Deforestation Policies in the Brazilian Legal Amazon: An analysis of the PPCDAm policy using the Triple Difference method

Área ANPEC: Área 11 – Economia Agrícola e do Meio Ambiente

Roberto B. de M. Junior[1] Bruno Benevit[2] Carolina S. da Trindade[3]
Daniel de Abreu Pereira Uhr[4] Júlia Gallego Ziero Uhr[5]

Abstract

This study evaluates the effects of the implementation of the PPCDAm from 2004 on the observed deforestation in the Brazilian Legal Amazon. The triple difference method is used to explore the relative differences between the group of non-metropolitan municipalities with indigenous lands and the group of other municipalities in the region. The results indicate an average reduction in the increase in deforestation of approximately 16.1 km^2 per municipality between 2004 and 2007, equivalent to a reduction of 10,293 km^2 in deforestation and a stock of 498 million tons of CO_2. We verify the robustness of the results using placebo tests, analysis of heterogeneous effects, and analysis with the flexibility of the composition of the groups. Robustness tests corroborate the results. The results highlight the importance of remote monitoring policies to control deforestation in isolated regions and indigenous lands.

Keywords: Brazilian Legal Amazon, deforestation, environmental legislation, indigenous lands, triple difference.

Resumo

Este estudo avalia os efeitos da implementação do PPCDAm a partir de 2004 no desmatamento observado na Amazônia Legal brasileira. Utilizamos o método de tripla diferença para explorar as diferenças relativas entre o grupo dos municípios não metropolitanos com terras indígenas e grupo dos demais municípios da região. Os resultados indicam uma redução média no incremento do desmatamento de aproximadamente 16,1 km^2 por município entre 2004 e 2007, equivalente à redução de 10.293 km^2 no desmatamento e ao estoque de 498 milhões de toneladas de CO_2. Verificamos a robustez dos resultados realizando os testes de placebo, análise de efeitos heterogêneos e análise com flexibilização da composição dos grupos. Os testes de robustez corroboram os resultados. Os resultados destacam a importância de políticas de monitoramento remoto para o controle do desmatamento em regiões isoladas e em terras indígenas.

Palavras-chave: Amazônia Legal brasileira, desmatamento, legislação ambiental, terras indígenas, tripla diferença.

JEL: C31, Q51, Q58.

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[1] Department of Economics, Federal University of Pelotas - UFPel. E-mail: robertomelojr@outlook.com
[2] Department of Economics, Federal University of Pelotas - UFPel. E-mail: bruno.benevit@gmail.com
[3] Department of Economics, Federal University of Pelotas - UFPel. E-mail: carolina.silva.trindade@hotmail.com
[4] Department of Economics, Federal University of Pelotas - UFPel. E-mail: daniel.uhr@gmail.com
[5] Department of Economics, Federal University of Pelotas - UFPel. E-mail: zierouhr@gmail.com

1. Introduction

The environment has been consolidated as a public, governmental and international topic of interest. The planet's tropical forests are mostly found in emerging countries (Saatchi et al. 2011). This phenomenon in these countries is mainly related to land use and conflicts of interest due to the production of primary goods (Assunção, Gandour and Rocha, 2015; Hargrave and Kis-Katos, 2013). In this sense, Brazil is important in discussing such a theme, where 70% of the Amazon Forest is found in the country, covering 7% of the planet's surface (Castro et al. 2019). Furthermore, it is home to various indigenous ethnicities in its domains (BenYishay et al. 2017; B. Soares-Filho et al. 2010; Walker, Hamilton, and Groth 2014). The Brazillian Amazon deforestation has once again brought global concern due to the growth in deforestation rates observed in Brazil in recent years (Azevedo et al. 2021) and legal changes that have taken place in the last decade (Azevedo et al. 2021; Britaldo Soares-Filho et al. 2014). The deforestation in Brazil was around 13,853 km^2 in 2020, and more than 80% occurred in the Brazilian Legal Amazon territory (Azevedo et al. 2021).

However, the annual deforestation rate in Brazil presented a drastic reduction over the 2000s, moving from a record rate of 29,059 km² in 1995 to a level of 4,571 km² in 2012 (Arima *et al.*, 2014). The studies of Arima *et al.* (2014), Assunção, Gandour and Rocha (2013), Hargrave and Kis-Katos (2013) and Rosa, Souza and Ewers (2012) show that the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon - PPCDAm (Brasil, 2003) was effective in reducing deforestation observed between 2004 and 2012 in the Brazilian Legal Amazon. The PPCDAm promoted institutional changes coordinated between different ministries, the private sector, and civil society entities, aiming to combat deforestation in the Brazilian Legal Amazon. In this sense, this study analyzes the effectiveness of the PPCDAm in reducing deforestation. The PPCDAm was implemented in Brazil in 2004, aiming to monitor environmentally vulnerable areas, restrain the high rates of deforestation registered in the region, and promote territorial and land planning. The plan was executed in four parts from 2004 to 2020. One of the central policies of the PPCDAm in its first phase was implementing the Real-Time System for the Detection of Deforestation – DETER in 2004. DETER allowed the monitoring of the Brazilian Amazon region via satellite in near real-time, facilitating the identification and punishment of environmental infractions in the Brazilian Legal Amazon. In addition to DETER, several other measures such as Presidential Decrees No. 6,321/2007 and No. 6,514/2008 and Resolution of the National Monetary Council – CMN No. 3,545/2008 presented institutional changes, demonstrating a favorable governmental environment for combating deforestation (PPCDAm 2009).

To identify the causal effect of the first phase of the PPCDAm on deforestation in the Brazilian Legal Amazon, we propose using the Triple Difference method. We defined as a result variable the increase in annual deforestation made available by the Project for Monitoring Deforestation in the Legal Amazon (PRODES) of the National Institute for Space Research (INPE). The Triple Difference method makes it possible to assess the impact of the first phase of the policy on deforestation by exploring different variabilities between the characteristics of municipalities. Several data sources provide geographic and demographic characteristics, agricultural commodities prices, and the municipality's indigenous land proportion. The analysis period is from 2002 to 2007, and the data are arranged at the municipal level, comprising 756 municipalities in the Brazilian Legal Amazon region. As robustness analysis, we propose the application of placebo tests for the treatment and the outcome variable, the heterogeneous effect analysis, and the flexibility of the composition of the groups.

The results demonstrate that the first phase of the PPCDAm policy provided an average annual reduction of up to 16.1 km^2 per municipality on the increase in deforestation. This result represents a total reduction in deforestation of 10,293 km² during the period from 2004 to 2007. This reduction represented an additional stock of 498 million tons of carbon dioxide (CO_2), equivalent to approximately US$ 2.5 billion in 2012. The results remain strong after performing the robustness analyses. These results complement the

studies of Assunção, Gandour and Rocha (2013, 2015), Hargrave and Kis-Katos (2013), Mello and Artaxo (2017) and Walker, Hamilton and Groth (2014), as they indicate that the PPCDAm was effective in containing deforestation in the Brazilian Legal Amazon in the 2000s.

This work contributes to the literature in several ways. First, the article innovates by being the first work in the literature to identify the causal effect of the first phase of the PPCDAm for the pre-2008 period. Second, it innovates in methodological terms by applying the triple difference method to identify the impact of the PPCDAm on deforestation. Third, the article explores several sources of variation in the increase in deforestation in the region, including the presence, number, and proportion of indigenous lands in the municipalities. Fourth, the article provides new evidence on the importance of monitoring and enforcement policies for the protection of indigenous peoples in Brazil and highlights the importance of these mechanisms for the effectiveness of protected areas in containing environmental degradation. Finally, the article provides a cost-benefit analysis of the program for the pre-2008 period.

