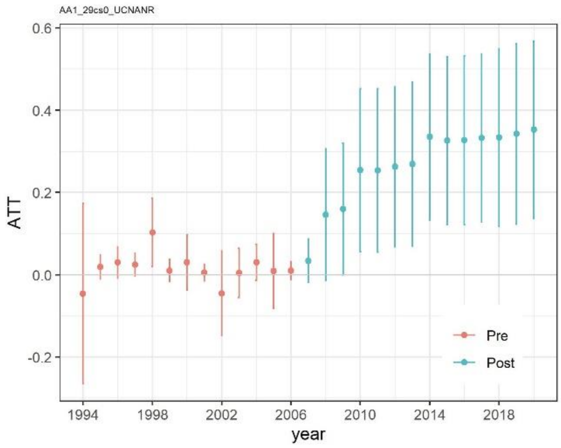
Note: * p < 0.1; ** p < 0.05; *** p < 0.01
Robust standard errors are in parenthesis
EPA: Area of Environmental Protection; PNHR: Private Natural Heritage Reserve
Overlays among different categories of Conservation Units were removed

Figure 34 – Atlantic Forest Law effects on Conservation Units coverage (as % of MCA area) for different groups of categories of Cons. Units, no anticipation. Conditional on state, Cons. Units coverage and other covariates in the baseline. Cluster at the MCA level. In (d), data from before 1996 were ignored to keep common support for all covariates.

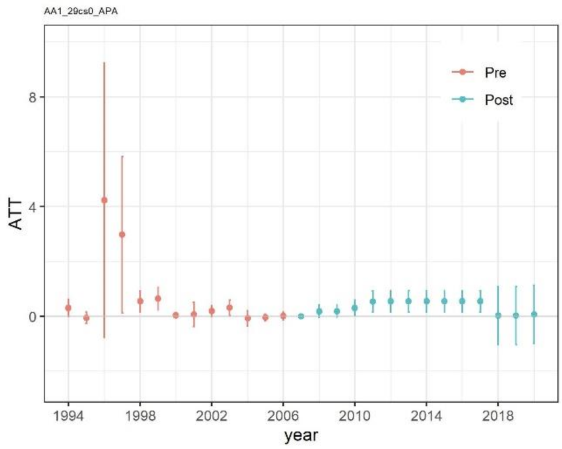
(a) All categories of Conservation Units



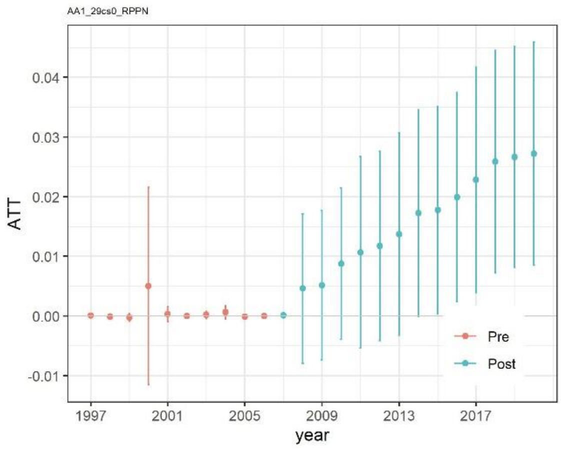
(b) Except Environmental Protection Area (EPA) and Private Natural Heritage Reserve (PNHR)



(c) Environmental Protection Area (EPA) only



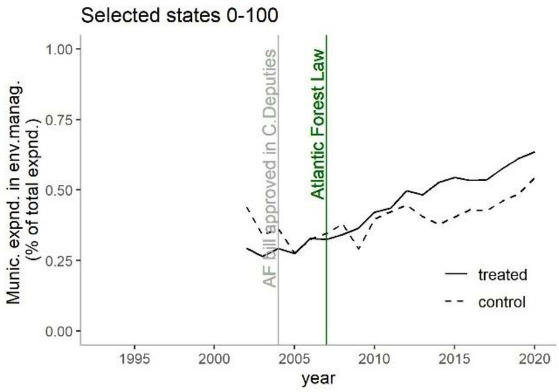
(d) Private Natural Heritage Reserve (PNHR) only



9.3 Municipal government expenditures

Finally, we explore whether there was a differential effort by municipal governments on environmental management after the AFL by analyzing the share of expenditures dedicated to the environment. In general, municipalities dedicate a small share of total expenses to environmental management (less than 1%), but this share seems to be increasing over time (Figure 35). We have used data from Finbra, a database formed by accounting, budgetary and financial information sent by federation entities to the National Treasury and part of the Brazilian Public Sector Accounting and Tax Information System (Siconfi, Portuguese acronym).[77] This analysis is restricted to the period of 2002-2020 as expenditures for environmental management are available only from 2002 on. Only municipalities with data in the whole period (without missing data in any year) were considered.

Figure 35 –Municipal expenditures on environmental management (as % of total expenditures), 2002-2020



Despite this increase, the variation in municipal expenditures from treated areas is not significantly different from untreated ones (Table 14 and Figure 36).

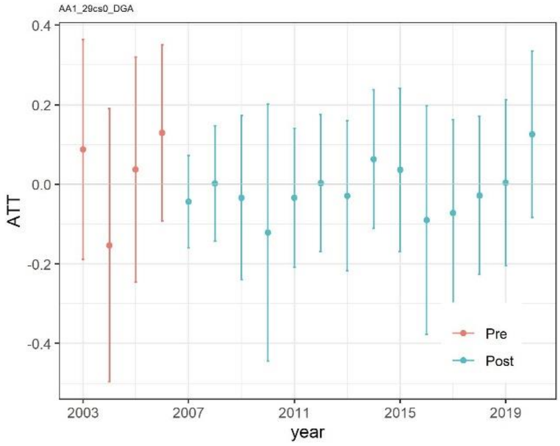
Table 14 - Aggregate effect of Atlantic Forest Law on Municipal expenditures on environmental management (as % of total expenditures)

	Dependent variable: Municipal expenditures on environmental management (as % of total expenditures)			
	(1)	(2)	(3)	(4)
ATT	-0.016	0.114	0.151	-0.003
	(0.056)	(0.085)	(0.146)	(0.065)
MCA cluster	✓	✓	✓	✓
State dummies	✓	✓	✓	✓
Baseline control variables	✓	✓	✓	✓
Anticipation periods	0	1	2	3
Qty. of treated MCAs	1246	1246	1246	1246
Qty. of control MCAs	1007	1007	1007	1007
Note:				* p < 0.1; ** p < 0.05; *** p < 0.01 Robust standard errors are in parenthesis

[77] https://siconfi.tesouro.gov.br/siconfi/index.jsf;jsessionid=F++sFo3Rpf3xpNMpoW4Mh7Mb.node4

Figure 36 – Atlantic Forest Law effects on Municipal expenditures on environmental management (as % of total expenditures). Conditional on other covariates in the baseline. Cluster at the MCA level

(a) No anticipation



10 Conclusions and policy implications

Our results indicate that the AFL had positive and significant effects on the natural forest cover. Increases in natural forest cover occur mainly through the increase in the recovery process, with positive annual net recovery even in the absence of significant changes in the forest loss process after the law. This finding is consistent with the progressive rejuvenation of native forest cover (by loss of older native forest and gain of younger native forest cover mostly on marginal lands for mechanized agriculture) documented by Rosa et al. (2021) for the Atlantic Forest. The increase in the natural forest cover and net recovery is observed immediately after the law's approval (in 2007), and society might have anticipated the AFL by increasing the deforestation up to three years prior to the law, which is consistent with the timing when the draft bill was approved in the Chamber of Deputies and then in the Senate. Estimated effects are robust to these anticipations. Robustness check using a subsample with municipalities with less than 25% of natural forest cover in the baseline confirms the results while reducing the possibility of bias coming from spillover effects from the Amazon region. Also, the lack of changes when comparing crops between treated and untreated areas suggest that differencial responses to variation in commodity prices are unlikely affecting our results.

The analysis of heterogeneity shows that groups with different percentages of natural cover in the baseline responded differently to the policy. The group with a high percentage of natural forest cover in the baseline (> 75%) showed a significant decrease on natural forest cover (in all anticipation periods case), while group with a low percentage of natural forest cover in the baseline (> 25%) showed a significant increase on natural forest cover. Despite this fact, the effect in the opposite side for the first group was not strong enough to counterbalance and cancel the observed effect in the aggregated sample. Among the three individual states analyzed (SP, MG and BA), Minas Gerais (MG) is the only case where the AFL positively affected the forest cover regardless of anticipation periods and removing its municipalities from the reference specification reduces the aggregate effect to zero in the remaining municipalities (in the case of three anticipation periods). Therefore, apart from Minas Gerais, it seems that the pre-emptive clearing delayed the net benefit from the policy in the majority of regions. The event study estimates indicate that the gradual increase in the forest cover compensated the pre-emptive clearing over the years and but only after 10 years these municipalities started having net benefit from the policy. The case of the state of Sao Paulo is also peculiar because it showed positive effect of the AFL in the case of no anticipation even with the state law that protects

Cerrado (the biome in the untreated area in SP) since 2009. We also confirm that the effects of the AFL on the natural forest cover are similar to the reference specification inside private lands and inside pre-existing Conservation Units, with positive and significant results that loose their effect due to the pre-emptive clearing. Surprisingly, these effects are sustained even inside Conservation Units from categories of higher restrictions, where we would not expect the AFL to change the legal limits to land convertion. The analysis is complemented by looking at the effects of AFL on all types of natural cover that are protected by the law, *i.e.*, including other types of vegetation such as grasslands or wetlands. Forests are the main type of natural cover in the Atlantic Forest, but adding these other types of vegetation did not change the results. Effects on different anthropic land cover also confirmed that the relative increase in natural cover occurred at the expense of a relative reduction on farming cover.

We also try to explore some of the mechanisms from the command-and-control side by checking if there was any differential pattern in the frequency of Environmental Infraction Notices (EIN) in the state of Sao Paulo. We document a relative increase in the state's flora related EIN frequency in the case of no anticipation but these effects are close to zero in the case of three periods of anticipation. Future studies are necessary to tease out potential endogeneity involving infractions and the detection rate. Exploring state EIN frequency from other states would enrich the analysis.

Interestingly, the coverage by Conservation Units was positively affected by the AFL, in every category of Conservation Unit that we analyzed. One interesting feature of this result is that positive effects were also observed in private Conservation Units (PNHR), showing that the private sector also responded positively to the AFL by increasing its protected areas. Contrary to the evidence on Conservation Units, municipal expenditures on environmental management increase over time, but this increase occurs in both treated and untreated areas, *i.e.*, these expenditures were not significantly affected by the AFL.

The estimated effects are not negligible. With three periods of anticipation, in the reference specification (the one that excludes the states of RJ, ES, PR, SC, and municipalities in the boundary of the AFL application area), we estimated that there was an accumulated increase of 2.4 pp up to 2020 in natural forest cover in municipalities protected by the AFL relative to the unprotected ones, equivalent to a relative increase of 1.6 Mha. From 2007 to 2020, these municipalities experienced an increase in the natural forest cover stock of 0.5 Mha, which means that the AFL not only has influenced all the observed increment of forests in these areas but also avoided an additional loss of 1.1 Mha in the period. Restricting to the case that excludes the municipalities from the state of MG, with the same three anticipation periods, the estimated effect was an accumulated increase of 1.5 pp up to 2020 in natural forest cover, equivalent to a relative increase of 0.7 Mha. The increment in the natural forest cover was 0.4 Mha from 2007 to 2020, and analogously, there were at least 0.3 Mha in avoided loss with the AFL.

AFL might be seen as a case of success to be followed, and there are indeed some initiatives trying to replicate it in other biomes (*e.g.*, there is a draft bill in the Chamber of Deputies which tries to regulate native vegetation protection in the Pantanal biome similarly).[78] But the replication and the success of such policy in other biomes may be limited. Our estimates also suggest that the state's characteristics (which includes physical, environmental, social, and institutional characteristics) are determinant of potential outcomes and therefore anyone interested in replicating AFL in other biome protection policies will have to take that into account. Moreover, other biomes may not have the same engagement from the civil society as does the Atlantic Forest for many reasons, but one is the simple fact that the majority of the Brazilian population lives in the Atlantic Forest biome. Finally, it is important to recognize that the benefit of the AFL is limited in the sense that it is not enough to prevent old native vegetation clearance, that in turn results in negative effects on tropical biodiversity conservation as a whole, as many species rely on more structurally developed and biodiverse habitats (Gibson et al., 2011).

