THE EFFECT OF RURAL CREDIT RESTRICTION ON FIRE FOCUS IN BRAZILIAN AMAZON BIOME

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RESUMO
Este artigo tem como objetivo analisar o efeito das políticas de restrição de crédito rural implementadas com a Resolução 3.545/2008 sobre os incêndios florestais do Bioma Amazônia. Tal resolução restringiu o acesso ao crédito rural aos produtores do Bioma Amazônia que estivessem seguindo as leis de preservação ambiental instituídas pelos órgãos ambientais brasileiros. Para mensurar o impacto da politica de restrição de crédito rural, utilizou-se a abordagem diferenças em diferenças em um painel de dados com informações mensais dos grupos de tratamento e controle entre 2005 e 2020. Os resultados encontrados permitem concluir que o impacto da Resolução 3.545/2008 sobre os incêndios florestais do Bioma Amazônia foi positivo, pois as estimativas indicam uma redução dos incêndios florestais desde o período em que a política foi implantada até o final do período de abrangência desse estudo.
Palavras chaves: Incêndios florestais. Restrição de crédito. Bioma Amazônia
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Classificação JEL: Q14, Q23, Q28.

ABSTRACT
This article aims to analyze the effect of rural credit restriction policies implemented with Resolution 3,545/2008 on forest fires in the Amazon Biome. This resolution restricted access to rural credit to producers in the Amazon Biome who were following the environmental preservation laws instituted by Brazilian environmental agencies. To measure the impact of the rural credit restriction policy, the differences in differences approach was used in a panel of data with monthly information on the treatment and control groups between 2005 and 2020. The results found allow us to conclude that the impact of Resolution 3,545 /2008 on forest fires in the Amazon Biome was positive, as estimates indicate a reduction in forest fires from the period in which the policy was implemented until the end of the period covered by this study.
Key words: Forest fires. Credit restriction. Amazon Biome
JEL Classification: Q14, Q23, Q28.

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1 INTRODUCTION

The public and scientific debate on the management of forest fires has been a recurring theme in several countries around the world, as these fires cause different adverse impacts on the quality of life of a population. In the health area, for example, studies document the existence of a direct positive relationship between forest fires and mortality from various causes, especially due to respiratory problems (RIBEIRO; ASSUNÇÃO, 2002; GONÇALVES; CASTRO; HACON, 2012; YOUSSOUF *et al.*, 2014; LIU *et al.*, 2015; REID *et al.*, 2016; BLACK *et al.*, 2017; CASCIO, 2018; CONCEIÇÃO *et al.*, 2020; MARLIER; BONILLA; MICKLEY, 2020). Thus, it can be said that forest fires also cause negative impacts on the economy, since, when the incidence of diseases increases, public spending on treatments is expected to increase.

In the environmental area, forest fires cause numerous adverse indirect effects, driving climate change through increased greenhouse gas emissions (WERF *et al.*, 2010; AKAGI *et al.*, 2011; WIEDINMYER *et al.*, 2011; URBANSKI, 2014). As a result of the risks posed by climate change, such as warming, heat waves, precipitation, drought, floods, storms, sea level rise and changes in natural land cover and ocean chemistry, risks to human health, quality water supply, food production, infrastructure and the security of families affected by the floods also increase (MORA *et al.*, 2018). Therefore, all these indirect effects generated by forest fires also have negative impacts on the economy of a region.

Having said that, it is necessary to draw attention to the fact that the great direct and indirect effects caused by forest fires represent an important threat to humanity, as the increase in these fires promotes the intensification of various hazards, to which the population is vulnerable. Thus, the formulation of public policies that seek to mitigate or control fires is essential to contain their harmful effects.

In the context of public policies, access to rural credit is an important source of financing for Brazilian agriculture, as well as an important policy instrument in the country (ASSUNÇÃO *et al.*, 2020). However, if the resource obtained by farmers is used to increase rural production by changing land use and forests, the greater availability of credit is likely to lead to an increase in forest fires as forest areas are deforested and burned, to be converted into agricultural land. Thus, access to rural credit emerges as an important mechanism to control the actions of farmers, regarding their environmental practices.

Given this scenario, with the main purpose of associating rural credit with good environmental practices and environmental preservation in rural activities in the Amazon Biome, the National Monetary Council (CMN) made some changes to the Brazilian legislation that regulates rural credit. Through Resolution 3,545/2008, agricultural financing credit for the Amazon Biome became conditional on the presentation of documentation proving the property's environmental regularity. Therefore, in 2008, in the Amazon Biome, access to rural credit was limited to producers who were following the environmental preservation laws established by Brazilian environmental agencies. The main implication of imposing this restriction is the loss of competitiveness of producers who do not have the requirements to obtain credit, making rural producers in the Amazon Biome more likely to adhere to environmental preservation laws.

Regarding empirical evidence, the literature dealing with the effects of Resolution 3,545/2008 is quite scarce. Using econometric techniques, the work of Assunção *et al.* (2020) is the only evidence found that tests the impact of the rural credit restriction provided by Resolution 3,545/2008 on deforestation in the Amazon.The authors use the differences-in-differences model and compare the municipalities of the Amazon Biome, which received the policy, with the neighboring municipalities, but which do not participate in the policy. The results found indicate that Resolution 3,545/2008 led to a reduction in deforestation, especially in municipalities where livestock is the main economic activity. In addition, Assunção *et al.* (2020) show that R$2.9 billion of rural credit was not contracted between 2008 and 2011, due to the restrictions imposed by the measure. This credit reduction prevented the deforestation of approximately 2,700 km^2 of forest area, which represents a 15% reduction in deforestation in the period. That said, this work seeks to contribute to the national literature by studying the impact of restricting access to rural credit on fire outbreaks in the Amazon Biome.