In addition to this introduction, the article reviews the literature on the topic in its second section. In section three, we present the identification strategy. Section four presents the database used and the construction of the variables for the estimations. Section five presents the results. Section six presents the robustness analysis and its results. Section seven presents the political considerations. Finally, section eight presents the final considerations.

2 Literature review

2.1 Brazilian Legal Amazon and environmental legislation

Brazil is essential for discussing environmental issues as it contains 70% of the Amazon Forest, corresponding to 28% of the South American subcontinent (Castro et al., 2019). The Brazilian Amazon represents 58.9% of the country's total territory and contains the Amazon biomes and part of the Cerrado and Pantanal biomes. The Brazilian Legal Amazon was made official in 1953 by the Brazilian federal government (C. C. Brasil 1953) through Law nº 1.806/1953[6], which also established the Superintendence of the Economic Valorization Plan for the Amazon (SPVEA) to develop the region economically through agricultural, mineral and industrial production. After the dismemberment of the state of Mato Grosso from Complementary Law nº 31/1977[7], the Brazilian Legal Amazon began to comprehend the regions that currently correspond to the states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, and Roraima, in addition to part of the state of Maranhão (west region of the 44° meridian). However, the objective of the Brazilian federal government to develop the Amazon region economically with the SPVEA did not promote harmonious development between social, environmental, political, and economic aspects (Mello and Artaxo 2017).

The Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) was created in 1989 by Federal Law nº 7,735/1989 to promote harmony between institutions in favor of environmental management and natural resources in Brazil. IBAMA is a federal agency linked to the Ministry of the Environment (MMA) with jurisdiction throughout the Brazilian territory and is part of the National Environment System (SISNAMA). The environmental management in Brazil was dissonant among the institutions responsible for its management until then: the Special Secretariat for the Environment – Sema (responsible for environmental conservation and rational use of natural resources)

[6] The law can be accessed at https://www.planalto.gov.br/ccivil_03/leis/1950-1969/l1806.htm
[7] The law can be accessed at http://www .planalto.gov.br/ccivil_03/leis/lcp/lcp31.htm

was linked to the Ministry of the Interior[8], the Brazilian Institute for Forestry Development – IBDF (responsible for forest management), and the Fisheries Superintendence - Sudepe (responsible for fisheries management) were linked to the Ministry of Agriculture, and the Rubber Superintendence - SUDHEVEA (responsible for the development of rubber production) was linked to the Ministry of Industry and Commerce. IBAMA was founded from the merger of these four bodies and had the purpose of (i) exercising the power of the federal environmental police force; (ii) operating the environmental licensing; (iii) inspecting, monitoring, and executing environmental control; iv) authorizing the use of natural resources, and v) execute supplementary federal actions and policies of the MMA regarding environmental standards.

The migratory expansion and disorderly land occupation led to the deforestation of approximately 18 million hectares in the Amazon region between the late 1980s and the 1990s (Laurance et al. 2001; Malhi et al. 2008; Mello and Artaxo 2017), reaching its peak between 1994 and 1995 with the mark of 2.9 million deforested hectares (Fundo Amazônia 2012). In 1998 Law No. 9,605/1998[9] was implemented in response to the escalation of deforestation in Brazil at the time, entitled the "Environmental Crimes Law" - LCA (Brazil, 1998). IBAMA lacked legal tools for prosecuting crimes committed against the environment before the LCA, in addition to existing discrepancies regarding punishments for different crimes committed against the same legal object. The LCA started to centralize and standardize the legal norms related to the subject, providing criminal and administrative sanctions for activities and conducts harmful to the environment. It also typified crimes against flora and fauna, environmental pollution, and administrative infractions for any actions or omissions that violate the norms of use, protection, promotion, and recovery of the environment (regardless of the occurrence of environmental damage). The application of the penalty for environmental crimes began considering the severity of the infraction (reasons and consequences), the offender's background of environmental crimes, and the offender's economic situation (in the case of fines). The Law also began to hold legal persons responsible for crimes against the environment administratively, civilly, and criminally, and, in a non-exclusive way, the legal representative or those responsible for the administration of infringing companies.

However, the early 2000s presented high deforestation rates in the Amazon region (Malhi et al., 2008; Mello and Artaxo, 2017; Soares-Filho et al., 2006). The deforested area in the Brazilian Legal Amazon already corresponded to 837 thousand km² in 2001 (Soares-Filho et al., 2006). According to data from PRODES/INPE, the annual deforestation in the Amazon region grew from 17,383 km² in 1998 to 25,396 km² in 2003 (Fundo Amazônia, 2012). Faced with this scenario, the Presidential Decree of July 3, 2003, was signed, establishing a Permanent Interministerial Working Group (WG) to establish measures and coordinate actions to reduce deforestation rates in the Legal Amazon[10] (Brasil, 2003). In this sense, the Interministerial WG planned a set of actions by various public authorities to curb the deforestation of the Brazilian Amazon rainforest, resulting in the 2004 Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm). The PPCDAm was a strategic initiative of the Brazilian government that established guidelines and priorities under the Sustainable Development Plan for the Amazon – PAS. It coordinated partnerships between various ministries, the private sector, and civil society entities to reduce deforestation rates in the Brazilian Legal Amazon (Mello and Artaxo 2017). The PPCDAm has three main axes: promoting sustainable practices, territorial and land use management, and intensifying deforestation control and containment. This way, specialized institutions such as the Federal

[8] Although SEMA aimed at sustainable management, the Ministry of the Interior had among its objectives the management of regional development, territorial occupation (colonization), and the national housing program. It is possible to access the decree-law with the areas of competence of the Ministry of the Interior through the address http://www.planalto.gov.br/ccivil_03/decreto-lei/del0200.htm

[9] The law can be accessed at http://www.planalto.gov.br/ccivil_03/leis/l9605.htm

[10] The decree can be accessed at http://www.planalto.gov.br/ccivil_03/dnn/2003/dnn9922 .htm

Police, the Federal Highway Police, the Brazilian Army, and INPE work together to combat deforestation. So far, the plan has had four phases: phase I (2004-2008), phase II (2009-2011), phase III (2012-2015), and phase IV (2016-2020).

Some policies and institutional changes promoted during the execution of the PPCDAm were prominent. The first phase of PPCDAm (phase I) introduced DETER in 2004 to improve remote monitoring and control of the region. The system was designed by INPE and enabled faster and more effective monitoring of the forest cover of the Brazilian Legal Amazon via satellite through the georeferenced MODIS[11] (Moderate-Resolution Imaging Spectroradiometer) images generated every two weeks. DETER allowed the identification of shallow forest cuts, forest degradations in preparation for future deforestation, and scars of forest fires with a minimum size of 25 hectares (Azevedo et al. 2021). The region's monitoring relied on voluntary reports indicating each area's condition within the Legal Amazon before the implementation of DETER, imposing limitations on IBAMA's prompt legal repression against environment infractors.

The National Monetary Council – CMN (Brasil, 2008) implemented Resolution No. 3,545/2008 in 2008 aiming to mitigate the effects of the expansion of agribusiness on deforestation in the region (Assunção, Gandour, Romero, *et al.*, 2013; Assunção, Gandour and Rocha, 2015; Hargrave and Kis-Katos, 2013). This institutional change imposed restrictions on rural credit in the Amazon by requiring proof of compliance with environmental legislation on the credit takers. The resolution began to demand the absence of embargoes and proof of ownership to borrowers, and rural credit would be subject to suspension and termination in the event of irregularities in the use of land. In the same year, the Ministry of the Environment – MMA established a list of priority municipalities in the fight against deforestation in the Brazilian Legal Amazon through MMA Ordinance nº 28/2008 (MMA, 2008).