Our results suggest that the increase in the legal certainty given by the law played a central role in the protection of natural forest cover. However, part of the benefits are canceled by the pre-emptive clearing behaviour in the few years prior to the law and it took almost 10 years for forests to recover from this pre-emptive clearing and start registering net positive increase in their stock. Also, our results suggest that the effectiveness of the AFL was based on a set of different initiatives from different stakeholders. The public sector contributed by increasing the Conservation Units' coverage. The private sector contributed to the increase in the coverage by private Conservation Units, as well as by complying with the law in private lands relative to untreated areas. Natural forest cover inside pre-existing Conservation Units

[78] Draft bill no. 9950/18 in the Chamber of Deputies, that tries to protect remaining natural cover in the Pantanal. (https://www.camara.leg.br/noticias/696167-projeto-determina-as-condicoes-de-protecao-e-uso-sustentavel-do-pantanal)

was positively affected by the AFL, possibly by the combinations of actions from the public and private sectors. Unfortunately, these multiple and decentralized initiatives hamper the possibility to look at the cost side of the policy to prioritize interventions based on a cost-effectiveness analysis. This is one of the potential significant challenges faced by the ones trying to produce this type of evidence (Pienkowski, Cook, Verma, & Carrasco, 2021). We hope that the results presented here could add to the efforts to overcome this challenge. Other future studies could also explore differential compliance in private properties of different sizes.

References

Abadie, A. (2005). Semiparametric difference-in-differences estimators. *Review of Economic Studies*, *72*(1), 1–19. https://doi.org/10.1111/0034-6527.00321

Almeida, C. A. De, Eduardo, L., Maurano, P., Camara, G., Gomes, A. R., & Silva, D. E. (2021). *Methodology for forest monitoring used in PRODES and DETER projects*. Retrieved from http://mtc-m21c.sid.inpe.br/col/sid.inpe.br/mtc-m21c/2021/01.25.19.14/doc/publicacao.pdf

Arima, E. Y., Barreto, P., Araújo, E., & Soares-Filho, B. (2014). Public policies can reduce tropical deforestation: Lessons and challenges from Brazil. *Land Use Policy*, *41*, 465–473. https://doi.org/10.1016/j.landusepol.2014.06.026

Assunção, J., Gandour, C., & Rocha, R. (2015). Deforestation slowdown in the Brazilian Amazon: Prices or policies? *Environment and Development Economics*, *20*(6), 697–722. https://doi.org/10.1017/S1355770X15000078

Assunção, J., & Rocha, R. (2019). Getting greener by going black: The effect of blacklisting municipalities on Amazon deforestation. *Environment and Development Economics*, *24*(2), 115–137. https://doi.org/10.1017/S1355770X18000499

Azevedo, A. A., Rajão, R., Costa, M. A., Stabile, M. C. C., Macedo, M. N., Dos Reis, T. N. P., … Pacheco, R. (2017). Limits of Brazil's Forest Code as a means to end illegal deforestation. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(29), 7653–7658. https://doi.org/10.1073/pnas.1604768114

Bim, E. F., & Farias, T. (2015). Competência ambiental legislativa e administrativa. *Revista de Informações Legislativas*, *52*(208), 203–245. Retrieved from http://www2.senado.leg.br/bdsf/bitstream/handle/id/517705/001055894.pdf

BNDES; UICN. (2015). *Iniciativa BNDES Mata Atlântica*. Retrieved from https://web.bndes.gov.br/bib/jspui/handle/1408/4421

Burgess, R., Costa, F. J. M., & Olken, B. A. (2018). Wilderness Conservation and the Reach of the State: Evidence from National Borders in the Amazon. *NBER Working Paper, No. 24861*, 21. https://doi.org/10.3386/w24861

Callaway, B., & Sant'Anna, P. H. C. (2020). Difference-in-Differences with multiple time periods. *Journal of Econometrics*, (xxxx), 1–31. https://doi.org/10.1016/j.jeconom.2020.12.001

Chiavari, J., & Lopes, C. L. (2017). Forest and Land Use Policies on Private Lands: an International Comparison. In *INPUT iniciativa para o Uso da Terra*. Retrieved from https://climatepolicyinitiative.org/wp-content/uploads/2017/10/Full_Report_Forest_and_Land_Use_Policies_on_Private_Lands_-_an_International_Comparison-1.pdf

Chimeli, A. B., & Boyd, R. G. (2010). Prohibition and the Supply of Brazilian Mahogany. *Land Economics*, *86*(1), 191–208. https://doi.org/10.3368/le.86.1.191

Critical Ecosystem Partnership Fund. (2020). *Impact report CEPF 2001–2020*. Retrieved from https://www.cepf.net/sites/default/files/cepf_impact_report_2020.pdf

Dean, W. (1995). *A ferro e fogo: a história e a devastação da Mata Atlântica brasileira*. São Paulo: Companhia das Letras.

Ehrl, P. (2017). Minimum comparable areas for the period 1872–2010: An aggregation of Brazilian municipalities. *Estudos Economicos*, *47*(1), 215–229. https://doi.org/10.1590/0101-416147182phe

Ferraro, P. J., Hanauer, M. M., Miteva, D. A., Canavire-Bacarreza, G. J., Pattanayak, S. K., & Sims, K. R. E. (2013). More strictly protected areas are not necessarily more protective: Evidence from Bolivia, Costa Rica, Indonesia, and Thailand. *Environmental Research Letters*, *8*(2). https://doi.org/10.1088/1748-9326/8/2/025011

Fiorini, A. C. O., Mullally, C., Swisher, M., & Putz, F. E. (2020). Forest cover effects of payments for ecosystem services : Evidence from an impact evaluation in Brazil. *Ecological Economics*, *169*(October 2019), 106522. https://doi.org/10.1016/j.ecolecon.2019.106522

Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T. A., Barlow, J., … Sodhi, N. S. (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature*, *478*(7369), 378–381. https://doi.org/10.1038/nature10425

Heckman, J. J., Ichimura, H., & Todd, P. E. (1997). Matching As An Econometric Evaluation Estimator: Evidence from Evaluating a Job Training Programme. *Review of Economic Studies*, *64*(4), 605–654. https://doi.org/10.2307/2971733

IUCN. (2013). *Guidelines for Applying Protected Area Management Categories*. Retrieved from https://portals.iucn.org/library/sites/library/files/documents/PAG-021.pdf

Joppa, L. N., & Pfaff, A. (2011). Global protected area impacts. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1712), 1633–1638. https://doi.org/10.1098/rspb.2010.1713

Mello, N. G. R. de, & Artaxo, P. (2017). Evolução do Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal. *Revista Do Instituto de Estudos Brasileiros*, (66), 108. https://doi.org/10.11606/issn.2316-901x.v0i66p108-129

Miteva, D. A., Pattanayak, S. K., & Ferraro, P. J. (2012). Evaluation of biodiversity policy instruments: What works and what doesn't? *Oxford Review of Economic Policy*, *28*(1), 69–92. https://doi.org/10.1093/oxrep/grs009

Moz-Christofoletti, M. A., Pereda, P. C., & Campanharo, W. (2022). Does Decentralized and Voluntary Commitment Reduce Deforestation? The Effects of Programa Municípios Verdes. In *Environmental and Resource Economics* (Vol. 82). https://doi.org/10.1007/s10640-022-00659-0

Myers, N, Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, *403*(6772), 853–858. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10706275

Myers, Norman. (1988). Threatened biotas:" hot spots" in tropical forests. *Environmentalist*, *8*(3), 187–208. Retrieved from https://link.springer.com/content/pdf/10.1007%2FBF02240252.pdf

Neves, E. M. S. C. (2016). Institutions and environmental governance in Brazil: the local governments' perspective. *Revista de Economia Contemporanea*, *20*(3), 492–516. https://doi.org/10.1590/198055272035

Oliva, A. (2007). *Parecer Técnico PRSP/MPF no. 120/2007*. Retrieved from http://www.mpf.mp.br/atuacao-tematica/ccr4/dados-da-atuacao/grupos-de-trabalho/encerrados/gt-flora/oficios-docs/notas-tecnicas-pareceres/PT120-2007LeiMataAtlantica.pdf/at_download/file

Pfaff, A., Robalino, J., Lima, E., Sandoval, C., & Herrera, L. D. (2014). Governance, Location and Avoided Deforestation from Protected Areas: Greater Restrictions Can Have Lower Impact, Due to Differences in Location. *World Development*, *55*, 7–20. https://doi.org/10.1016/j.worlddev.2013.01.011

Pienkowski, T., Cook, C., Verma, M., & Carrasco, L. R. (2021). Conservation cost-effectiveness: a review of the evidence base. *Conservation Science and Practice*, *3*(5), 1–12. https://doi.org/10.1111/csp2.357

Rezende, C. L., Scarano, F. R., Assad, E. D., Joly, C. A., Metzger, J. P., Strassburg, B. B. N., … Mittermeier, R. A. (2018). From hotspot to hopespot: An opportunity for the Brazilian Atlantic Forest. *Perspectives in Ecology and Conservation*, *16*(4), 208–214. https://doi.org/10.1016/j.pecon.2018.10.002

Ribeiro, M. C., Metzger, J. P., Martensen, A. C., Ponzoni, F. J., & Hirota, M. M. (2009). The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. *Biological Conservation*, *142*(6), 1141–1153.

https://doi.org/10.1016/j.biocon.2009.02.021

Rosa, M. R., Brancalion, P. H. S., Crouzeilles, R., Tambosi, L. R., Piffer, P. R., Lenti, F. E. B., … Metzger, J. P. (2021). Hidden destruction of older forests threatens Brazil's Atlantic Forest and challenges restoration programs. *Science Advances*, *7*(4), 1–9. https://doi.org/10.1126/sciadv.abc4547

Ruggiero, P G C, Pfaff, A., Pereda, P., Nichols, E., & Metzger, J. P. (2022). The Brazilian intergovernmental fiscal transfer for conservation : A successful but self-limiting incentive program. *Ecological Economics*, *191*(September 2021), 107219. https://doi.org/10.1016/j.ecolecon.2021.107219

Ruggiero, Patricia G.C., Metzger, J. P., Reverberi Tambosi, L., & Nichols, E. (2019). Payment for ecosystem services programs in the Brazilian Atlantic Forest: Effective but not enough. *Land Use Policy*, *82*(December 2018), 283–291. https://doi.org/10.1016/j.landusepol.2018.11.054

Sant'Anna, P. H. C., & Zhao, J. (2020). Doubly robust difference-in-differences estimators. *Journal of Econometrics*, *219*(1), 101–122. https://doi.org/10.1016/j.jeconom.2020.06.003

Sills, E. O., Herrera, D., Kirkpatrick, A. J., Brand, A., Dickson, R., Hall, S., … Pfaff, A. (2015). Estimating the Impacts of Local Policy Innovation : The Synthetic Control Method Applied to Tropical Deforestation. *PLoS ONE*, 1–15. https://doi.org/10.1371/journal.pone.0132590

Simmons, B. A., Law, E. A., Marcos-Martinez, R., Bryan, B. A., McAlpine, C., & Wilson, K. A. (2018). Spatial and temporal patterns of land clearing during policy change. *Land Use Policy*, *75*(April), 399–410. https://doi.org/10.1016/j.landusepol.2018.03.049

Simmons, B. A., Wilson, K. A., Marcos-martinez, R., & Bryan, B. A. (2018). Effectiveness of regulatory policy in curbing deforestation in a biodiversity hotspot. *Environmental Research Letters*, *13*. https://doi.org/https://doi.org/10.1088/1748-9326/aae7f9

SOS Mata Atlântica. (2019). *Valorização dos Parques e Reservas: ICMS Ecológico e as Unidades de Conservação Municipais da Mata Atlântica*.

SOS Mata Atlântica. (2022). *SAD Mata Atlântica: Sistema de Alertas de Desmatamento no. 1*. Retrieved from https://cms.sosma.org.br/wp-content/uploads/2022/02/SAD-Mata-Atlantica_01-1.pdf

Varjabedian, R. (2010). Atlantic Rainforest Law: Environmental Regression. *Estudos Avançados*, *24*(68), 147–160.