Although the main focus of the policy to restrict access to rural credit is to contain deforestation in the Amazon Biome, the levels of forest fires in the region can also be affected by the policy. This is because burning is a technique widely used by farmers to clean pastures and deforested areas and to prepare the soil before planting (BREDER; LOBOSCO; MOURA, 2020; FLOR, 2022). Thus, by reducing deforestation levels and improving environmental practices, a reduction in fires in the Amazon Biome is expected. Therefore, this article aims to analyze the effect of the policy of restricting access to rural credit implemented with Resolution 3,545/2008 on forest fires in the municipalities of the Amazon Biome. The hypothesis to be tested admits that the restrictions imposed on access to rural credit are contributing to contain forest fires in the Amazon Biome.

To test this hypothesis, the fact that Resolution 3,545/2008 is applied only to rural establishments belonging to the Amazon Biome is used, so that properties outside the biome are not subject to the impositions of the policy. Based on the identification strategy used in the article by Assunção *et al.* (2020), the external border of the Amazon Biome is considered as a control group to assess the policy of restricting rural credit within the biome. This feature was explored through a differences in differences approach. As the Amazon region is large and potentially heterogeneous due to unobservable variables, only border municipalities are considered. In the main identification strategy of this article, the treatment group is defined taking into account the municipalities that belong to the Amazon Biome and that are located exactly on the inner edge of the biome. The control group, on the other hand, is formed by municipalities that are not contained in the Amazon Biome, but are located exactly on the inner edge of the biome. A second strategy to identify the treatment and control groups considered all the municipalities of the first strategy and the municipalities whose territorial limits are occurring on the edge of the municipalities of the Brazilian border of the Amazon Biome.

To estimate the differences-in-differences model, monthly information from 283 municipalities was used between January 2005 and December 2020. The data that measure forest fires are unprecedented and were constructed from fire alerts from National Aeronautics and Space Administration (NASA, 2021). A set of control variables were also used, which are better described in the methodology section. To show that the control and treatment groups, defined by the two identification strategies used in this article, are comparable to each other, the mean difference test was used with regard to the covariates. This test was carried out in the pre-treatment period and found that most of the defining characteristics of the municipalities are not significantly different between the two groups defined by the two identification strategies and, therefore, it can be expected that the two groups, treated and control , are comparable to each other.

The results found indicate that the restrictions on access to rural credit imposed by Resolution 3,545/2008 helped to reduce forest fires in the Amazon Biome from the period in which the policy was implemented until the end of the period covered by this study. Although this effect is relatively small, it is important to emphasize that this result occurs at a low economic cost to the public sector, which allows us to infer that resolution 3545/2008 contributes to the reduction of fires in the Amazon Biome in an economically efficient way. Robustness tests validate the empirical strategy and corroborate the results.

In terms of organization, this article is divided into five parts, which includes this introduction. Section 2 describes aspects of Resolution 3,545/2008. Section 3 details the empirical model and the research database. At the end, Section 4 and Section 5 present the main results and final considerations, respectively.

2 INSTITUTIONAL CONTEXT

This section seeks to present the institutional context in which Resolution 3,545/2008 was created, which, as mentioned above, limited access to rural credit to rural producers in the Amazon Biome who practiced good environmental practices. To understand resolution 3,545/2008, it is necessary to know some concepts about the structure and agencies that make up the financial system in Brazil and that have autonomy over the definition of credit policies in the country. The highest deliberative body of the Brazilian national financial

system is the National Monetary Council (CMN), whose main objective is to ensure the stability of the purchasing power of the national currency. The CMN is responsible for defining the details of the national monetary policy and policies related to interest and credit rates [1] .

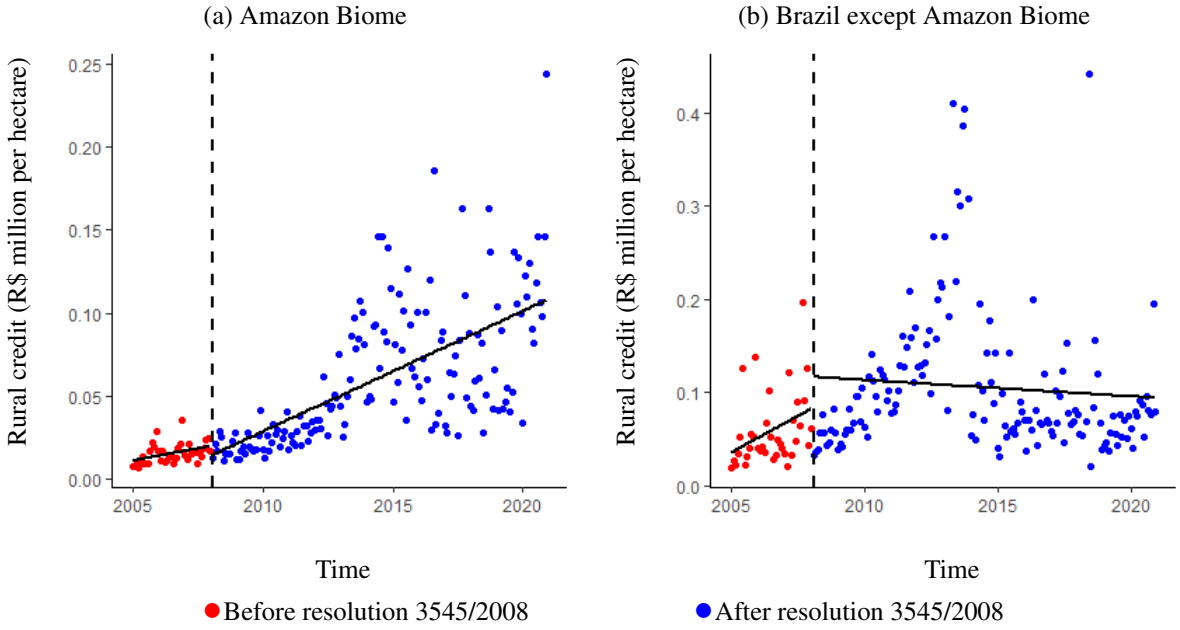
Therefore, any credit-related policy in Brazil must be previously approved by the members of the CMN. Thus, Resolution 3,545/2008 is a set of changes made by the CMN to the Brazilian legislation that regulates the granting of rural credit for the execution of agricultural activities in the national territory. It is important to highlight that rural credit was regulated in Brazil through Law N^o 4829/1965 [2], whose main objective was to institute and determine the legislation necessary for the implementation of a special credit regime for rural producers in Brazil. Resolution 3,545/2008 was instituted for all rural properties in the Amazon Biome on February 29, 2008. The application of the terms of the resolution by credit agencies was optional as of May 1, 2008, becoming mandatory as of 1st of July 2008.