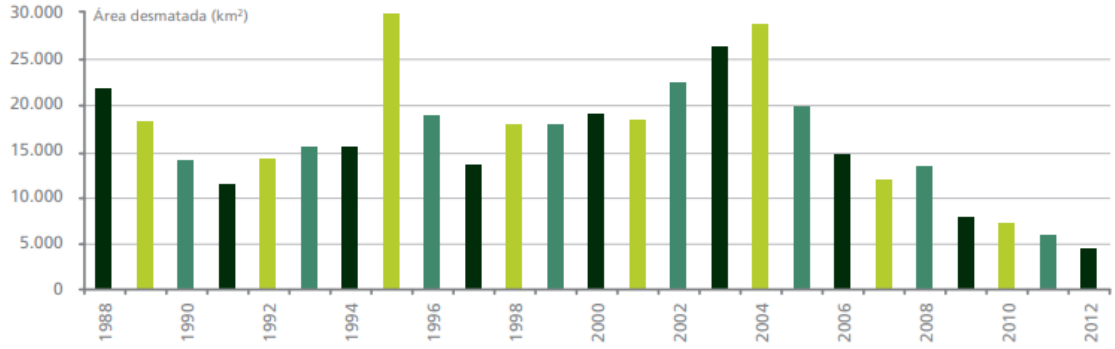
Another important change induced by PPCDAm was the increase in protected areas, which are conservation units (comprised of integral protection and sustainable use units), permanent preservation areas (PPAs), legal reserves (LR), and indigenous lands. Regarding indigenous lands, several authors highlight the importance of their demarcations as a protective measure for the protection of the environment and biodiversity (BenYishay *et al.*, 2017; Nepstad *et al.*, 2006; Pfaff *et al.*, 2015; Ricketts *et al.*, 2010; Soares-Filho *et al.*, 2010). Conservation Units in the Brazilian Legal Amazon increased by more than 520 thousand km² n between 2004 and 2009, and about 43% of the Legal Amazon area was considered a protected area in 2010 (Assunção, Gandour and Rocha, 2015).

According to the 2012 Amazon Fund's Annual Activity Report, the pace of deforestation in the Legal Amazon decreased substantially from the second half of the 2000s onwards. This behavior can be seen in Figure 1. Several studies consider the introduction of the PPCDAm as the main reason for this change of course (Arima *et al.*, 2014; Assunção, Gandour and Rocha, 2013; Assunção and Rocha, 2019; Mello and Artaxo, 2017; Sills *et al.*, 2015). Thus, the empirical literature related to deforestation in the Amazon territory indicates that the policies to combat deforestation implemented by the PPCDAm helped contain deforestation and reduce environmental devastation in the region from the second half of the 2000s onwards. The introduction of the "New Forest Code" in 2012 through Federal Law nº 12.651/2012[12] in 2012 established changes in the requirements that characterize PPAs and LRs, providing conditions for amnesty for illegal deforestation committed by small rural properties[13] until July 2008. Soares-Filho *et al.* (2014) highlight that these changes qualified 90% of rural producers for amnesty, resulting in the forgiveness of 58% of Brazil's "environmental debt" at the time. According to the authors, leniency with

[11] MODIS is a space instrument launched from Earth by NASA and started in 1999 and is part of the Earth Observing System (EOS). The program provides remote sensing data of high temporal and spectral resolution and moderate spatial resolution.
[12] The law can be accessed at http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm
[13] The size of properties considered small varies between 20 hectares, for the Brazilian Southeast, up to 440 hectares, for the Brazilian Legal Amazon.

environmental crimes provided by the 2012 Forest Code represented an institutional risk. Despite this, deforestation levels remained stable between 2013 and 2018 (Azevedo et al. 2021). The 2020 Annual Report on Deforestation in Brazil (2021) indicates that from 2018 onwards, environmental degradation in the Amazon region increased again, with a 30% increase in the number of alerts issued by DETER in the Amazon region between 2018 and 2019. Deforestation rates rose again in 2020 compared to the previous year, reaching the mark of 13,853 km², consolidating the annual rate of deforestation in the Brazilian Amazon at a level three times higher than the 4,571 km² recorded in 2012 (Azevedo et al. 2021).

Figure 1 – Annual deforestation in the Brazilian Legal Amazon (km²)



Source: Amazon Fund's Annual Activity Report using data from PRODES/INPE (2012).

2.2. The First Phase of PPCDAm

The Presidential Decree of July 3, 2003, promoted the creation of the PPCDAm in 2004, intending to reduce deforestation rates in the Legal Amazon. The PPCDAm was conceived by integrating several ministries. The Ministry of the Civil House of the Presidency of the Republic was responsible for coordinating the Interministerial WG that formulated the plan. This group was composed of the following governmental agencies: Ministry of Agriculture, Cattle and Supplying (MAPA); Ministry of Science and Technology (MCT); Ministry of Defense (MD); Ministry of Agrarian Development (MDA); Ministry of Development, Industry and Foreign Trade (MDIC); Ministry of National Integration (MI); Ministry of Justice (MJ); Ministry of the Environment (MMA); Ministry of Mines and Energy (MME); Ministry of Transport (MT); and Ministry of Labor and Employment (MTE). Since the decree was signed on March 15, 2004, the Ministry of Planning, Budget and Management and the Ministry of Foreign Affairs joined the group[14].

The Interministerial WG on Deforestation in the Amazon supported the coordination between different spheres of the public sector and provided subsidies for establishing the four working subgroups responsible for elaborating strategic proposals in their respective areas of activity. The working subgroups were divided into (i) Territorial Land Ordinance, working on territorial planning instruments with a focus on land policy, conservation units, and sustainable development strategies; (ii) Monitoring and Control, acting in instruments for monitoring, licensing, and inspection of deforestation, burning and logging; (iii) Promotion of Sustainable activities, operating in rural credit and tax incentives, technical assistance, and rural extension, and scientific and technological research; and (iv) Infrastructure, working on infrastructure policies, focusing on the transport and energy sectors[15].

[14] PPCDAm. Action Plan for the Prevention and Control of Deforestation in the Legal Amazon. Phase I. Brasília, DF: Civil House, 2004.

[15] The bodies responsible for each work subgroup are: i) Secretariat of Policies for Sustainable Development – SDS/MMA (coordinator), Secretariat for the Coordination of the Amazon – SCA/ MMA, MDA, MI, MDIC, MD, MJ/Funai; ii)

The instructions for deforestation containment strategies were based on the region's socioeconomic, environmental, and infrastructure context. In this sense, the PPCDAm followed a series of structuring policies in accordance with the following strategic guidelines: (i) promote the valorization and sustainable use of the forest for the purposes of biodiversity conservation and regional development; (ii) promote technological innovations as a way to increase productivity, reduce pressures on remaining forests and improve the recovery of degraded areas; (iii) attain land and territorial planning aimed at containing the predatory use of natural resources, creating conservation units and homologation of indigenous lands; (iv) improve the monitoring, licensing and inspection tools for deforestation; (v) encourage the strategic planning of infrastructure constructions according to cost-benefit, as well as socioeconomic and environmental impacts; (vi) strengthen cooperation between Federal Government institutions; (vii) execute public policies and environmental management in a decentralized manner involving the Union, states and municipalities; (viii) encourage the active participation of the different interested sectors of society in the management of policies related to the restriction and prevention of deforestation; (ix) encourage promising pilot experiences, providing opportunities for incorporation into public policies; and (x) establish a system for monitoring deforestation and public policies in the Amazon, aiming at a permanent process of learning and improvement in environmental preservation.[16] The Operational Plan for the first phase of the PPCDAm was established following the strategic guidelines and the working subgroups by their respective areas of activity. The subgroups are detailed as follows: (i) Monitoring and Control, (ii) Land Ordinance and Territorial, (iii) Promotion of Sustainable Activities, and (iv) Infrastructure.