Appendix

Appendix 1 – Mapbiomas details

Table A 1 - Land use and land cover categories from Mapbiomas collection 6

1.	Forest
1.1	Forest Formation
1.2	Savanna Formation
1.3	Mangrove
1.4	Wooded Restinga
2.	Non Forest Natural Formation
2.1	Wetlands
2.2	Grassland
2.3	Salt Flat
2.4	Rocky Outcrop
2.5	Other non Forest Formations
3.	Farming
3.1	Pasture
3.2	Agriculture
3.2.1	Temporary Crop
3.2.1.1	Soybean
3.2.1.2	Sugar cane
3.2.1.3	Rice
3.2.1.4	Other temporary crops
3.2.2	Perennial Crop
3.2.2.1	Coffee
3.2.2.2	Citrus
3.2.2.3	Other Perennial Crop
3.2	Forest Plantation
3.1	Mosaic Agriculture and Pasture
4.	Non vegetated Area
4.1	Beach, Dune and Sand Spot
4.2	Urban Area
4.3	Mining
4.4	Other non Vegetaded Areas
5.	Water
5.1	River,Lake and Ocean
5.2	Aquaculture
6.	Non Observed

Appendix 2 – Results from non-normalized flow variables

Table A 2 - Aggregate effect of Atlantic Forest Law on flow variables for natural forests: net recovery, loss and recovery (as % of MCA area) with different anticipation periods

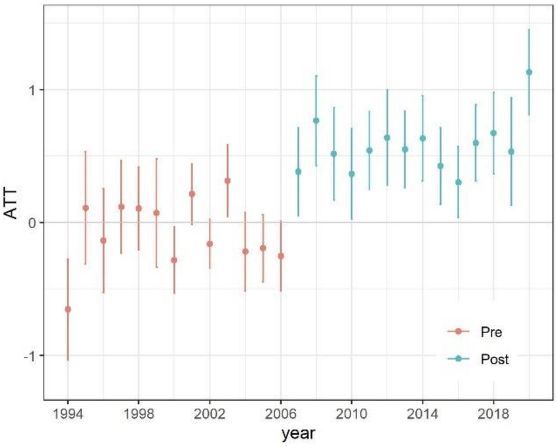
Dependent variable		Selected states, 0-100			
		(1)	(2)	(3)	(4)
(a) Net recovery for natural forests	ATT	0.575***	0.322***	0.130	-0.090
		(0.094)	(0.094)	(0.077)	(0.061)
(b) Loss for natural forests	ATT	-0.106***	-0.125***	-0.016	0.109***
		(0.033)	(0.041)	(0.036)	(0.032)
(c) Recovery for natural forests	ATT	0.469***	0.198***	0.114**	0.019
		(0.067)	(0.051)	(0.052)	(0.039)
MCA cluster		✓	✓	✓	✓
State dummies		✓	✓	✓	✓
Baseline nat. cover		✓	✓	✓	✓
Baseline control variables		✓	✓	✓	✓
Anticipation periods		0	1	2	3
Baseline nat. cover in treated MCAs (2006)		25.91	25.91	25.91	25.91
Qty. of treated MCAs		1661	1661	1661	1661
Qty. of control MCAs		1461	1461	1461	1461

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

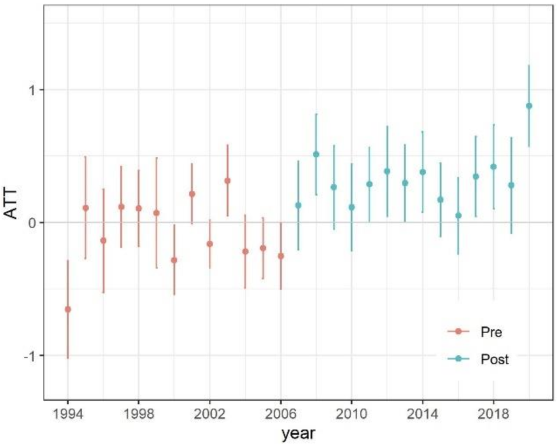
Robust standard errors are in parenthesis

Figure A 1 – Atlantic Forest Law effects on net recovery of natural forests (as % of MCA area), with different periods of anticipation. Cluster at the MCA level

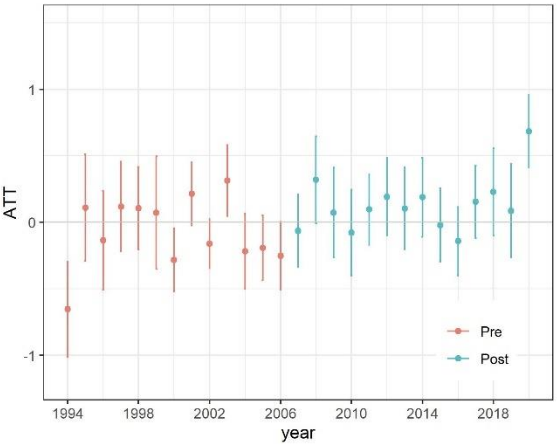
(a) No anticipation



(b) 1 period of anticipation



(c) 2 periods of anticipation



(d) 3 periods of anticipation

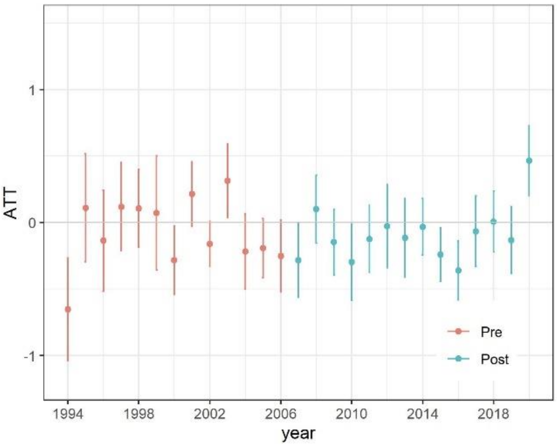
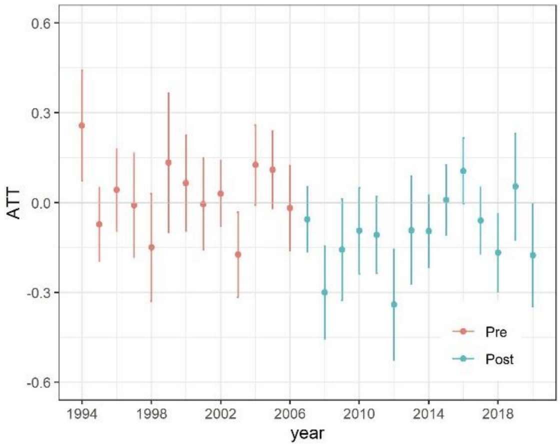
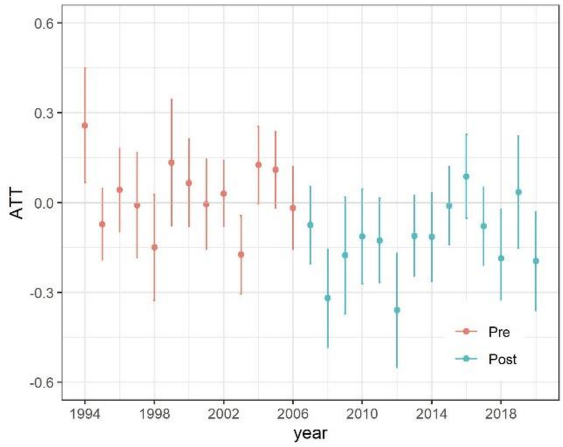


Figure A 2 – Atlantic Forest Law effects on loss of natural forests (as % of MCA area), with different periods of anticipation. Cluster at the MCA level

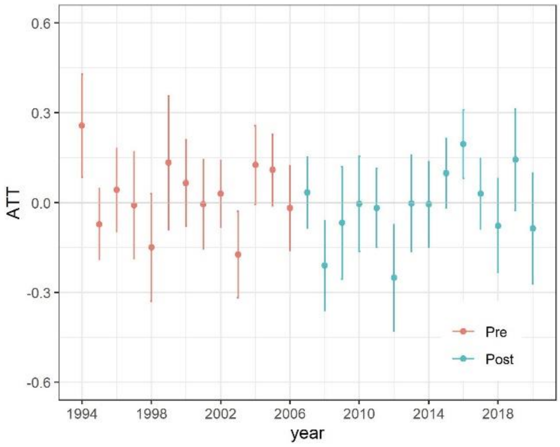
(a) No anticipation



(b) 1 period of anticipation



(c) 2 periods of anticipation



(d) 3 periods of anticipation

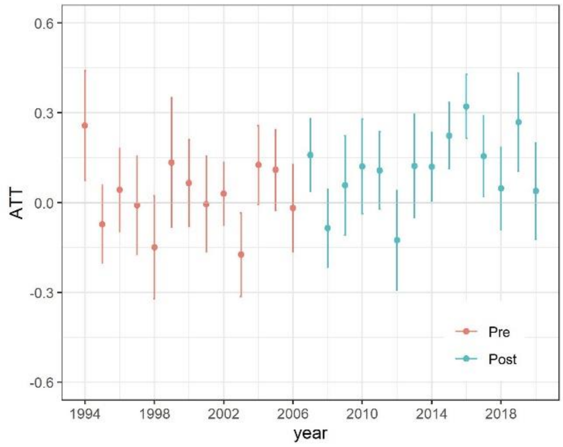
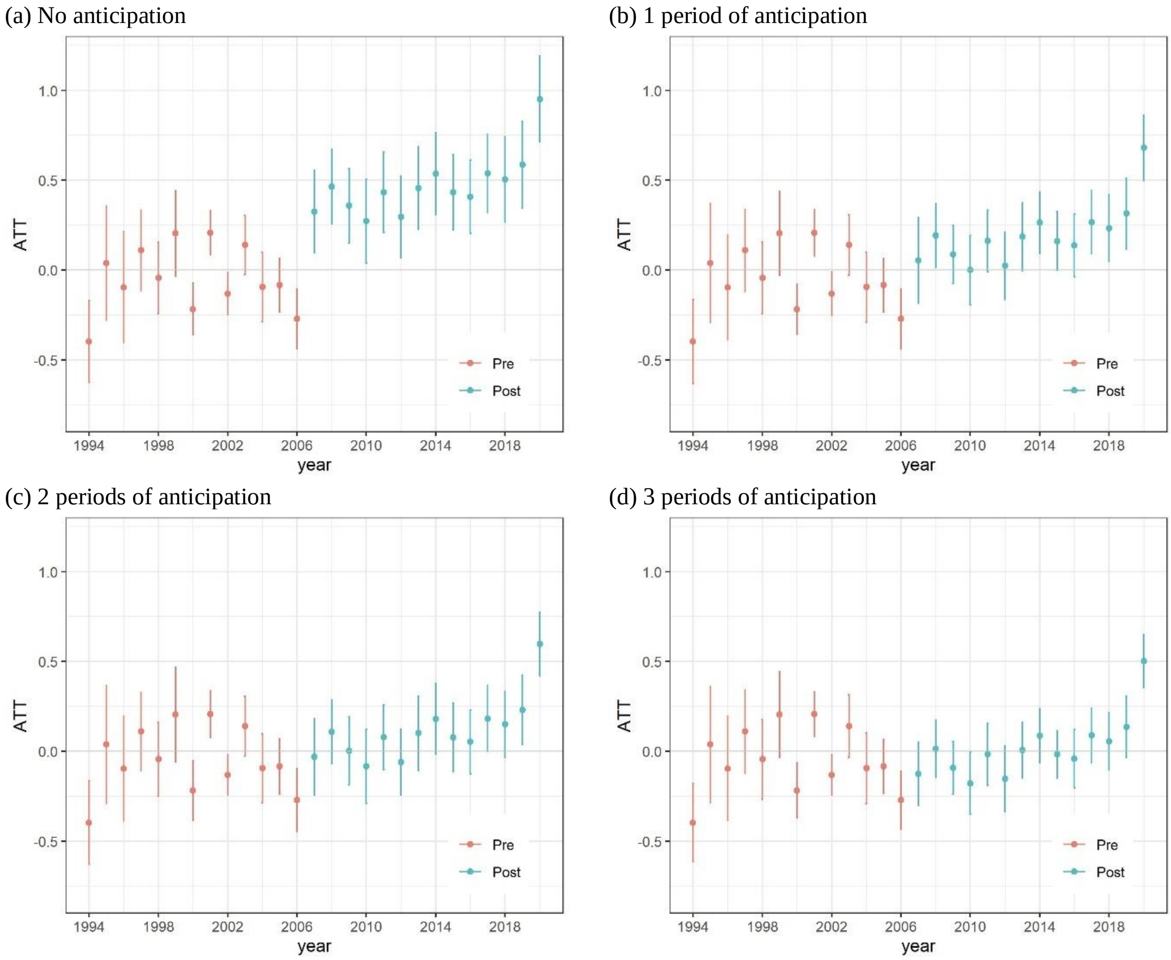