The main objective of Resolution 3,545/2008 was to associate rural credit with good environmental practices and environmental preservation in rural activities in the Amazon Biome. More specifically, Resolution 3,545 established that, in order to prove eligibility for access to rural credit, the beneficiary must present a certificate of registration of a rural establishment, in order to meet the legal requirements for titling. This registration proves that the property that will house the project to be financed is duly registered in the federal registry offices and that the document issued by the State attesting to the environmental regularity of the establishment where the project to be financed is located, as well as the declaration attesting that the property was not under embargoes arising from illegal deforestation. According to Assunção *et al.* (2020), in the Amazon, embargoes are an administrative sanction that can be applied to landowners as a punishment for illegal deforestation within private property. Therefore, the embargoed areas cannot be used for productive use. All requirements applied not only to landowners, but also to associates, sharecroppers and tenants. The main implication of this restriction for the granting of rural credit is the loss of competitiveness of producers who do not have the requirements to obtain rural credit, making rural producers in the Amazon Biome more likely to adhere to environmental preservation laws.

Thus, in fact, the implementation of resolution 3,545/2008 caused a structural change in Brazilian rural credit resulting from changes in the concession rules for financing activities carried out in rural establishments in the Amazon Biome. Figura 1 shows the change in the linear trend of rural credit in Brazil for the periods before and after the creation of resolution 3545/2008. It is possible to observe that, initially, there was a decrease in the trend of rural credit in the Amazon Biome and an increase in the trend in the rest of Brazil. However, in the months following the creation of resolution 3545/2008, the linear trend is increasing in the Amazon Biome and decreasing in the rest of Brazil. Given the mandatory compliance with environmental preservation rules in the Amazon Biome, established by the resolution, this growing trend may provide evidence that rural producers in the Amazon Biome have adhered to these laws, since the volume of rural credit granted to these producers has grown since the intervention period.

[1] See <https://www.gov.br/fazenda/pt-br/assuntos/cmn>.
[2] See (FEDERAL GOVERNMENT OF BRAZIL, 1965).

Figura 1: Linear trends for rural credit.



Source: Own elaboration based on data from (BCB, 2021).

In empirical terms, the literature dealing with the effects of Resolution 3,545/2008 is quite scarce. In this line of investigation, the work of Assunção *et al.* (2020) is the only evidence found that tests the impact of the rural credit restriction provided by Resolution 3,545/2008 on deforestation in the Amazon. The authors use the differences-in-differences model and compare the municipalities of the Amazon Biome, which received the policy, with the neighboring municipalities, but which do not participate in the policy. The results found indicate that Resolution 3,545/2008 led to a reduction in deforestation, especially in municipalities where livestock is the main economic activity. In addition, Assunção *et al.* (2020) show that R$2.9 billion of rural credit was not contracted between 2008 and 2011, due to the restrictions imposed by the measure. This credit reduction prevented the deforestation of approximately 2,700 km^2 of forest area, which represents a 15% reduction in deforestation in the period.

Given this scenario, it is expected that, in the same way that the greater adhesion to rural credit by producers in the Amazon Biome has negatively impacted deforestation levels, it will also have a negative impact on forest fires in the region.

3 METHODOLOGY

3.1 Data

The data used in this section are monthly and were extracted from different sources. The database has a total of 283 municipalities, with information between January 2005 and December 2020. The database is composed of an unbalanced panel, with a total of 53,420 observations. The choice of this period for analysis is justified by the fact that the imposition of restrictions on access to rural credit by Resolution 3,545/2008 began in 2008. Thus, when considering this time interval for analysis, it is possible to compare the levels of fires forests in the treatment and control municipalities, in periods before and after the implementation of the resolution.

The territorial division and the territorial limits used are based on the cartographic grids of the Brazilian Institute of Geography and Statistics (IBGE). It is also important to highlight that all variables based on financial values were updated to December 2020 values, by the Broad Consumer Price Index (IPCA).