DETER was the main instrument for improvement in the monitoring and deforestation control areas. The innovation of this system allowed near real-time monitoring and detection of deforestation events through satellite images. This georeferenced data provided the federal government and states with subsidies in identifying new deforestation occurrences and mapping critical areas to guide inspection actions and contain environmental crimes. These changes made it possible to overlay labor, environmental, fiscal, tax, and land ownership information to track activities linked to illegal The actions of the federal government in the land and territorial planning axis aimed at combating public land grabbing, the creation of new conservation units (sustainable use or integral protection) and the demarcation and approval of indigenous lands. It should be noted that this axis prioritized the regions of the *Arco do Deforestamento*[17], especially in the vicinity of the BR-163 (Santarém-Cuiabá Highway). The federal government acted with the state governments (Pará, Mato Grosso, Rondônia, and Acre) and civil society entities to execute the ecological-economic zoning (ZEE)[18] along the Deforestation Arch and the area of influence of BR-163. Further, the government encouraged the expansion of sustainable activities in deforested areas indicated by the ZEE (PPCDAm 2004).

New guidelines and criteria were established for granting credit through the Constitutional Funds for Financing in the North (FNO) and Midwest (FCO)[19] to promote sustainable activities with natural

IBAMA/MMA (coordinator), SCA/MMA, MCT, MD, MJ, TEM, Amazon Protection System - Sipam/CasaCivil; iii) Secretariat of Biodiversity and Forests – SBF/MMA (coordinator), SCA/MMA, MDIC, MAPA, MDA, MCT, MI, TEM, MF (guest); and iv) SCA/MMA (coordinator), MT, MME, MAPA, MI, MDIC.

[16] PPCDAm, op. cit., 2004

[17] The "Arc" comprised southeastern Maranhão, northern Tocantins, southern Pará, northern Mato Grosso, Rondônia, southern Amazonas and southeastern Acre. In the period 2000-2001, approximately 70% of deforestation in the Legal Amazon occurred in about 50 municipalities in the states of Mato Grosso, Pará and Rondônia, representing around 15.7% of the total area of the region (PPCDAM, 2004). (PPCDAm 2004).

[18] Established by Decree No. 4,297/2002, the ZEE establishes measures and standards for environmental protection in order to ensure environmental quality, water resources and soil and the conservation of biodiversity, promoting sustainable development and improving living conditions. population life.

[19] Regulated by Law No. 7,827/1989, the FNO and FCO aim to contribute to the economic and social development of the North and Midwest regions, through regional federal financial institutions, through the execution of financing programs productive sectors, in line with the respective regional development plans.

resources in the Amazon. The Green Protocol[20] was improved with its implementation by public and private banks responsible for complying with environmental laws in their credit operations. Additionally, the federal government provided training for labor focused on intensive agriculture (in areas that have already been deforested) and forest management, acting in partnership with state governments, civil society, and the business sector (PPCDAm 2004).

The federal and state governments jointly coordinated the strategic planning of infrastructure works to promote infrastructure development in the Amazon region along with socio-environmental responsibility. This joint action mitigated the environmental degradation caused by the construction of highways as in previous decades. It fostered the planning and execution of preventive, mitigating, and compensatory measures to be carried out in the works (PPCDAm 2004). However, the Infrastructure axis migrated to PAS in 2004, concentrating the PPCDAm's activities on activities directly related to illegal deforestation in the Amazon, with emphasis on productive activities linked to forest management, extractivism, recovery of degraded areas, and productive intensification of open areas (PPCDAm 2009).

According to the PPCDAm report (2004), the total budget provisioned in 2004 for actions to combat illegal deforestation was R$ 394 million, of which R$ 244.3 million (62%) were allocated to land and territory, R$ 82.7 million (21%) to the monitoring and control axis, and R$ 67 million (17%) to the promotion of sustainable activities. Compared to the amount allocated to the monitoring and control axis, R$ 4.7 million (1.2%) was allocated to improving monitoring systems and financing the planning, development, and installation of DETER. Between 2004 and 2007, INPE, responsible for developing and using DETER, had its annual Budget with Costing and Capital (OCC) increase from R$ 41.8 million in 2004 to R$ 116.8 million in 2007 (INPE, 2008). Furthermore, the annual budget provisioned for IBAMA also increased, from R$570 million in 2004 to more than R$1.1 billion in 2007. Converting to dollars, the two institutes spent more than U$ 1.8 billion[21] in this period.

Several results in its axes of action were achieved during the first phase of the PPCDAm due to a governmental environment favorable to institutional changes committed to combating deforestation (PPCDAm 2009). The edition of Ordinance MDA/INCRA nº 10 in December 2004 determined the re-registration of rural properties in municipalities in the Amazon whose declaration of legal status was characterized by possession[22] by simple occupation, and more than 60 thousand rural property titles were inhibited (PPCDAm 2009). Law 11,132 was sanctioned[23] in July 2005 as an amendment to the Law on the National System of Nature Conservation Units (SNUC). It established the instrument of "provisional administrative limitation" of areas to perform studies for the creation of UCs in conflict zones. More than 25 million hectares of conservation units strategically located near the Arch of Deforestation were created between 2004 and 2008. Additionally, more than 10 million hectares were created in Indigenous Lands, and 48 new Indigenous Lands were homologated (CIMI 2009). In the same period, Deforestation in the Integral Protection Conservation Units reduced from 499 km² to 119 km², from 1277 km² to 435 km² in the Sustainable Use Conservation Units, and from 567 km² to 398 km² in Indigenous Land.

The monitoring and control axis promoted several technological and institutional advances. The DETER creation and the PRODES improvement provided subsidies for strategic actions to combat deforestation strategically and quickly. Decree 6,321 of December 2007 started to establish priority municipalities with high deforestation rates based on three criteria: (i) total deforested area; (ii) total

[20] The Green Protocol is a letter of principles signed in 1995 by Brazilian financial institutions in favor of measures in harmony with sustainable socio-environmental development.

[21] Value corrected according to the free exchange rate of the US Dollar (sale) as provided for at address: https://www3.bcb.gov.br/sgspub/consultarvalores/consultarValoresSeries.do?method=consultarValores

[22] Squatter without title document, promising buyer who holds possession and holder of possession arising from a concession of use provided by the Federal, State or Municipal Government.

[23] The law can be accessed at https://www.planalto.gov.br/ccivil_03/_ato2004-2006/2005/lei/l11132.htm

deforested area in the last three years; and (iii) an increase in the deforestation rate in at least three of the last five years. Priority municipalities suffered indirect consequences, such as the refusal of slaughterhouses to purchase cattle from legally irregular farms, greater restrictions on obtaining rural credit, and the requirement for greater effort in more sustainable production.In addition, Decree 6,514 of July 2008 established more detailed and objective infractions and administrative sanctions related to environmental crimes, providing federal administrative processes to investigate such infractions and the appropriate measures. Thus, IBAMA started to adopt new inspection methodologies in the Brazilian Legal Amazon, working with the planning of operations in priority areas and jointly with the Army, the Federal Police, and the Federal Highway Police. It incurred greater effectiveness in the seizure of illegal wood, application of fines, and fight against corruption, resulting in the arrest of more than 600 public servants who committed crimes against the environment and public order (PPCDAm 2009).