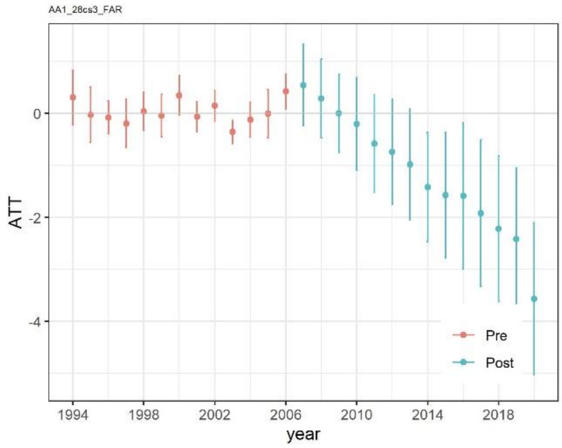
Figure A 3 – Atlantic Forest Law effects on recovery of natural forests (as % of MCA area), with different periods of anticipation. Cluster at the MCA level



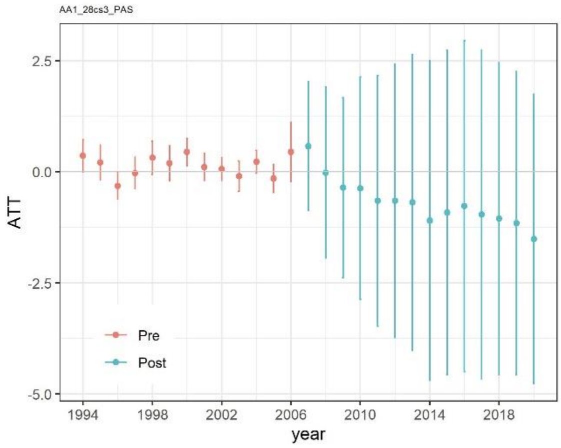
Appendix 3 – Robustness check

Figure A 4– Atlantic Forest Law effects on farming, pasture, crops, silviculture, mosaic of pasture/crops and urban cover (as % of MCA area), with three periods of anticipation. Conditional on state, natural cover and other covariates in the baseline. Cluster at the MCA level

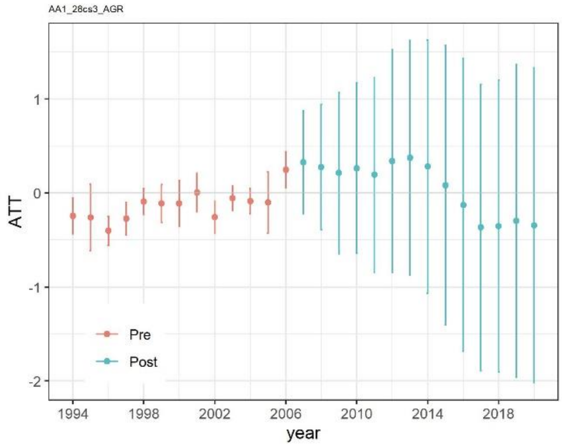
(a) Farming cover



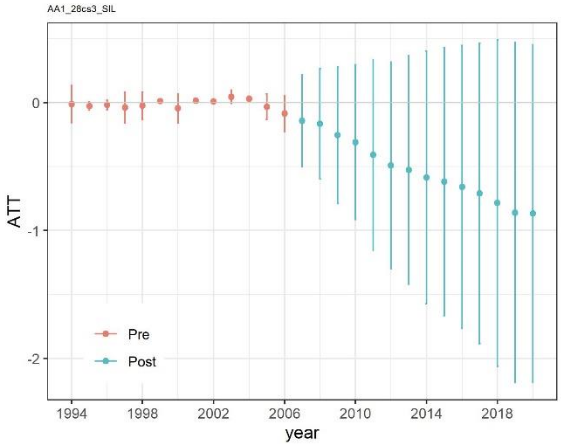
(b) Pasture cover



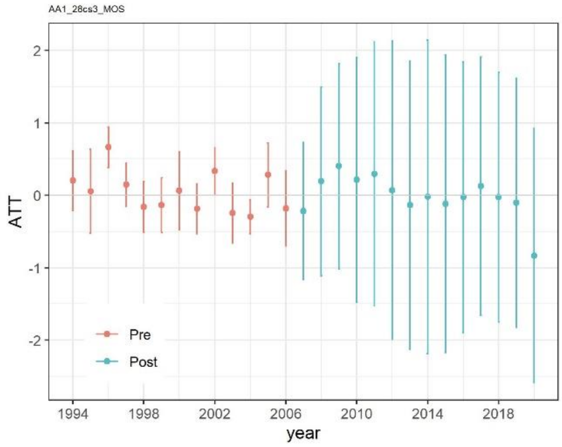
(c) Crops cover



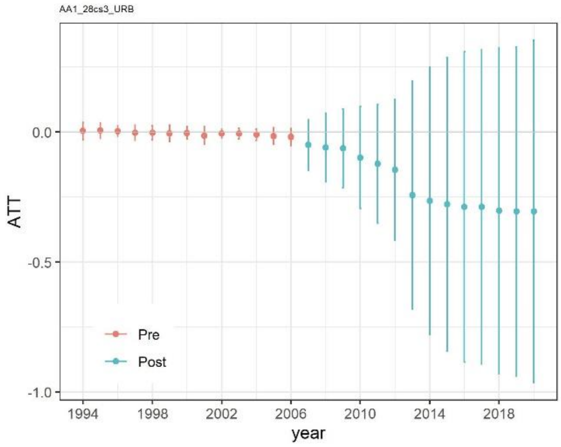
(d) Non-native forest plantation (silviculture) cover



(e) Mosaic of pasture and crops



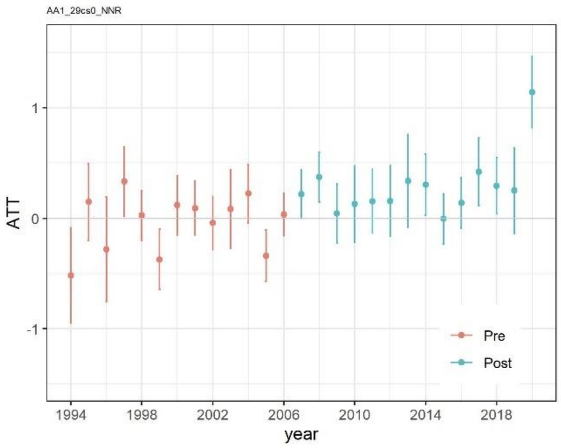
(f) Urban cover



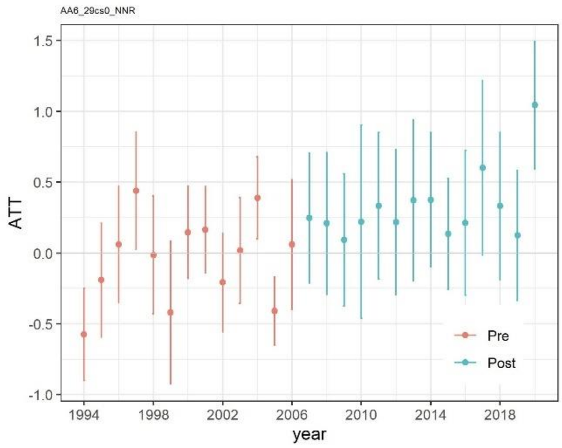
Appendix 4 – Analysis of heterogeneity

Figure A 5 –Atlantic Forest Law effects on normalized net recovery of natural forest cover for different groups, no anticipation. Conditional on state, natural forest cover and other covariates in the baseline. Cluster at the MCA level

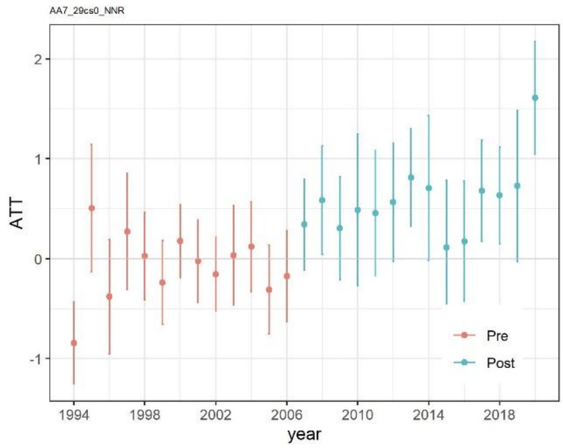
(a) 0-100



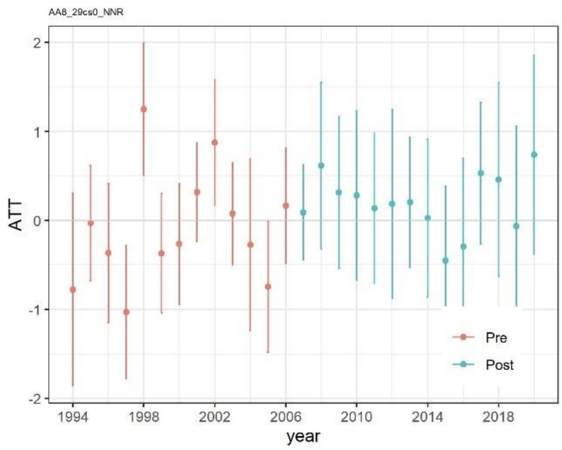
(b) 0-25



(c) 25-50



(d) 50-75



(e) 75-100

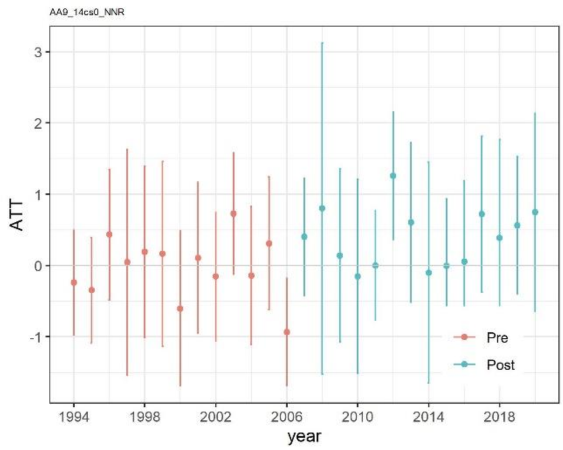
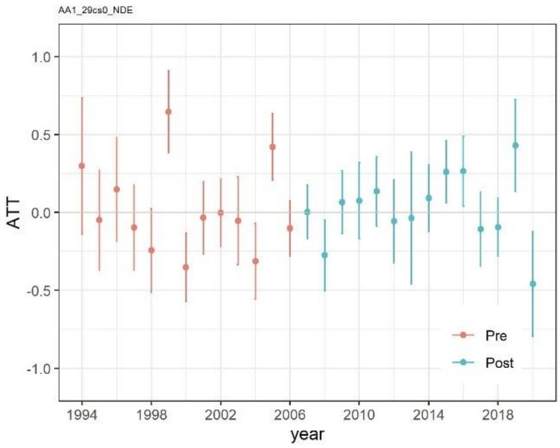
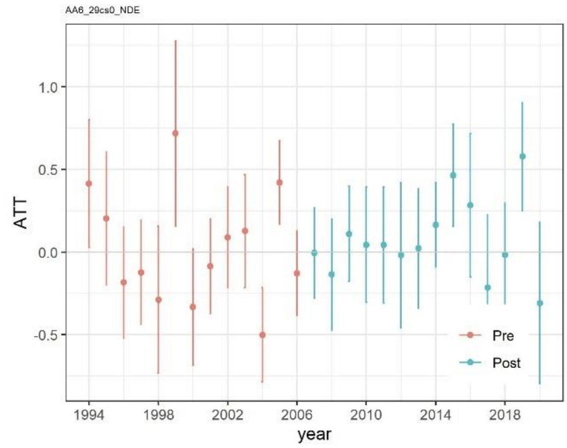