The dependent variable in this article is the number of fires per municipality. To create this variable, fire alerts provided by (NASA, 2021) were used, which were identified using an innovative strategy. Each fire focus in this database is georeferenced according to a geographic coordinate (latitude and longitude) of the centroid of the fire occurrence area. The information has the date and time of the fire, which allows calculating the number of fires in different periods. With this information, geoprocessing techniques were used to count the number of fire outbreaks located in the territory of each municipality for each month, between January 2005 and December 2020. Fire outbreaks located exactly on the border of two municipalities were disregarded.

The variables of interest, which capture the effects of Resolution 3,545/2008 on forest fires, are the following dummies:

- **Treatment 1:** assumes value 1 if the municipality belongs to the Amazon Biome and is located on the edge of the biome and zero if the municipality is located on the edge of the biome, but does not belong to the Amazon Biome;
- **Treatment 2:** assumes value 1 if the municipality belongs to the Amazon Biome and is located on the edge of the biome or if it borders a municipality that belongs to the Amazon Biome and is located on the edge of the biome; and zero if the municipality is located on the edge of the biome, but does not belong to the Amazon Biome or if it borders a municipality located on the edge of the biome, but does not belong to the Amazon Biome.

The variables that seek to control the observable characteristics of the municipalities under analysis are the following:

- **Rural credit per cultivated land:** is the ratio between the sum of total rural credit and total cultivated land in the municipality BCB (2021).
- **Protected areas:** is a variable dummy that takes the value 1 if the municipality has an area demarcated by the Ministry of the Environment as an environmental protection area and zero otherwise. The informations for building this variable is available at TerraBrasilis (2021).
- **Indigenous Area:** is a dummy variable that takes the value 1 if the municipality has an area demarcated by the Ministry of the Environment as an indigenous area and zero otherwise. The informations for building this variable is available at TerraBrasilis (2021).
- **Environmental embargoes:** is the number of environmental embargoes. The informations for building this variable is available at IBAMA (2021).
- **Environmental fines:** is the number of environmental fines distributed by protected assets. The informations for building this variable is available at IBAMA (2021).
- **Corn price:** is the average monthly price of a 60-kilogram bag of corn in the state of Paraná. The informations for constructing this variable is available in CEPEA (2021).
- **Fat ox's at sign price** Average monthly price for the fat ox's at sign in the state of Paraná . The Informations for constructing this variable is available in CEPEA (2021).
- **Soybean price:** is the average monthly price of a 60-kilogram bag of soybeans in the state of Paraná. The informations for constructing this variable is available in CEPEA (2021).

- **Rainfall (mm):** is the total rainfall in millimeters. The informations for building this variable is available at Camarillo-Naranjo *et al.* (2019).
- **Temperature ($\circ C$):** is the average temperature in degrees Celsius. The informations for building this variable is available at Camarillo-Naranjo *et al.* (2019).
- **Temperature deviation from average:** is the difference between the monthly average temperature and the annual average temperature for each municipality. The informations for building this variable is available at Camarillo-Naranjo *et al.* (2019).
- **Temperature deviation from the minimum:** is the difference between the monthly average temperature and the annual minimum temperature for each municipality. The informations for building this variable is available at Camarillo-Naranjo *et al.* (2019).
- **Temperature deviation from the maximum:** is the difference between the monthly average temperature and the annual maximum temperature for each municipality. The informations for building this variable is available at Camarillo-Naranjo *et al.* (2019).
- **Deviation of precipitation from the average:** is the difference between the average monthly precipitation and the average annual precipitation for each municipality. The Informations for building this variable is available at Camarillo-Naranjo *et al.* (2019).
- **Deviation of precipitation from the minimum:** is the difference between the average monthly precipitation and the minimum annual precipitation for each municipality. The informations for building this variable is available at Camarillo-Naranjo *et al.* (2019).
- **Deviation of precipitation from the maximum:** is the difference between the average monthly precipitation and the maximum annual precipitation for each municipality. The informations for building this variable is available at Camarillo-Naranjo *et al.* (2019).

A detailed justification for using each of the control variables is given in the following subsection.

3.2 Identification Strategy

The identification strategy is a way of identifying and selecting only comparable individuals from a sample so that it is possible to obtain estimates that reliably represent the true coefficients. In this work, the identification strategy aims to select a group of municipalities that benefited from the credit restriction policy (treatment group) and a group of municipalities similar to the treatment group, but which, however, did not benefit from the credit restriction policy (control group). It is important to highlight that all municipalities located in the Amazon Biome benefited from Resolution 3,545/2008.

However, to measure the effect of this policy on the variables of interest, it is necessary to select, among the treaties, only those municipalities that have at least one other correspondent in the control group. In this selection process, Assunção *et al.* (2020) considers that the municipalities that are outside the Amazon Biome, but that are located close to the border of the biome, have the same characteristics as the municipalities that are contained in the Amazon Biome and that these municipalities can be considered for a possible comparison group.