The promotion of sustainable activities during the first phase of the PPCDAm attained the institution of the Public Forest Management Law (Law 11,284/06)[24], promoting greater transparency in identifying public forests and facilitating the forest concession process. The federal agency Serviço Florestal Brasileiro became responsible for managing public forests in Brazil and the National Forestry Development Fund – FNDF. It promoted the development of sustainable forest-based activities in Brazil and technological innovations in the sector. Law 11,284/06 resulted in the first public bidding for a forest concession in Flona Jamari (RO), and the Sustainable Forest District of BR-163 (PPCDAm, 2009) was created.

2.3. The importance of PPCDAm and evidence from the literature

The magnitude and difficulty of accessing the Brazilian Legal Amazon impose great challenges in the fight against illegal deforestation. In this sense, DETER offered an important monitoring instrument for isolated regions with little integration with the rest of society (Walker, Hamilton, and Groth 2014), subsidizing greater inspection and potentially increasing the scrutiny of the rest of society regarding conflicts. They were related to illegal deforestation in such regions (Aldrich et al. 2020). Indigenous people were in a vulnerable situation before the implementation of the PPCDAm due to the lack of prompt monitoring (Walker, Hamilton, and Groth 2014) and the lack of regulation around indigenous lands (BenYishay et al. 2017). Additionally, Börner, Marinho and Wunder (2015) highlight the importance of *enforcement* that guarantees Indigenous land ownership for indigenous peoples. The authors also reinforce that property vulnerability is associated with the deforestation of these lands and neighboring municipalities and that the isolation of indigenous peoples can make Indigenous Lands more susceptible to extractive threats. Ricketts *et al.* (2010) report that the probability of deforestation within indigenous lands or protected areas (TIAP) is between 7 and 11 times lower concerning areas around them and emphasize that the TIAPs established between 2003 and 2007 in the Amazon Brazilian law can prevent deforestation of up to 272 thousand km² by 2050, equivalent to one-third of CO_2 in the world.

The relationship between the expected profitability of agricultural production, the environmental policies of the PPCDAm, and deforestation between 2002 and 2007 are addressed by Hargrave and Kis-Katos (2013). The authors assess how land use methods are affected by variations in beef, soy and wood prices, as well as by the actions of the environmental police (IBAMA) and by the flow of rural credit. It is identified that the greater availability of agricultural credit and the increase in soy and cattle prices are associated with higher deforestation rates. On the other hand, the presence of environmental policing was effective in reducing deforestation. The study also presents an analysis using the GMM estimator on differences considering environmental fines and rural credit endogenously to the model. It identifies that the percentage increase in the intensity of fines resulted in a reduction of about 0.5% in deforestation.

[24] The law can be accessed at http://www.planalto.gov.br/ccivil_03/_ato2004-2006/2006/lei/l11284.htm

Vasconcelos *et al.* (2013) analyze the incidence of fires in the Amazon between 2004 and 2012 using a quasi-GLM Poisson model. The authors identify that 95% and 99% of fire outbreaks occur during high fire periods, presenting strong seasonality between August, September, and October and a strong negative correlation with rainfall. According to the authors, these results indicate that environmental degradation in the Brazilian Legal Amazon is associated with agricultural production, establishing a relationship between fire outbreaks and the management of deforested lands. Assunção, Gandour and Rocha (2013) article verify the impact of Resolution nº 3,545/2008 on rural credit. The authors employ the difference-in-differences strategy, controlling for fixed effects of seasonal months, agricultural commodity prices, and other relevant conservation policies. The results show that the institutional change caused a reduction in the granting of rural credit in the Amazon biome. Counterfactual simulations indicate that the deforestation of 2,700 km² between 2009 and 2011 was avoided.

Arima et al. (2014) study assess the impact of Ordinance MMA nº 28/2008 on deforestation in the Brazilian Legal Amazon using difference-in-differences and propensity score methods. It compares priority municipalities to municipalities outside the list. The results indicate that increased inspections in the list's municipalities resulted in a reduction in deforestation between 2,304 and 10,653 km^2 between 2009 and 2011, equivalent to a stock of 110 million to 528 million tons of carbon. Assunção and Rocha (2019) also checked the effectiveness of the MMA Ordinance nº 28/2008 with the difference-in-differences method, controlling for agricultural prices and the share of protected areas in each municipality. The study demonstrates that the deforestation of 11,396 km² in priority municipalities was avoided between 2008 and 2011 and that the main mechanisms that motivated this drop were advances in monitoring and the applicability of the Law.

The literature indicates that it is advantageous to interact institutional changes favorable to environmental conservation with other determinants, such as monitoring capacity and economic sanctions (Assunção *et al.*, 2013; Assunção, Gandour and Rocha, 2013; Pfaff *et al.*, 2015; Ricketts *et al.*, 2010). Thus, many studies for the Brazilian Legal Amazon focus on the synergy between policies to combat deforestation and institutional changes introduced in 2004 and 2008. Assunção, Gandour and Rocha (2015) report, after controlling for the effects of prices of agricultural products, that due to the first phase of the PPCDAm, the policies implemented both in 2004, with the advent of DETER, and in 2008, with Presidential Decrees nº 6,321 /2007 and nº 6,514/2008 and resolution nº 3,545/2008 of the CMN, contributed to a significant containment of deforestation. According to the authors' estimate, deforestation would have been 56% higher between 2005 and 2009 in the absence of policies, equivalent to the deforestation of 73,000 km² during the period. In another study, Assunção, Gandour and Rocha (2013) assess the impact of the combination of increased monitoring of deforestation after 2004, resulting from the implementation of DETER, with the total number of fines for environmental infractions applied to result from the implementation of resolution nº 3.545/2008 of the CMN (Brasil, 2008). The study applies two-stage estimates (2SLS) for municipalities in the Amazon biome between 2007 and 2011. The study results demonstrate that the increase in the number of fines applied in a given year significantly reduces deforestation in the following year for the same municipality and that the application of fines prevented the deforestation of 122,700 km² of the Amazon biome, reducing the emission of 900 million tCO2 annually.

3. Identification strategy

The first phase of the PPCDAm implemented a system for almost real-time remote monitoring of deforestation in the Brazilian Legal Amazon, in addition to promoting advances in inspection, land ordinance, and delimitation of environmental protection areas and indigenous lands. The municipalities of the Legal Amazon present differences in socioeconomic, cultural, and infrastructure terms. Therefore, we can explore the variability of certain areas of the region, disaggregating these areas into two groups of municipalities. Those municipalities represent the first group with higher population density, higher income, better infrastructure, and close to better quality roads. The second group is municipalities with opposite characteristics, being more isolated and difficult to access regions. An additional source of variability is whether or not indigenous lands exist within the municipalities of these groups. Indigenous lands in Brazil have specific rules regarding the severity of environmental crimes in their domains. Non-metropolitan municipalities and indigenous land areas are more sensitive to the innovations brought by DETER. We can assume that the ratio of characteristics between these groups is maintained over time. Thus, non-metropolitan municipalities with indigenous lands are relatively more affected by PPCDAm than metropolitan municipalities or municipalities without indigenous lands.