Figure A 6 –Atlantic Forest Law effects on normalized loss of natural forest cover for different groups, no anticipation. Conditional on state, natural forest cover and other covariates in the baseline. Cluster at the MCA level

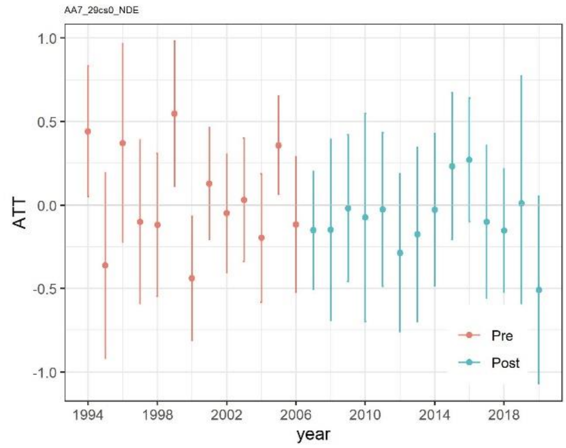
(a) 0-100



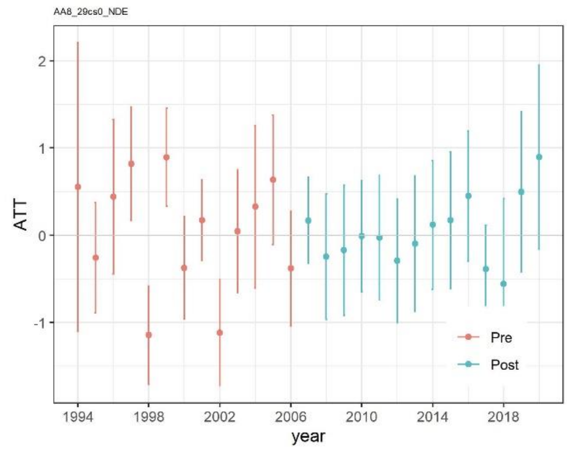
(b) 0-25



(c) 25-50



(d) 50-75



(e) 75-100

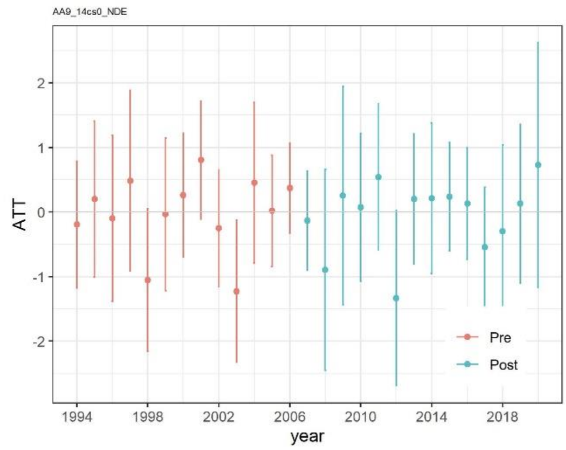
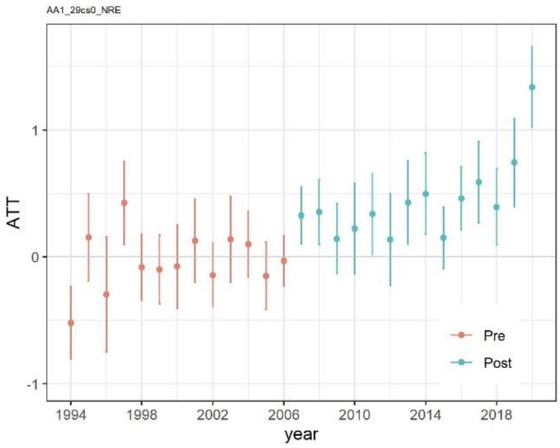
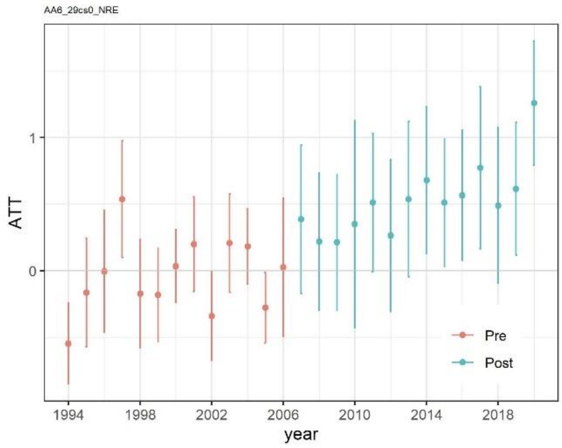


Figure A 7 –Atlantic Forest Law effects on normalized recovery of natural forest cover for different groups, no anticipation. Conditional on state, natural forest cover and other covariates in the baseline. Cluster at the MCA level

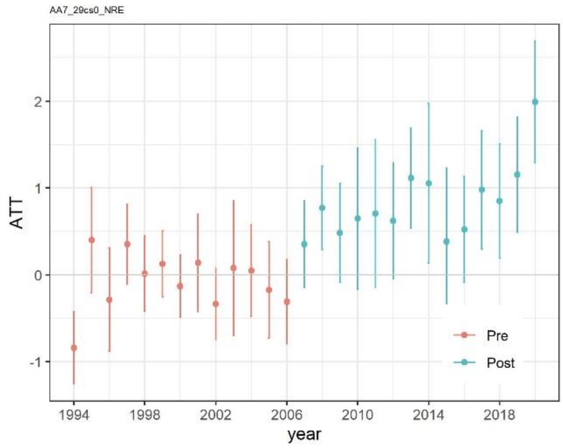
(a) 0-100



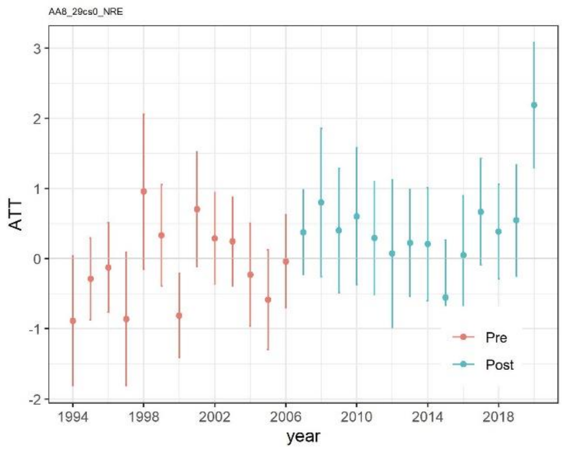
(b) 0-25



(c) 25-50



(d) 50-75



(e) 75-100

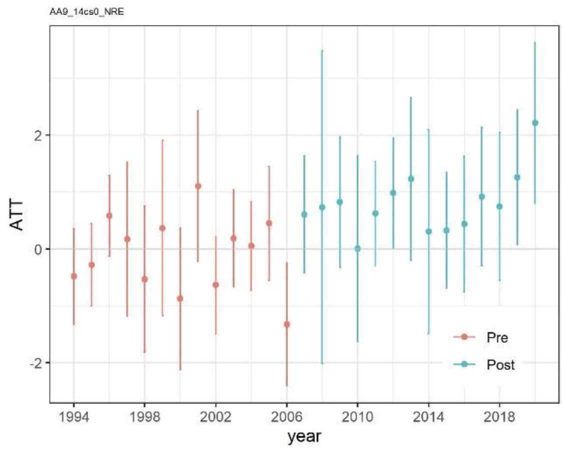


Figure A 8– Atlantic Forest Law effects on natural forest cover for different groups of states, three periods of anticipation. Conditional on the state (when applicable), natural forest cover and other covariates in the baseline. Cluster at the MCA level

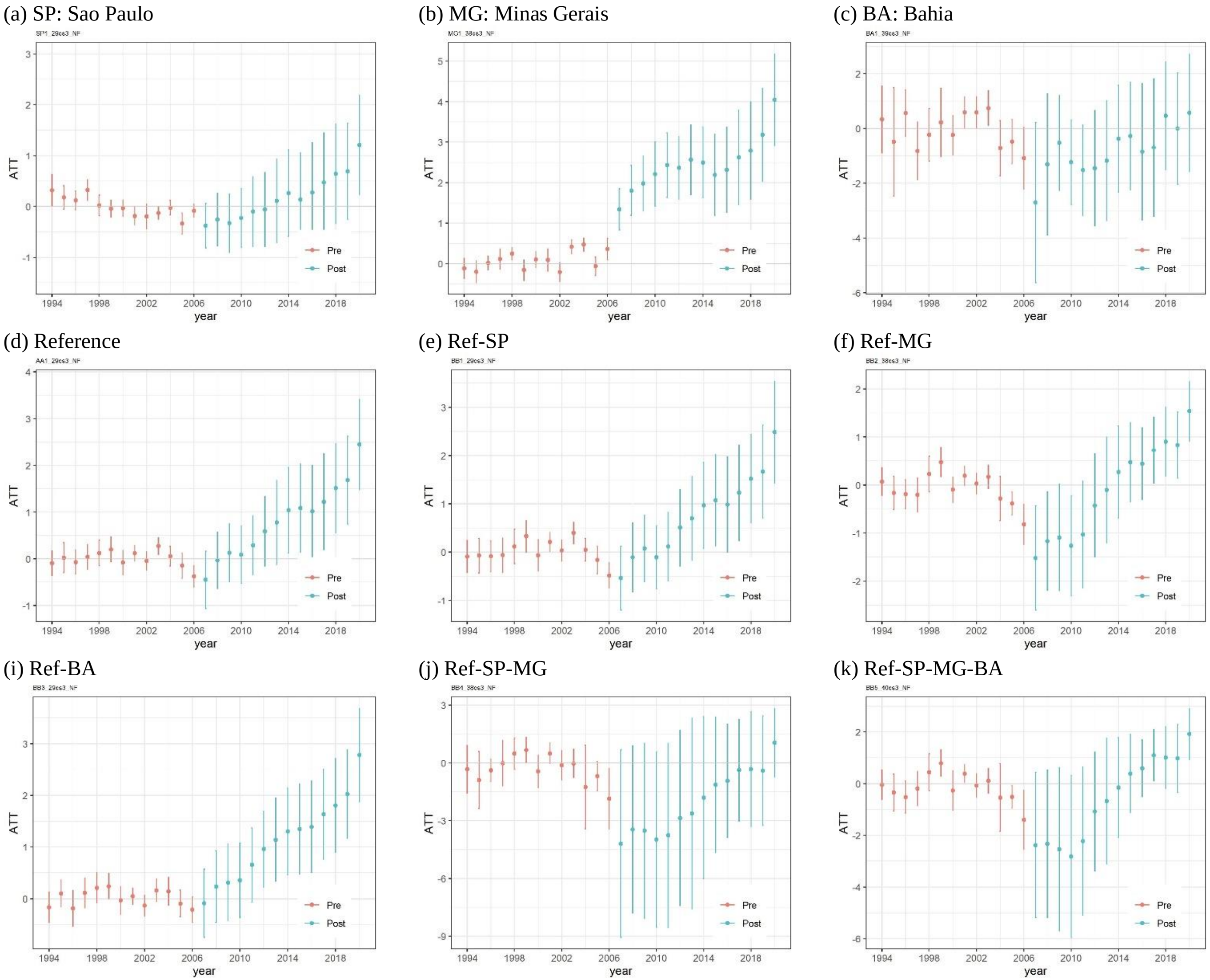


Figure A 9– Atlantic Forest Law effects on normalized net recovery of natural forest cover for different groups of states, no anticipation. Conditional on the state (when applicable), natural forest cover and other covariates in the baseline. Cluster at the MCA level