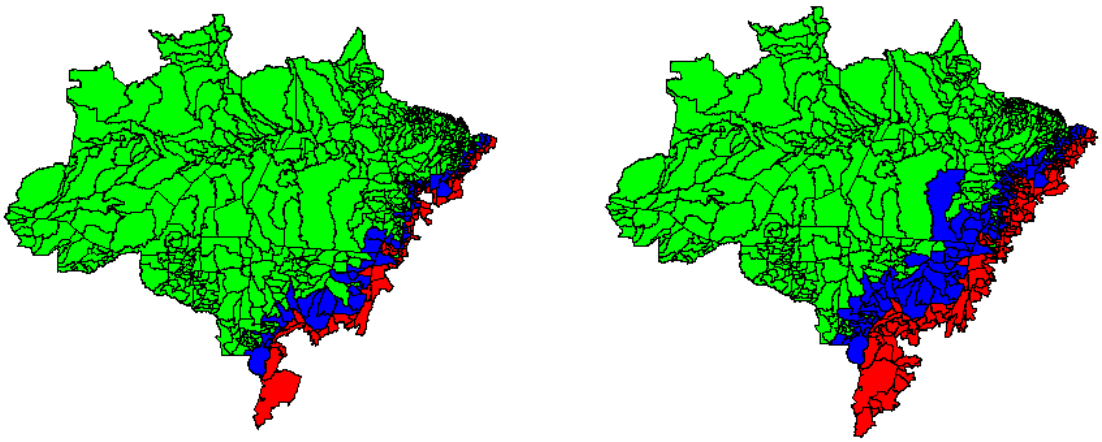
Based on this premise, the treatment group of this study considers the municipalities that belong to the Amazon Biome and that are located exactly on the inner edge of the biome. On the other hand, the control group is composed of municipalities that are not contained in the Amazon Biome, but which, however, are located exactly on the inner edge of the biome.

To improve the robustness of the results found, a second strategy for identifying treatment and control groups was considered. In this case, all the municipalities mentioned above and the municipalities whose territorial limits are occurring on the edge of the municipalities of the Brazilian border of the Amazon Biome were considered. The Figura 2 below shows which municipalities are considered in the treatment and control groups in the two cases analyzed.

Figura 2: Definition of treatment and control groups

(a) First identification strategy

(b) Second identification strategy



Source: Own elaboration.

3.3 Measurement of effects

To measure the effect of treatment on forest fires in the Amazon Biome, the difference-in-differences model was used. Let Y_{it} be the number of forest fires for each square kilometer in the municipality i in the month t, let D_{it} be a binary variable that takes the value 1 if the municipality i belongs to the group of treatment in month t and zero otherwise and let T be a binary variable with value 1 if month t occurs after the implementation of resolution 3.545/2008 and zero otherwise, the model of differences in differences can be written as the Equação 1:

$$Y_{it} = \alpha_i + \beta_1 T + \beta_2 D_{it} + \beta_3 T * D_{it} + \theta X_{it} + \varepsilon_{it} \quad (1)$$

Where X is a matrix of control variables and θ is a vector of unknown parameters, α_i measures the individual fixed effects of municipalities and β_1, β_2 and β_3 are unknown parameters that will be estimated. The treatment effect occurs according to the following Tabela 1:

Tabela 1: Treatment effects according to the differences in differences model

	Before	**After**	**After - Before**
Control	α	$\alpha + \beta_1$	β_1
Treatment	$\alpha + \beta_2$	$\alpha + \beta_1 + \beta_2 + \beta_3$	$\beta_1 + \beta_3$
Treatment -Control	β_2	$\beta_2 + \beta_3$	β_3

Source: Own elaboration.

To reduce the effects of heterogeneity in the parameters, the differences-in-differences model was estimated considering fixed effects of time and municipality. These heterogeneities may result from unobservable and time-invariant facts, such as, for example, the political skills of the municipal manager.

It is important to highlight which variables compose the vector X of control variables and how these variables act to reduce the bias of the estimate. In order to reduce the bias of incentives to forest fires caused by profitability in agriculture and livestock, the average monthly prices of corn, soybeans and arroba of cattle provided by the Center for Advanced Studies in Applied Economics of the University of São Paulo were used (**??**).

According to Assunção, Gandour & Rocha (2015) and Assunção *et al.* (2020), agricultural prices are endogenous to local agricultural production and environmental degradation caused by local economic activities. To correct this problem, these authors suggest the creation of a variable that captures exogenous variations in the demand for agricultural commodities produced locally. To this end, Assunção, Gandour & Rocha (2015) and Assunção *et al.* (2020) suggest using price series for commodities produced outside the study area, but which are still affecting local production, however, in an exogenous way. Thus, following the strategy of Assunção *et al.* (2020), monthly quotations of corn, soybeans and Fat ox's were used referring to the state of Paraná, located in the southern region of Brazil.

To control the bias caused by the financial incentive to environmental degradation and forest fires, the total value of rural credit per capita for each municipality and each month was included in the estimates. These data are available at BCB (2021). As a result, a variable was included that identifies whether the municipality has environmental protection areas, another variable that shows whether the municipality has any territory demarcated as indigenous areas, and another variable that indicates whether the municipality is part of the list of municipalities with priority in the distribution of resources and in the implementation of policies to combat deforestation [3].

To control the bias caused by government interventions in environmental actions, two control variables were considered. The first is the number of fines imposed on environmental degradation actions, while the second corresponds to the number of embargoes carried out as a result of actions harmful to the environment. To reduce the bias caused by climate change, the monthly rainfall and the monthly average temperature of each municipality in the sample were considered. Finally, the deviations of temperature and precipitation in relation to the average, minimum and maximum values in each year were also considered.

4 Results

This results section is divided into three parts. Initially, some characteristics of the data used in the research are exposed. The second part brings the econometric results. Finally, in the last part, a placebo analysis is performed to validate the results of the estimations.