We propose to identify the causal effect of PPCDAm on deforestation from 2002 to 2007 between the non-metropolitan municipalities with indigenous lands and the group of other municipalities through the Triple Difference (DDD) method. The main hypothesis of the DDD method is the existence of parallel trends in the outcome variable between the groups of municipalities compared to the pre-intervention period[25]. The method allows the addition of covariates, which can make estimating the causal effect more accurate. In terms of econometric specification, the relationship has the following form:

$$Y_{it} = \beta_0 + \beta_1 * NM_i + \beta_2 * IL_i + \beta_3(NM_i * IL_i) + \lambda_1 * d_t + \lambda_2(d_t * NM_i) + \lambda_3(d_t * IL_i) + \lambda_4(d_t * NM_i * IL_i) + \theta_{it} * X_{it} + \pi_{it} + \varepsilon_{it} \quad (1)$$

where Y_i represents the result variable "increase in the area of deforestation" for the municipality "*i*" of the Brazilian Legal Amazon. The variable NM_i represents a dummy variable identifying the non-metropolitan municipality. The variable IL_i represents a binary variable identifying if the municipality has indigenous lands (lands greater than 0 km²). The variable d_t identifies the period after the implementation of the environmental policy (2004 to 2007). The interaction between the environmental policy treatment variables captures the causal effect of the environmental policy change on the outcome variable. The vector X_i represents the covariates for the municipality. The parameters μ_i and π_t represent the municipal and time-fixed effects, respectively. The magnitudes of the effects are captured by the parameters β, λ, and θ. The parameter ε_{it} represents the error term.

We estimated four different models concerning the vector of covariates considered. The first model considers only municipal fixed effects and time fixed effects. The second model considers the geographic control covariates (*AreaKm2*, *NoForest*, *Hydrography*, *Population*, *UF*, *DistanceCapUF*, *DistanceCapUFSqrd*, *DistanceCapProx* and *DistanceCapProxSqrd*). The third model considers the geographic control covariates and the agricultural and livestock covariates of the municipalities (price indices of agricultural products and *TemporaryTilArea*). Finally, the fourth model considers all the previous covariates and adds the covariates referring to the characteristics of indigenous lands in the municipalities (*ILProportion* and *ILNumber*). All models consider cluster-robust standard errors by the municipality.

[25] The difference-in-differences method has already been adopted in other evaluations of policies to combat deforestation (Arima *et al.*, 2014; Assunção, Gandour, Romero, *et al.*, 2013; Assunção and Rocha, 2019).

4. Data

We utilized seven municipal-level databases for the period from 2002 to 2007. The first database comes from PRODES/INPE and provides annual deforestation rates of municipalities in the Brazilian Legal Amazon. The second database is the Registry of Metropolitan Regions, Urban Agglomerations, and Integrated Development Regions for the year 2010 of the Brazilian Institute of Geography and Statistics (IBGE). The third database is related to the demarcation of indigenous territories and was prospected through the Terras Indígenas no Brasil website. The fourth database is IBGE's Population Estimates (EstimaPop), which provides annual data on population estimates for each municipality. The fifth database was collected from the Secretary of Agriculture and Supply of the State of Paraná (SEAB-PR) of the Department of Rural Economy (DERAL) and provides the prices of agricultural commodities. The sixth database used in the analysis is IBGE's Municipal Agricultural Production (PAM). Finally, the seventh database was extracted from INPE's TerraBrasilis portal, enabling the municipalities to generate geographic coordinates.

To measure the effect of the first phase of the PPCDAm on deforestation, we used the result variable of deforestation increment (*DeforestationIncrement*) from the PRODES/INPE database, which provides an estimate of the annual variation of deforestation[26] in km² for 760 municipalities in the Brazilian Legal Amazon. We considered the period from 2002 to 2007 to identify the effect of introducing the first phase of the PPCDAm from 2004 onwards. A binary variable was created to identify the treatment, assuming a value of one for 2004 to 2007, and zero for the previous years. We estimated the effect of the intervention by the relative differences in *DeforestationIncrement* between non-metropolitan municipalities with Indigenous Lands and the other municipalities for the post-intervention period. For this purpose, we established the interaction between two binary variables. The first binary variable refers to the region of the municipality (*NMetropMunicipality*), assuming a value of one when the municipality is located in a non-metropolitan region and zero if the municipality is located in a metropolitan region. The criterion for identifying the metropolitan region was based on the Registry of Metropolitan Regions, Urban Agglomerations and Integrated Development Regions for 2010 of the Brazilian Institute of Geography and Statistics (IBGE). The second binary variable was collected through data from the *Terras Indígenas no Brasil* ("Indigenous Lands in Brazil") website. It captures the existence of indigenous lands in the municipality approved until 2007 (*ILMunicipality*), assuming a value of one when the municipality has a non-null area of Indigenous Lands (km²) in its domains and zero otherwise. From the interaction of these two variables, we identified non-metropolitan municipalities with Indigenous Lands (*NMetropMunicipalityWIL*), assuming value one when both variables *NMetropMunicipality and ILMunicipality* are equal to one and zero otherwise.

The set of covariates considers geographic and population characteristics, prices of agricultural products, and the predominance of lands and indigenous peoples. These data enable controlling heterogeneous demography and location among the municipality's aspects in the sample. We constructed the municipal covariate's total area in km² (*AreaKm2*), the area of non-forest in the municipality in km² (*NoForest*), the hydrographic area in km² (*Hydrography*), and dummies of the federative units (*UF*) from the PRODES/INPE data. The covariate population (*Population*) indicates the size of the municipality's population in the year, which was obtained by the IBGE's Population Estimates (EstimaPop) database. The agricultural covariates used by Assunção *et al.* (2013) are represented by the price indices of agricultural products deflated for the year 2000. For this, we used the data from the Secretary of Agriculture and Supply of the State of Paraná (SEAB-PR) to create the covariates (i) real price index for rice (*RiceIndex2000*), (ii) real price index for sugarcane (*SugarcaneIndex2000*), (iii) real price index for live cattle (*CattleIndex2000*),

[26] These estimates are calculated by the analysis of images captured between August 1st and July 30th of the following year.

(iv) price index real price index for cassava (*CassavaIndex2000*), (v) real price index for corn (*CornIndex2000*), and (vi) real price index for soybeans (*SoybeanIndex2000*)[27]. We also create the covariates indicating the number of Indigenous Lands in the municipality (*NILNumber*) and the proportion of the sum of the Indigenous Lands area in the municipality in square kilometers (*ILProportion*). We prospected the geographic coordinates of the municipalities through the TerraBrasilis/INPE database to control the heterogeneity of distance of the municipalities to large urban centers. We established the centroid of each municipality and constructed the covariate of the linear distance between the centroid of the municipality and the centroid of the capital of its federative unit (*DistanceCapUF*) and its quadratic term (*DistanceCapUFSqrd*). Furthermore, we constructed the covariate of the linear distance between the municipality and the centroid of the closest capital independent of the state (*DistanceCapProx*) and its quadratic term (*DistanceCapProxSqrd*).

The descriptive statistics of the variables used in this study are shown in Table 1, containing their mean, standard deviation, minimum and maximum statistics.