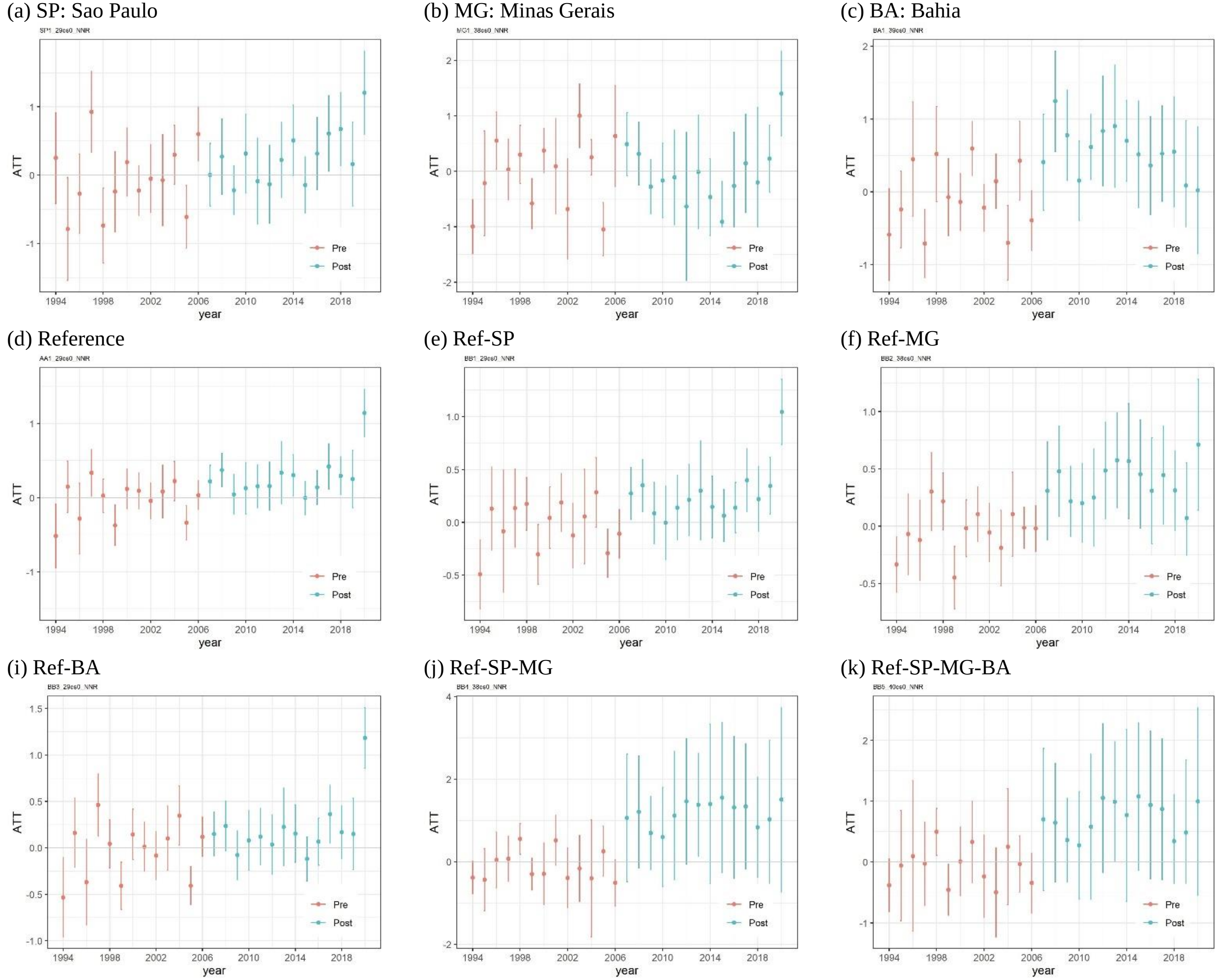


Figure A 10– Atlantic Forest Law effects on normalized loss of natural forest cover for different groups of states, no anticipation. Conditional on the state (when applicable), natural forest cover and other covariates in the baseline. Cluster at the MCA level

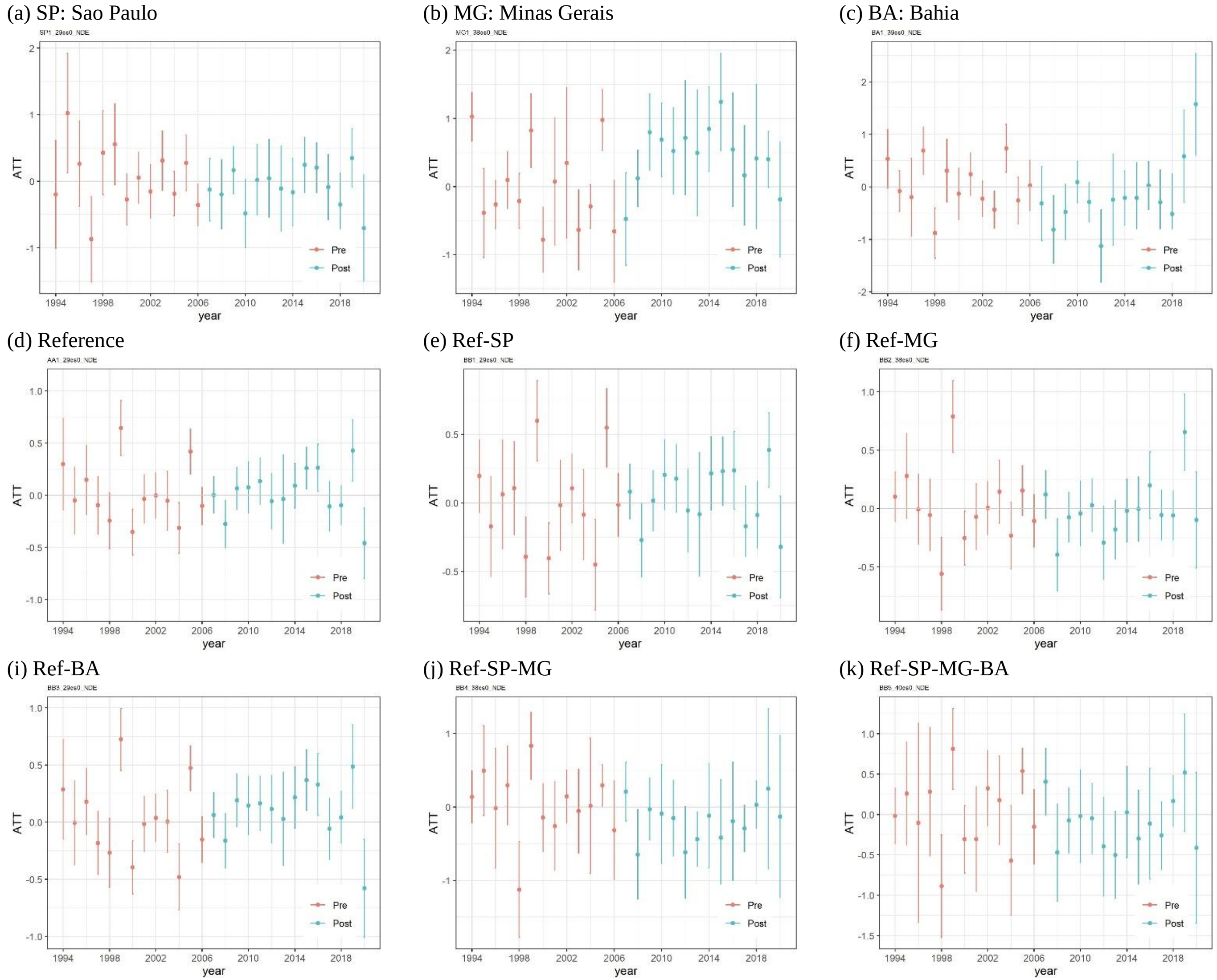


Figure A 11– Atlantic Forest Law effects on normalized recovery of natural forest cover for different groups of states, no anticipation. Conditional on the state (when applicable), natural forest cover and other covariates in the baseline. Cluster at the MCA level

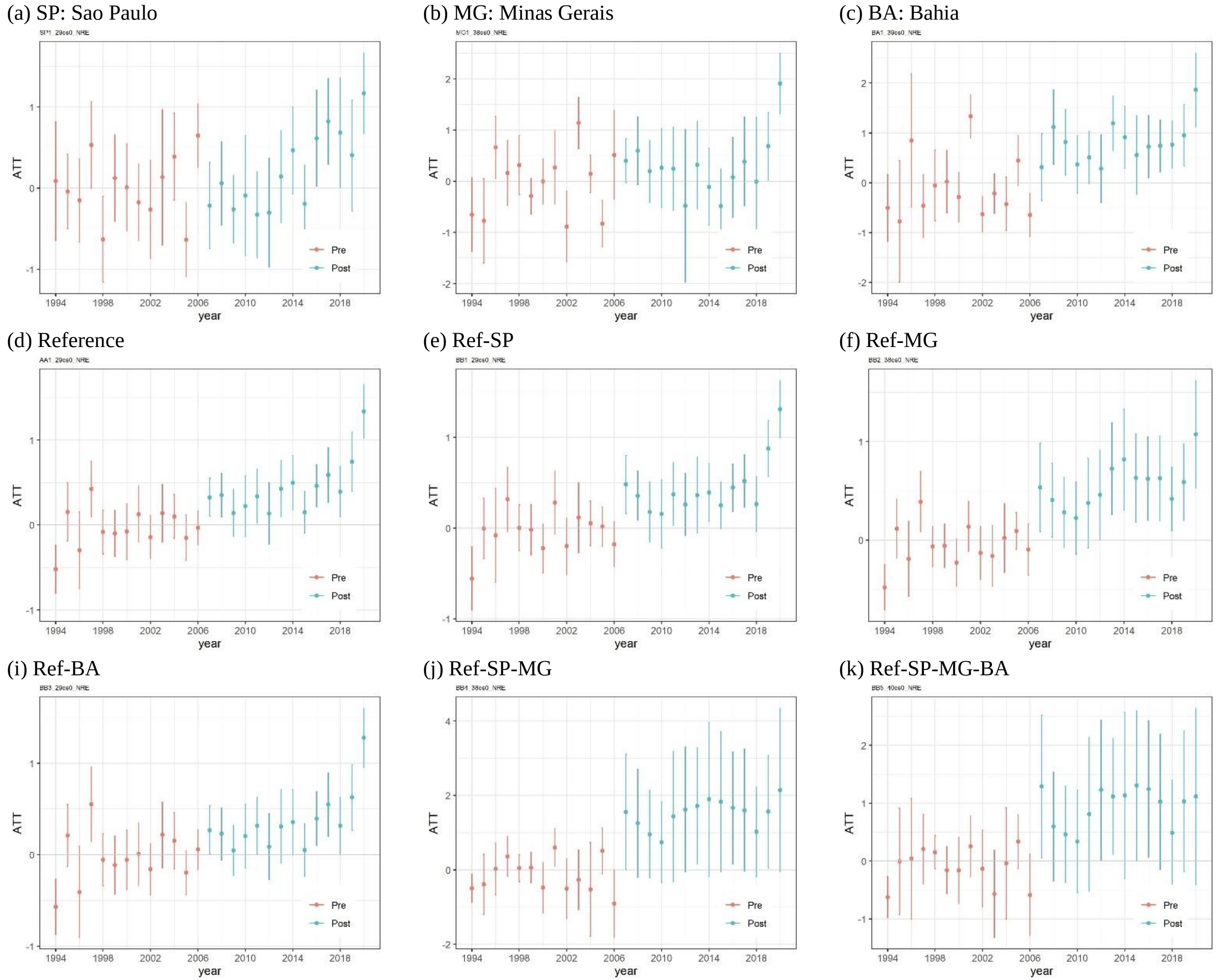
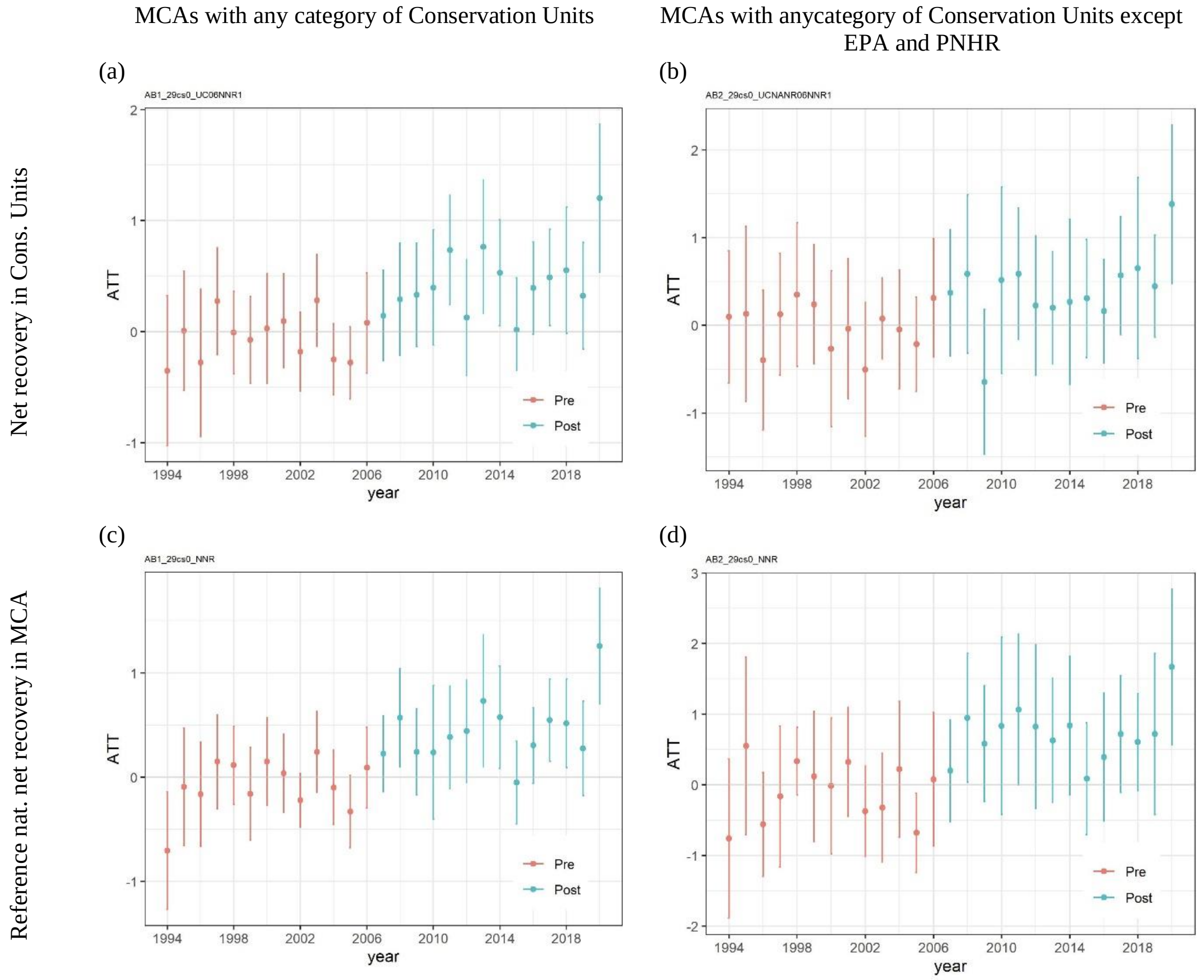