[3] See <https://www.gov.br/mma/pt-br/assuntos/servicosambientais/controle-de-desmatamento-e-incendios-florestais/municipios-prioritarios>

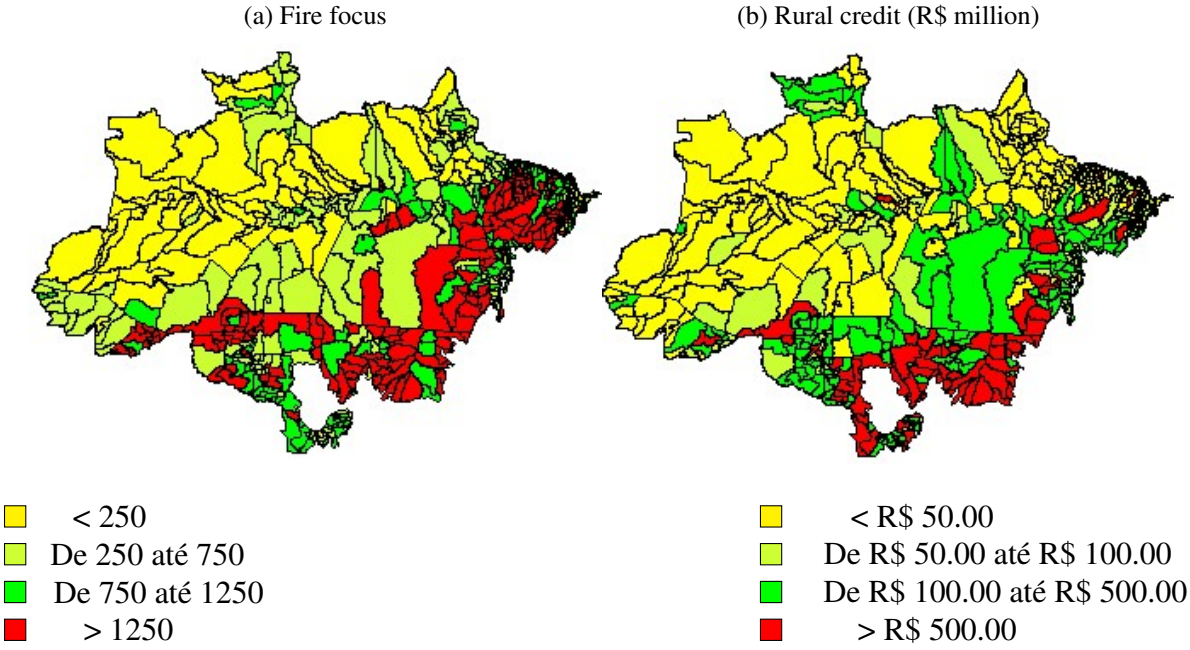
4.1 Data analysis

Preliminarily, Figura 3 shows the dispersion of accumulated values for the number of fires and rural credit for each municipality in the Amazon Biome from January 2005 to December 2020. Through Figure 3a, It is possible to notice that the highest values for the accumulation of fire outbreaks occurred in the municipalities located in the south, southeast and northeast regions of the biome, while the municipalities located in the center and east of the Amazon Biome have the lowest accumulated values of fire outbreaks.

The accumulated value of rural credit follows a spatial dispersion similar to that observed for fires, so that these values are more concentrated in the southern, southeastern and eastern regions of the Amazon Biome (see Figure 3b). This dispersion can be explained by the proximity of municipalities with a higher incidence of extractive activities, located outside the biome, which may be expanding their activities to nearby municipalities. This finding is confirmed in the study by (SIMON; GARAGORRY, 2005), where it is demonstrated that primary activities such as agriculture have been expanding in the Amazon biome, which can cause social, environmental and economic consequences.

From the spatial dispersion of fires and the values of rural credit granted to rural producers in the Amazon Biome, it is possible to visualize a symmetry in the distribution of the two variables, that is, the largest beneficiaries of rural credit are located in the region where the higher accumulated values of fires. If the two variables have a cause and effect relationship, then a policy that changes the value of rural credit granted to producers in the Amazon Biome would cause changes in the number of fires in that same region.

Figura 3: Accumulated values of the main variables in the Amazon Biome.



Source: Own elaboration based on research data.

The Tabela 2 presents the results of descriptive statistics of the variables used in this study. The results show that, between 2005 and 2020, the monthly average of fire outbreaks was approximately 8.55 fire outbreaks for every 1000 square kilometers, in the municipalities that make up the sample. The monthly average of rural credit values granted to rural producers in the municipalities in the sample was approximately R$217.54 per hectare of cultivated area. Descriptive statistics also show that approximately 10.83% of the sample observations correspond to municipalities that have some territory defined as an environmental protection area, while

about 13.36% of the sample observations refer to municipalities that have some area defined as indigenous land.

The descriptive statistics of the variables that seek to capture the bias resulting from government intervention in the environmental results of the municipalities in the sample show that the monthly average of environmental embargoes applied in the municipalities that make up the sample was approximately 0.18 embargoes. On the other hand, the monthly average of environmental fines applied in these municipalities was approximately 0.48 fines per month, which corresponds to an amount close to an environmental fine applied every two months. In addition, it is possible to note that approximately 1.27% of the observations in the sample are related to priority municipalities in raising funds to combat deforestation.

In turn, the descriptive statistics of the climatic variables show that the sample has an average rainfall of approximately 31.32 millimeters of rain, ranging from a municipality without rain to a municipality with more than 500 millimeters of rain, in a single month. The results also indicate that the average temperature of the municipalities in the sample is approximately 27.48 ^oC, with a minimum temperature of 18.70 ^oC and a maximum of 34.20 ^oC.