Table 1 – Descriptive Statistics

Variable	Mean	S.D.	Min	Max
Outcome Variable				
DeforestationIncrement	28.193	80.408	0	1,407.80
Municipalities Types				
NMetropMunicipalityWIL	0.212	0.409	0	1
NMetropMunicipalityWoIL	0.733	0.443	0	1
MetropMunicipality	0.056	0.229	0	1
Covariates				
Population	28,829.34	92,908.65	981	1,688,524
AreaKm2	6,684.467	13,892.57	64	159,540
NoFlorest	1,266.804	2,407.819	0	19,780.8
Hydrography	149.300	431.435	0	4,499.9
DistanceCapUF	324.976	238.172	0	1,485.384
DistanceCapUFSqrd	162,322.9	24,6075.7	0	2,206,364
DistanceCapProx	281.3542	165.651	0	902.557
DistanceCapProxSqrd	106,594.4	113,722	0	814,609.1
RiceIndex2000	216.950	49.782	151.681	296.464
SugarcaneIndex2000	172.397	30.241	123.964	219.615
CattleIndex2000	135.119	12.657	111.244	151.948
CassavaIndex2000	167.483	72.805	67.912	284.257
ÍndiceMilho2000	137.555	14.410	119.748	164.541
SoybeanIndex2000	182.313	25.918	151.652	220.662
ILNumber	0.522	1.457	0	14
ILProportion	0.049	0.140	0	0.999

Notes: Descriptive state statistics have been omitted for space considerations. The municipality types presented in this table are the group of non-metropolitan municipalities with indigenous lands (NMetropMunicipalityWIL), the group of non-metropolitan municipalities without indigenous lands (NMetropMunicipalityWoIL), and metropolitan municipalities (MetropMunicipality).

[27] Four municipalities that did not have agricultural data in the PAM database were excluded, resulting in a sample of 756 municipalities.

5. Results

5.1. Main Analysis

The hypothesis of identification of the triple differences method assumes the existence of parallel trends between the analyzed groups. The results of the statistic test for this identification hypothesis demonstrate that we can accept the hypothesis that the groups show parallel trends in the period before the intervention, presenting an F statistic of 1.91 with a probability of approximately 20%[28]. Table 2 presents the results of the main analysis of the effects of the first phase of the PPCDAm from 2004 on the deforestation increment in the Brazilian Legal Amazon. We estimate four different models.

In table 2, all models present effects with at least 5% confidence significance. Column 1 results indicate that the PPCDAm implied a reduction in the deforestation increment of 15.3 km² (p-value < 0.05) per municipality on average. After adding covariates, the results in Columns 2, 3, and 4 indicate a reduction in deforestation increment of approximately 16.1 km^2 (p-value < 0.05). This result represents an average annual reduction in deforestation between 2,452 and 2,573 km² in the Brazilian Legal Amazon per municipality. It corresponds to a total reduction between 9,807 and 10,293 km² from 2004 to 2007[29].

Table 2 - Effect of the first phase of PPCDAm 2002-2007

	(1)	(2)	(3)	(4)
DDD Effect	-15.324**	-16.083**	-16.083**	-16.069**
	(6.709)	(6.761)	(6.761)	(6.762)
Cov. Demographics	NO	YES	YES	YES
Cov. Agropecuary	NO	NO	YES	YES
Charact. Indig Lands	NO	NO	NO	YES
FE Municipalities	YES	YES	YES	YES
FE Time	YES	YES	YES	YES
N	4,536	4,536	4,536	4,536

Notes: This table presents the results for the triple difference regressions. The symbols *, ** and *** represent statistical significance of 10%, 5% and 1%, respectively. Column 1 presents the results for the model controlling for municipal and temporal fixed effects. Column 2 presents the results for the model controlling for fixed effects and demographic covariates. Column 3 presents the results for the model controlling for fixed effects, demographic covariates, and agropecuary covariates. Column 4 presents the results for the model controlling for fixed effects, demographic covariates, agropecuary covariates, and characteristics of indigenous lands covariates. The values in parentheses are standard deviations of the coefficient. Covariate coefficients were omitted for space considerations.

Assunção, Gandour and Rocha (2015) report a 56% reduction in deforestation in the Amazon between 2005 and 2009. Also, in line with these results, Soares-Filho *et al.* (2010) identify that the expansion of protected areas, especially indigenous lands, led to a decline in deforestation from 1997 to 2008. Arima *et al.* (2014) indicate that the increase in inspections in priority municipalities through the Ordinance MMA nº 28/2008 resulted in an average annual reduction in deforestation between 2,304 and 10,653 km^2 between 2009 and 2011. In another study, Assunção and Rocha (2019) identified that the MMA Ordinance nº 28/2008 avoided the deforestation of 11,396 km² in the priority municipalities between 2008 and 2011. In this sense, our results are within the range of those of Arima et al. (2014) and Assunção and Rocha (2019). They indicate that the first phase of the PPCDAm was successful in the environmental protection of municipalities with indigenous lands.

[28] The test was performed with cluster-robust standard errors by the federative unit.

[29] We consider the 160 non-metropolitan municipalities with indigenous lands in the sample.

6. Robustness analyzes

6.1. Placebo tests

We conducted placebo tests to check the robustness of the results found. The placebo test checks whether the estimated treatment effect occurred by chance. Thus, the results of these tests should be statistically non-significant. This test allows checking whether the results are related to the treatment effect or the time trajectory of the variable of interest. Thus, we performed the placebo test for the treatment period and the outcome variable.

Table A1 (Appendix) reports the results of the placebo tests. Columns 1 and 2 report the results of the placebo test on the variable identifying the treatment period for the first phase of the PPCDAm using the year 2003 as a placebo. There should be no effect for the previous period as the Law was implemented in 2004. Columns 3 and 4 show the results of the placebo test for the outcome variable. For that, the effect on the area of the permanent farming variable was analyzed instead of the deforestation increment. The objective is to test whether implementing policies to combat deforestation impacted other outcome variables unrelated to treatment. We expect no effects considering that this variable is not related to deforestation[30]. These tests verify that the effects found were not type I errors. The results of the placebo tests shown in Table A1 were not statistically significant, indicating that the effects identified in the main analysis (Table 2) did not occur by chance.

6.2. Heterogeneous analysis

We want to verify the heterogeneous effects of the policy each year after its application. Thus, we perform a heterogeneous analysis for the policy applied from 2004 onwards, identifying its effect for each year after its implementation. All estimated values are within the 95% confidence interval, and we used cluster-robust standard errors[31]. Table A2 (Appendix) presents the significant heterogeneous temporal effects. Columns 1, 2, and 3 present 2005, 2006, and 2007, respectively. We identified a reduction of approximately 13.2 km² (p-value < 0.1) in 2005. In 2006 and 2007, more significant effects were identified (p-value < 0.01), resulting in reductions in the deforestation increment of 24.9 km² and 23.8 km², respectively. A possible explanation for the lack of effect in 2004 would be the existence of an adaptation period on the part of the agents for the assimilation of the policy due to the DETER's remote aspect.

6.3. Flexibility in the composition of groups

We want to test the robustness of the treatment variable municipalities for different proportions of indigenous lands in its territorial composition (*ILProportion*). Thus, we propose to limit the group of non-metropolitan municipalities with Indigenous Lands according to the percentile of the variable *ILProportion*. In addition to the original model (independent of *ILProportion*), three new DDD models were established considering non-metropolitan municipalities with Indigenous Lands with *ILProportion* (i) equal to or above 25%, (ii) equal to or above 50%, and (iii) equal to or above 75%. Additionally, we performed the Wald test to verify the null hypothesis of equality between the coefficients associated with the DDD effect of the four models.

The estimations are presented in Table A3 (Appendix). Column 1 presents the result for the model with the treatment variable independent of the *ILProportion* (main analysis estimates), Column 2 presents

[30] According to Assunção, Gandour and Rocha (2015), rice, sugarcane, cassava, corn and soybean (temporary) harvests corresponded to approximately 70% of the harvest in the region between 2002 and 2009.
[31] We cluster the subjects in the municipal level

the result of the treatment variable considering the *ILProportion* equal to or above 25%, and Column 3 presents the result for the treatment variable considering the ILProportion equal to or above 50%. Column 4 presents the result for the treatment variable considering the *ILProportion* equal to or above 75%. Wald test indicates whether the treatment effect considering different compositions of *ILProportion* are equal. Columns 1 to 3 show effects with significance up to 5%, and Column 4 shows an effect with significance up to 10%. The Wald test presents a χ^2 statistic of 0.55 with 3 degrees of freedom. The p-value of 0.907 demonstrates the non-rejection of the null hypothesis and indicates statistical equality between the treatment effect coefficients of the four regressions.