Figure A 12 – Atlantic Forest Law effects on normalized net recovery of natural forests in pre-existing Conservation Units, no anticipation. Conditional on state, natural forest cover and other covariates in the baseline. Cluster at the MCA level.



Appendix 5 – Conservation Units categories in Brazil

The Conservation Units in Brazil are divided into two classes according to the governance of protection: full protection and sustainable use.[79] Full protection units are under more restricted regulation, and any economic use based on extraction or clearing is forbidden. Indirect use of natural resources (such as tourism or research) is allowed though. There are five different types of full protection conservation units: Ecological Station, Biological Reserve, National Park,[80] Wildlife Refuge, and Natural Monument. Sustainable use unities are less restrictive, and direct use of natural resources is allowed as long as ecological processes are not harmed. There are seven different types of sustainable use conservation units in Brazil: National Forest,[81] Fauna Reserve, Environmental Protection Area, Area of Significant Ecological Interest, Extractive Reserve, Sustainable Development Reserve, and Private Natural Heritage Reserve.[82] Those 12 different conservation unities also differ in terms of land ownership. Ecological Stations, Biological Reserves, and National Parks are full protection Conservation Unit types where land is State property, whereas Natural Monuments and Wildlife Refuges can be constituted by private areas. Sustainable use Conservation Unit types such as National Forest, Fauna Reserve, Sustainable Development Reserve, and Extractive Reserve are State property and public domain. Environmental Protection Area and Area of Significant Ecological Interest can have a mix of private and public properties. Finally, a Private Natural Heritage Reserve consists of private properties by definition. Figure A 13 shows the current Brazilian Conservation Units per category of protection.

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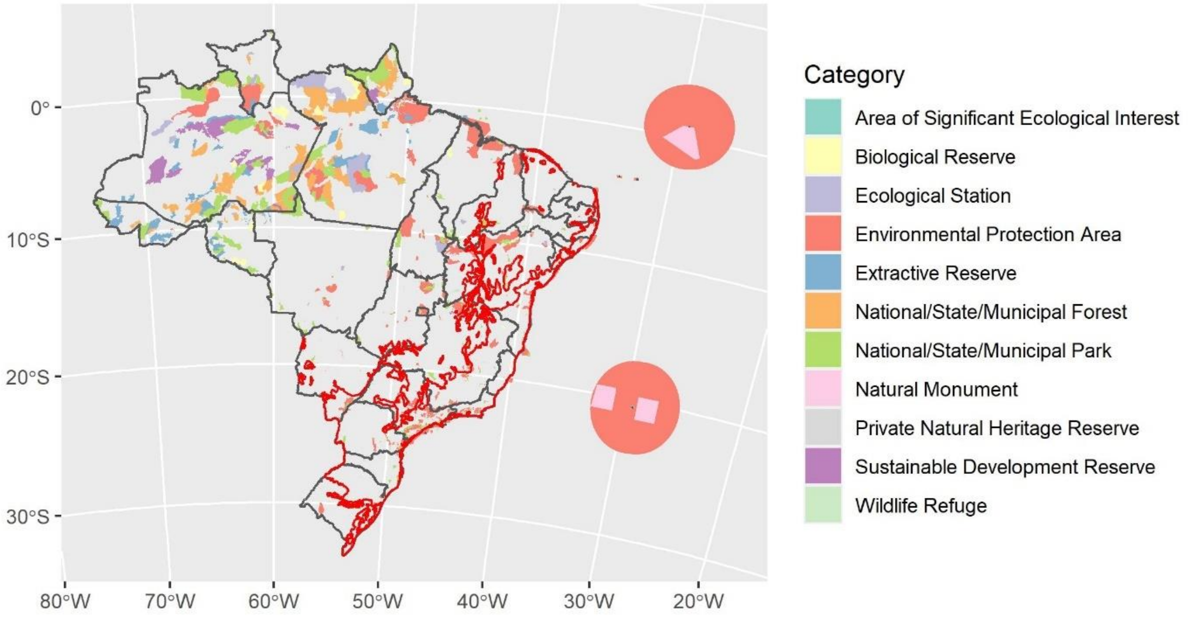
[79] In contrast, IUCN divides protected areas in six categories.
[80] Can be changed to State Park or Municipal Park according to the Governmental sphere.
[81] Can be changed to State Forest or Municipal Forest according to the Governmental sphere.
[82] Only few countries follow the international system for the classification of protected natural areas developed by the IUCN. The correspondence of the Brazilian categories to the IUCN categories are shown in parenthesis. For full protection units: Ecological Station (subcategory Ia), Biological Reserve (subcategory Ia), National Park (category II), Wildlife Refuge (category II) and Natural Monument (category III). For sustainable use units: National Forest (category IV), Fauna Reserve (category IV), Environmental Protection Area (category V), Area of Significant Ecological Interest (category V), Extractive Reserve (category VI), Sustainable Development Reserve (category VI) and Private Natural Heritage Reserve (category VI).

Figure A 13 – Conservation Units in Brazil



Data source: National Register of Conservation Units, Ministry of Environment

Appendix 6 – Complementary analysis

Figure A 14 – Natural cover evolution in treated and control AMCs, 1993-2020. (a) Natural cover as % of AMC area (b) Natural cover as index (% of AMC area, 1993= 100)

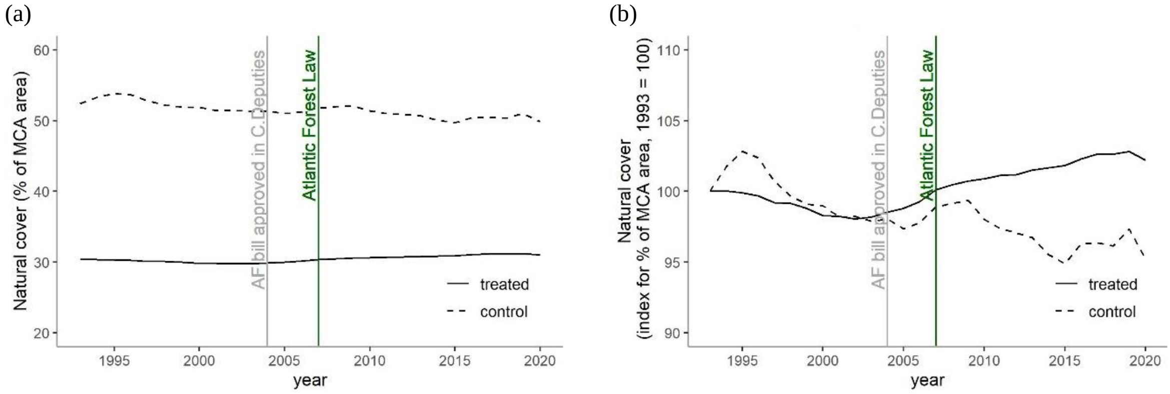
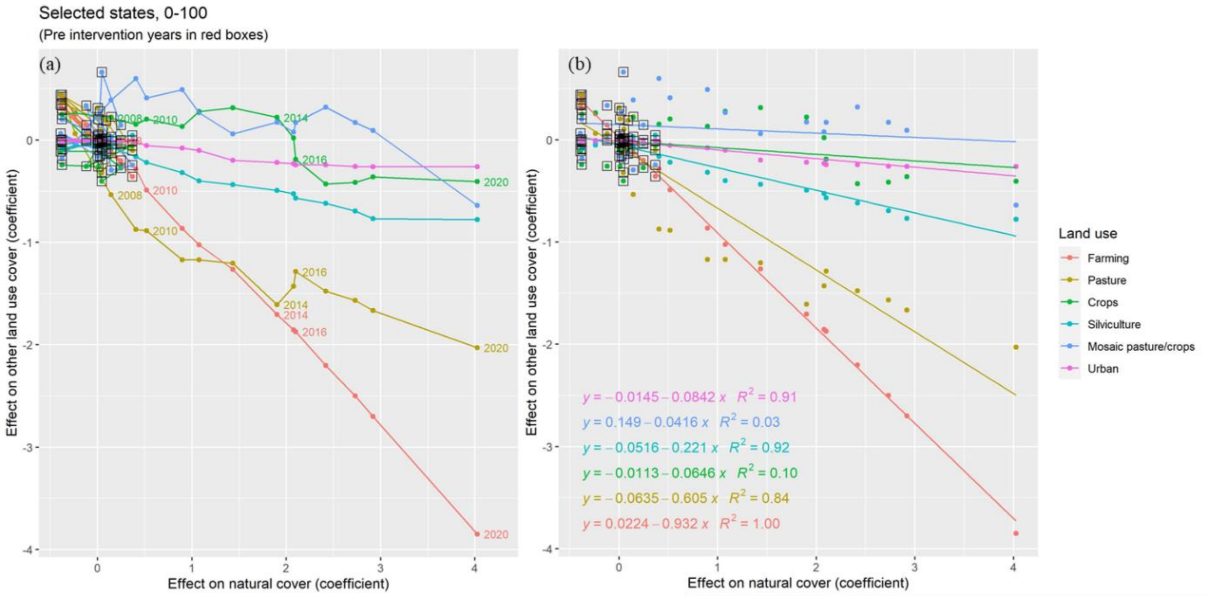


Figure A 15 – Coefficients of estimated effects of AFL on the natural cover (as % of MCA area) against the coefficients of estimated effects of AFL on different types of anthropic land use (as % of MCA area). No anticipation, conditional on state, natural cover and other covariates in the baseline, cluster at the MCA level. Panel (a) shows the effects dynamics and panel (b) shows the correlation between the estimated effects.