Tabela 2: Descriptive statistics of variables.

Variable	**Observations**	**Average**	**Standard deviation**	**Minimum**	**Maximum**
Fires per 1,000 km^2		8.5473	19.2712	0.0119	466.0954
Rural credit per cultivated land		217.5409	471.0310	0.0000	11794.2807
Treatment (1)		0.4361	0.4959	0.0000	1.0000
Treatment (2)		0.4697	0.4991	0.0000	1.0000
Protected areas		0.1083	0.3108	0.0000	1.0000
Indigenous area		0.1336	0.3402	0.0000	1.0000
Priority municipality		0.0127	0.1118	0.0000	1.0000
Environmental embargoes		0.1773	1.2251	0.0000	51.0000
Environmental fines		0.4812	6.2010	0.0000	576.0000
Corn price		44.1904	8.8931	30.3007	82.1217
Fat ox's at sign price		161.7413	29.9301	105.2474	291.7507
Soybean price		86.0816	17.3869	53.8631	168.2578
Precipitation (mm)		31.3175	30.5329	0.0000	509.6000
Temperature ($\circ C$)	53,421	27.4764	1.4157	18.7000	34.2000
Deviation of precipitation from the maximum		-1.7783	1.2526	-10.6000	0.0000
Deviation of precipitation from the average		0.0000	1.1054	-6.5167	4.7250
Deviation of precipitation from the minimum		1.7023	1.3901	0.0000	10.6000
Deviation of temperature from the maximum		-1.7783	1.2526	-10.6000	0.0000
Deviation of temperature from the average		0.0000	1.1054	-6.5167	4.7250
Deviation of temperature from the minimum		1.7023	1.3901	0.0000	10.6000

Source: Own elaboration based on research data.

4.2 Econometric results

This section presents the econometric results of the two identification strategies proposed in the methodology. The analyzes use a panel of data with monthly information between January 2005 and December 2020. Given that the policy of restrictions on access to rural credit by Resolution 3,545/2008 for rural producers in the Amazon Biome began in 2008, it allowed to compare the levels of forest fires in the treatment and control

municipalities, in periods before and after the implementation of the resolution.

In the main identification strategy, the treatment group is defined taking into account the municipalities that belong to the Amazon Biome and that are located exactly on the inner edge of the biome. The control group, on the other hand, is formed by municipalities that are not contained in the Amazon Biome, but are located exactly on the inner edge of the biome. Tabela 3 presents the mean tests for the two groups of the first identification strategy with regard to the control variables. This test is carried out in the pre-treatment period and aims to verify whether the two groups of municipalities are comparable. It can be observed that most of the defining characteristics of the municipalities are not significantly different between the two groups and, therefore, the two groups, treated and control, can be expected to be comparable to each other.

Tabela 3: Difference in means between the control variables of the treated and control groups before treatment for the first identification strategy

Variable	Control group	Treatment group	Difference
Rural credit log for cultivated land	1.099	1.5741	0.4752*
Protected areas	0	0.2203	0.2203*
Indigenous area	0	0.2712	0.2712*
Priority municipality	0	0	0
Environmental embargoes	0.095	0.1827	0.0877*
Environmental fines	0.5131	0.8569	0.3437
Corn price	44.6353	44.6353	0
Fat ox's at sign price	124.5609	124.5609	0
Soybean price	70.629	70.629	0
Precipitation (mm)	27.3241	27.3235	-0.0006
Temperature ($\circ C$)	27.3241	27.3235	-0.0006
Deviation of precipitation from the average	-0.0726	0.0708	0.0018
Deviation of precipitation from the minimum	1.2192	1.178	-0.0412
Deviation of precipitation from the maximum	-1.4853	-1.4636	0.0217
Deviation of temperature from the average	-0.0726	-0.0708	0.0018
Deviation of temperature from the minimum	1.2192	1.178	-0.0412
Deviation of temperature from the maximum	-1.4853	-1.4636	0.0217

Source: Own elaboration based on research data.

The second strategy of identification of treatment and control groups considered all the municipalities of the first strategy and the municipalities whose territorial limits are occurring on the edge of the municipalities of the Brazilian border of the Amazon Biome. As for the first strategy, the test for differences in means is also carried out for the two groups of the second strategy with regard to the control variables (see Tabela 4). In the same way as for the first strategy, it can be observed that, for the second strategy, most of the defining characteristics of the municipalities are also not significantly different between the two groups and, therefore, it can be expected that the two groups, treated and control, are comparable to each other.

It is important to highlight that the use of these identification strategies is justified by the fact that the Amazon region is large, in territorial terms, and potentially heterogeneous, due to unobservable variables, considering, therefore, only border municipalities. Tabela 5 presents the results obtained with the difference-in-difference models for the two proposals. Three estimates were performed for each identification strategy: in the first, the models were estimated using the Ordinary Least Squares (OLS) method with fixed effects of municipalities; in the second estimate, fixed effects of months were included, but fixed effects of municipalities were not considered; and, in the third estimate, fixed effects of municipalities and months were considered. It is important to highlight that, in order to improve the estimates, the logarithm was applied to the number of fire outbreaks. Therefore, the parameters of Tabela 5 can be interpreted directly as the percentage effect of the policy.