7. Political Considerations

Quantifying the effect of the PPCDAm policy on deforestation is fundamental for understanding such policies' real impact, enabling future strategies' design and improvement. It is possible to identify the amount of deforestation avoided in the Brazilian Legal Amazon through the causal effect of the policy. From that, we can calculate the volume of carbon stock in tons in carbon dioxide emissions per square kilometer (tCO2/km²)[32]. The Amazon Fund (2012) began to estimate the CO_2 emissions in the Brazilian Legal Amazon, resulting from the difference between the historical average rate of deforestation and the deforestation rate in the year under evaluation multiplied by the amount of carbon present in biomass, measured in tons of carbon per hectare (tC/ha). Since 2012 the entity has adopted the reference value of 132.2 tC/ha of Amazon forest, equivalent to 48,473 tCO_2/km^2 [33].

According to the results identified in Table 2, we estimate that the conservation of approximately 10,293 km² caused by the introduction of the first phase of the PPCDAm in the course of 2004 to 2007 provided an additional stock of 498 million tCO_2 [34]. It represented a value of approximately U$ 2.5 billion[35]. We evaluate the PPCDAm annual cost two with two approaches. First, using the budget for actions to combat deforestation for 2004 (R$ 394 million)[36] as a reference, presenting an average annual cost of 0.97 U$/tCO2. Second, considering the main instruments to combat deforestation during the period, which belongs to the monitoring and control axis, is mostly represented by IBAMA's and DETER's budget. According to IBAMA's total annual budget and INPE's Cost and Capital Budget (OCC), the average annual cost could potentially be 3.54 U$/tCO2 from 2004 to 2007. We calculate that the PPCDAm generated a potential profit between U$ 737 million and U$ 2 billion.

8. Final considerations

The debate around climate change, the preservation of biodiversity, and the integrity of indigenous gained prominence again with the recent advance in the Brazilian Legal Amazon's deforestation rate. However, the Brazilian Amazon region experienced a drastic reduction in deforestation rates between 2004 and 2012. Therefore, understanding how public policies have affected deforestation in the region is essential for preserving the Amazon rainforest.

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[32] The parameters presented by the IPCC 2006 Guidelines for National Greenhouse Gas Inventories (Eggleston *et al.*, 2006) are frequently used to estimate the loss of carbon stocks resulting from deforestation, using aspects such as the loss of forests, the ratio of belowground to aboveground biomass, the carbon fraction of dry matter and the conversion factors for the tree species.

[33] According to the 2012 Amazon Fund's Annual Activity Report, the value of 100 tC/ha is equivalent to 367 tCO_2/ha.

[34] We consider the conversion factor of 48,473 tCO_2/km^2.

[35] We consider the standard price of 5 U$/$tCO_2$ commonly used at the time (Assunção, Gandour, and Rocha 2013; Fundo Amazônia 2012).

[36] We assume a budget growth for the following years in the same proportion as that observed in IBAMA's budget in the same period. The dollar amounts have been corrected according to the free exchange rate of the US Dollar (sale) for each year.

This study aimed to analyze the effects of PPCDAm on deforestation in the Brazilian Legal Amazon. We explored the variability between the regional municipalities' characteristics through the triple difference method when comparing the annual increase in deforestation between non-metropolitan municipalities with indigenous lands and other municipalities in the Brazilian Amazon.

This article innovated the literature in several ways. First, the article innovates by identifying the causal effect of PPCDAm for the period between 2004 and 2007. Furthermore, it innovates methodologically by using the triple difference method to assess the effect of PPCDAm on deforestation. The article also presented new evidence on the effectiveness of initiating the PPCDAm in safeguarding the forest in municipalities with indigenous lands in the Amazon and explored sources of variation such as the number of indigenous lands and the proportion of indigenous land area in the municipalities.

The results showed a reduction of potentially 10,293 km² in deforestation of non-metropolitan municipalities with indigenous lands between 2004 and 2007. Additionally, the analysis of heterogeneous effects indicated that the policy became more effective after 2005. Our estimates regarding the effects on carbon emissions indicate the retention of 498 million tCO2 in the carbon stock resulting from forest preservation. Our cost-benefit analysis shows that the program had a profit of at least $737 million in the period, suggesting that the policy was also financially efficient.

We identify that the institutional changes promoted by the PPCDAm in favor of environmental crime monitoring in the Amazon, such as the improvement of remote monitoring of deforestation spots resulting from the introduction of DETER, were significant for reducing deforestation in municipalities isolated from large urban centers. Regarding the limitations of this study, the databases used do not allow classifying the types of environmental crimes that cause the levels of deforestation observed in the municipalities. Additionally, the population size of indigenous lands was not considered due to the lack of population data for several isolated peoples. We recommend the application of new methodologies for isolating the causal effect of PPCDAm on deforestation rates in Amazonian municipalities may be relevant, as well as new analysis to verify the efficiency of different policies that reinforce the environmental surveillance and monitoring of indigenous lands and isolated municipalities.

Disclosure statement

The authors declare that there is no conflict of interest.

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Appendix

Table A1 - Placebo Tests

	(1)	(2)	(3)	(4)
Placebo DDD Effect	0.656 (11.936)	-0.096 (22.899)	0.346 (0.860)	0.020 (0.942)
Fixed Effects	YES	YES	YES	YES
Covariates	NO	YES	NO	YES
N	4,536	4,536	4,536	4,536

Note: The symbols *, ** and *** represent statistical significance of 10%, 5% and 1%, respectively. Columns 1 and 2 presents the results of the placebo test on the variable identifying the treatment period for the first phase of the PPCDAm using the year 2003 as a placebo. Columns 3 and 4 presents the results of the placebo test using the municipality's permanent crop area as the result variable. Covariate coefficients were omitted for space considerations.

Table A2 - Heterogeneous Effects Analysis

	(1)	(2)	(3)
DDD Effect	-13.159* (6.975)	- 24.926*** (8. 217)	-23.814*** (8.829)
Fixed Effects	YES	YES	YES
Covariates	YES	YES	YES
N	4,536	4,536	4,536

Note: The symbols *, ** and *** represent statistical significance of 10%, 5% and 1%, respectively. Columns 1, 2, and 3 present the results for the analysis of heterogeneous effects for the years 2005, 2006, and 2007, respectively. Covariate coefficients were omitted for space considerations. No significant effect was identified for the year 2004.

Table A3 - Effect of PPCDAm conditioned to IL Proportion

	(1)	(2)	(3)	(4)
	ILProportion > 0%	ILProportion > 25%	ILProportion > 50%	ILProportion > 75%
DDD Effect	-16.069** (6.762)	-19.211*** (6.737)	-20.398** (8.599)	-15.900* (8.766)
Fixed Effects	YES	YES	YES	YES
Covariates	YES	YES	YES	YES
N	4,536	4,536	4,536	4,536
Wald Test		0.55		
(p-value)		(0.907)		

Note: The symbols *, ** and *** represent statistical significance of 10%, 5% and 1%, respectively. Columns 1 to 4 present the results for the analysis with the treatment variable considering non-metropolitan municipalities with indigenous lands with the TI *Proportion* above 0%, 25%, 50%, and 75%, respectively. The Wald test verifies the null hypothesis of equality between the coefficients of the four models. The Wald test statistic is distributed as χ^2. Covariate coefficients were omitted for space considerations.