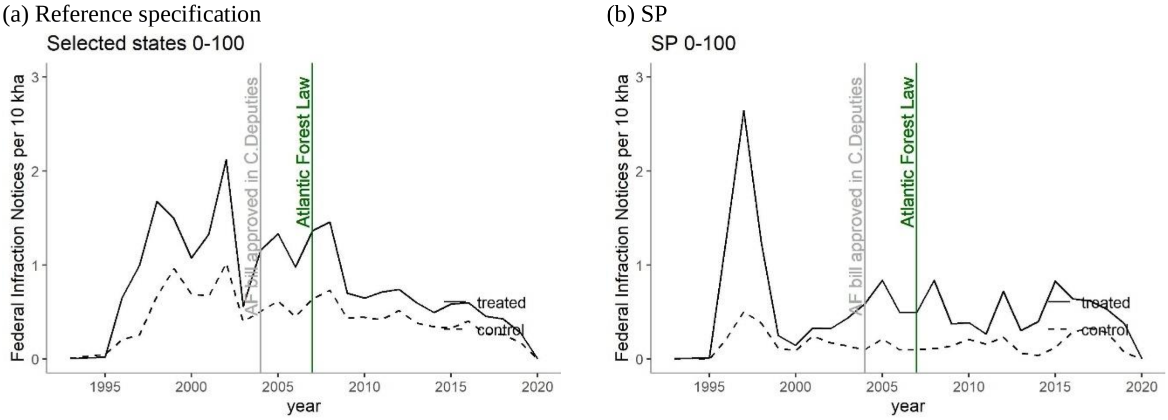
Appendix 7 – Federal Infraction Notices

In this section, we use Federal EIN data from IBAMA and explore the effects of the AFL on the relative frequency of these EIN. IBAMA's Federal environmental infraction notices comprise only a share of possible EIN, as the three tiers of the government have common jurisdiction over legislative and administrative actions related to the environment. These infraction notices are related to any environmental infraction, including vegetation removal and fires but also wildlife trafficking[83].

We present results from the reference specification and from the state of Sao Paulo (see Figure A 16 for the EIN frequency evolution (frequency per 10 kha of MCA area)). In general, treated areas have a higher frequency of EIN.

Figure A 16 – Federal environmental infraction notices frequency (quantity per 10kha) evolution in treated and control MCAs for different groups, 1993-2020

(a) Reference specification (b) SP



Aggregate effects of AFL on the relative frequency of EIN in different samples are shown in Table A 3. There wre no effect of the AFL on the EIN frequency regardless of the group or the anticipation periods considered.

83 Unfortunately, the database is not organized by category of infractions.

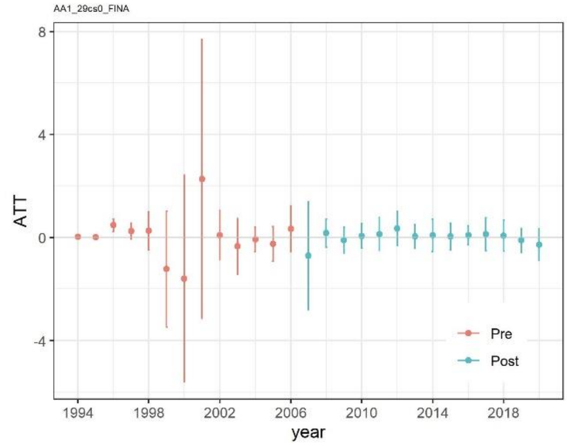
Table A 3 - Aggregate effect of Atlantic Forest Law on Federal environmental infraction notices frequency (quantity per 10 kha) for different groups

	Anticipation periods	Reference	SP
		(1)	(2)
Frequency of Federal EIN (quantity per 10 kha)	0	-0.001 (0.115)	-0.080 (0.110)
	1	0.345 (0.429)	0.235 (0.608)
	2	0.096 (0.172)	-0.115 (0.156)
	3	0.027 (0.095)	-0.022 (0.141)
MCA cluster		✓	✓
State dummies		✓	
Baseline nat. cover		✓	✓
Baseline control variables		✓	✓
Baseline EIN frequency (per 10 kha) in treated MCAs (2006)		0.98	0.50
Qty. of treated MCAs		1661	399
Qty. of control MCAs		1461	111

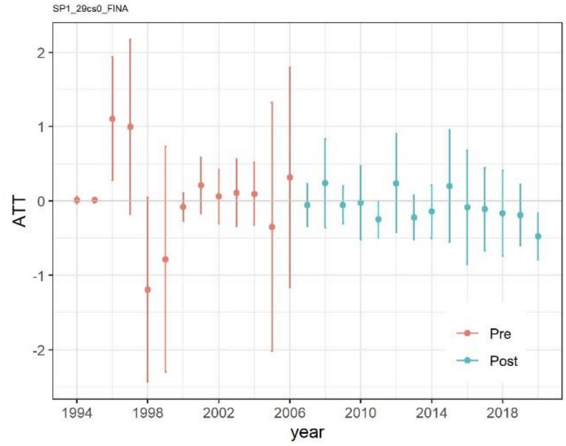
Note: * p < 0.1; ** p < 0.05; *** p < 0.01
Robust standard errors are in parenthesis

Figure A 17 – Atlantic Forest Law effects on Federal environmental infraction notices frequency (quantity per 10kha) for different groups, no anticipation. Conditional on state, natural forest cover and other covariates in the baseline. Cluster at the MCA level

(a) Reference specification



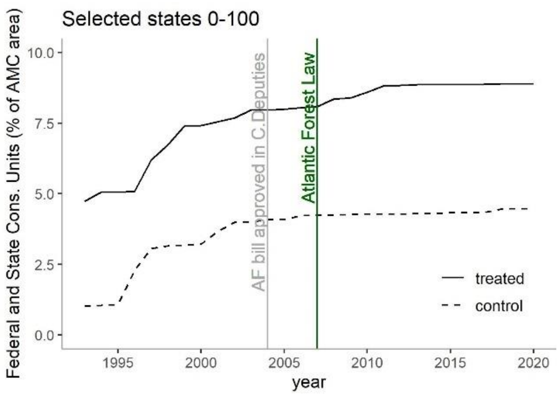
(b) SP



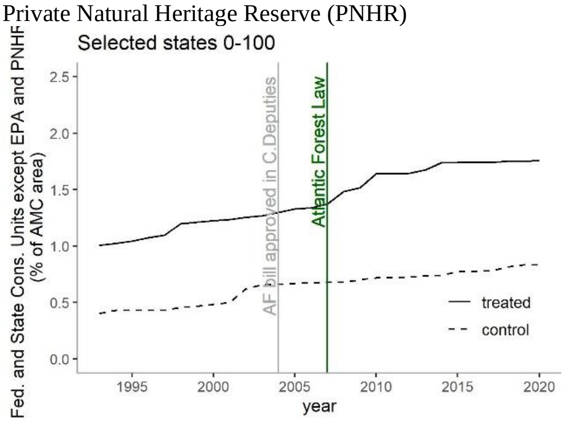
Appendix 8 – Conservation Units

Figure A 18 – Conservation Units (except municipal) area evolution (as % of MCA area) in treated and control MCAs, 1993-2020

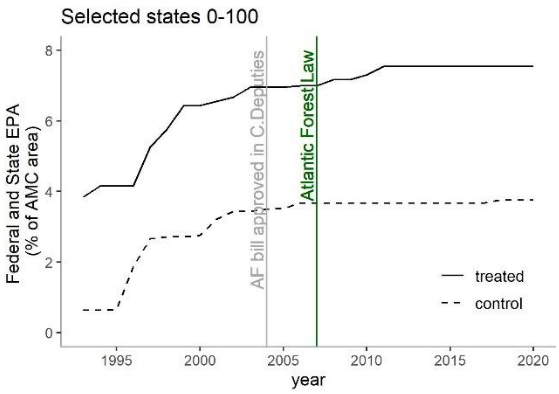
(a) All categories of Conservation Units



(b) Except Environmental Protection Area (EPA) and Private Natural Heritage Reserve (PNHR)



(c) Environmental Protection Area (EPA) only



(d) Private Natural Heritage Reserve (PNHR) only

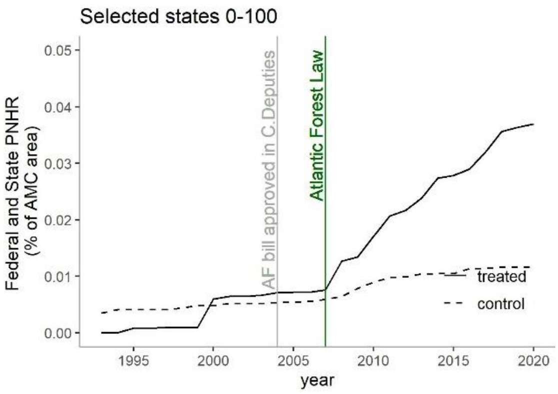


Table A 4 - Aggregate effect of Atlantic Forest Law on Conservation Units coverage (as % of MCA area) for different groups of categories of Conservation Units (except Municipal)

	Dependent variable: Conservation Units except municipal (% of MCA area)			
	(1) All	(2) Except EPA and PNHR	(3) EPA	(4) PNHR
ATT	0.510***	0.254***	0.341**	0.015**
	(0.156)	(0.072)	(0.147)	(0.006)
MCA cluster	✓	✓	✓	✓
State dummies	✓	✓	✓	✓
Baseline Conservation Units	✓	✓	✓	✓
Baseline control variables	✓	✓	✓	✓
Anticipation periods	0	0	0	0
Baseline Conservation Units coverage in treated MCAs (2006)	8.05	1.34	6.99	0.007
Qty. of treated MCAs	1661	1661	1661	1661
Qty. of control MCAs	1461	1461	1461	1461

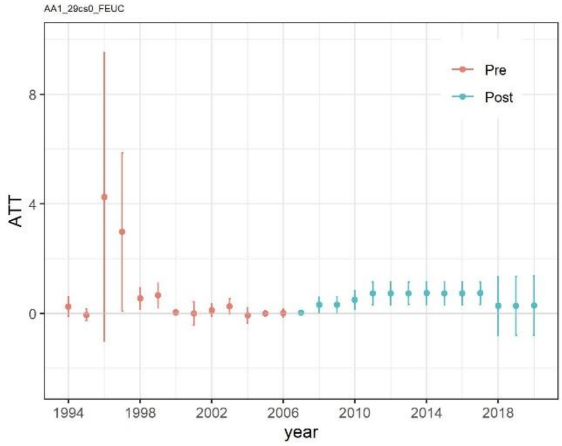
Note: * p < 0.1; ** p < 0.05; *** p < 0.01

Robust standard errors are in parenthesis

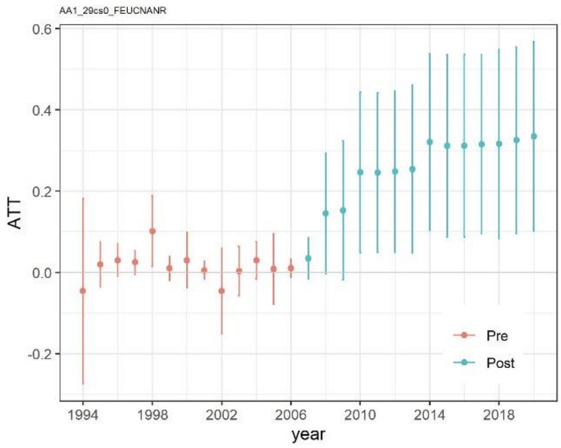
EPA: Area of Environmental Protection; PNHR: Private Natural Heritage Reserve

Figure A 19 – Atlantic Forest Law effects on Conservation Units coverage (as % of MCA area) for different groups of categories of Cons. Units (except municipal), no anticipation. Conditional on state, Cons. Units coverage and other covariates in the baseline. Cluster at the MCA level. In (d), data from before 1996 were ignored to keep common support for all covariates.

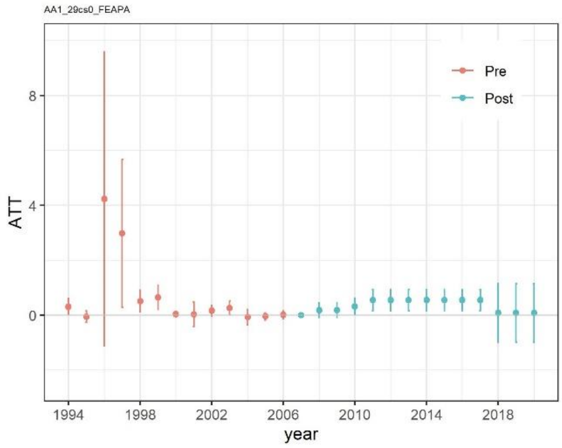
(a) All categories of Conservation Units



(b) Except Environmental Protection Area (EPA) and Private Natural Heritage Reserve (PNHR)



(c) Environmental Protection Area (EPA) only



(d) Private Natural Heritage Reserve (PNHR) only