Tabela 4: Difference in means between control variables of the treated and control groups before treatment for the second identification strategy

Variable	Control group	Treatment group	Difference
Rural credit log per cultivated land	2.1594	2.6807	0.52138*
Protected areas	0	0.2203	0.2203*
Indigenous area	0	0.2712	0.2712*
Priority municipality	0	0	0
Environmental embargoes	0.0725	0.1975	0.125*
Environmental fines	0.3128	0.4414	0.1286
Corn price	44.1531	44.1531	0
Fat ox's at sign price	172.0441	172.0441	0
Soybean price	90.0405	90.0405	0
Precipitation (mm)	34.5537	34.7202	0.1665
Temperature ($\circ C$)	27.6266	27.7374	0.1108*
Deviation of precipitation from the average	0.0189	0.0184	-0.0005
Deviation of precipitation from the minimum	10.4098	10.44	0.0302
Deviation of precipitation from the maximum	-19.3224	-19.1329	0.1895
Deviation of temperature from the average	0.0189	0.0185	-0.0004
Deviation of temperature from the minimum	1.621	1.6013	-0.0197
Deviation of temperature from the maximum	-1.8626	-1.7837	0.0789*

Source: Own elaboration based on research data.

Comparing the results of the estimates, it is possible to notice that, regardless of the identification strategy, the values of the coefficients have the same sign. The only exception is the parameter β_1, in which the sign is negative, for the models estimated only with the inclusion of municipal fixed effects, and negative for the others. From the values found for the adjusted coefficient of determination (R^2), it can be seen that the inclusion of fixed effects improves the fit of the regression line, since the highest value for the adjusted R^2 was obtained for estimates with fixed effects for month and municipality.

The estimates also resulted in similar coefficients, depending on the identification strategy, differing only in the magnitude of the estimated parameter. One exception occurred in the estimation of the intercept of the regression equation when fixed effects of month and municipality were used. In this case, the parameter obtained statistical significance only in the first identification strategy. It is important to note, however, that this change in sign was not able to significantly alter the other coefficients. To ensure that the results in Tabela 5 are true, regressions without the vertical intercept of the straight line were also estimated. From this procedure, it was found that both the signs of the coefficients and their respective levels of statistical significance were not altered.

The main result of the differences-in-differences model is the coefficient β_3. According to (WOOLDRIDGE, 2015), this coefficient represents the estimate of the average effect of the treatment on the treated. Regarding the intervention being studied in this article, the coefficient β_3 measures the average effect of resolution 3545/2008 on forest fires in the municipalities of the Amazon Biome. According to the results of Tabela 5, the coefficient β_3 was negative and statistically significant for both identification strategies, changing only the magnitude of the effect, depending on the chosen strategy.

Tabela 5: Estimate results.

	Fixed effect municipality	**Fixed effect Month**	**Fixed effect municipality and month**
First identification strategy			
α	-0.1654*	-0.1430*	-6.2230*
β_1	-0.4158*	1.6670*	1.3340*
β_2	0.4746*	0.0060	0.4259
β_3	-0.1077*	-0.1233*	-0.0951*
R^2 ajustado	0.3457	0.4970	0.5623
Second identification strategy			
α	-8.5009*	-9.1040*	-8.1160
β_1	-0.4368*	1.3700*	1.0620*
β_2	0.7958*	0.1537*	0.7193*
β_3	-0.1942*	-0.1879*	-0.1718*
Adjusted R^2	0.3141	0.4653	0.5571

Source: Own elaboration.

Tabela 6 shows the results of the difference-in-differences model according to the decomposition effects (WOOLDRIDGE, 2015). Although there are few differences in the coefficients of the estimates, only the estimates with the highest adjusted R^2 were considered for both identification strategies, in order to obtain the effects of the implementation of resolution 3545/2008 on fires in the Amazon Biome. Thus, the results presented in Tabela 6 were extracted from estimates with fixed effects of month and municipality.

The difference between the results of treated and untreated, before and after the intervention, shows the average effect of the implementation of resolution 3545/2008 on forest fires in the municipalities of the Amazon Biome. The objective of this procedure is to compare the difference between the average number of fires between treated and untreated municipalities, before and after the implementation of the resolution. Thus, the result of this procedure represents, on average, how much the implementation of resolution 3,545/2008 changed the number of forest fires in the municipalities affected by the resolution.

The coefficient that measures the effect of the treatment on the treated was negative for both identification strategies, changing only the intensity of the effect. Considering the estimate associated with the identification strategy with the best degree of regression adjustment (higher adjusted R^2), the results show that resolution 3545/2008 reduced the number of forest fires by approximately 0.10% , in the municipalities affected by the resolution, compared to the control group. In the second identification strategy, the effect is greater, reaching -0.17%. These results corroborate the conclusions of (ASSUNÇÃO *et al.*, 2020), which demonstrate that the aforementioned resolution has positive effects on improving environmental indicators.

Compared with the effect of resolution 3545/2008 on deforestation, available at (ASSUNÇÃO *et al.*, 2020), the effect of resolution on forest fires obtained with the estimates of the differences-in-differences model performed in this research is relatively small. On average, the effect of resolution 3545/2008 on deforestation presented in the article by (ASSUNÇÃO *et al.*, 2020) is approximately nine times greater than the coefficient obtained with the first identification strategy and is about five times greater than the coefficient of the differences model in differences obtained with the second identification strategy. This result demonstrates that resolution 3545/2008 causes an improvement in the environmental indicators of the Amazon Biome, so that, although the aforementioned policy causes a decrease in forest fires in the municipalities benefited, this reduction is relatively small when compared to the effect that the policy has on other environmental indicators already studied in the literature.

In general, the relatively low effect of resolution 3545/2008 on forest fires obtained with the differences-

in-differences model may be associated with some characteristic factors of the agricultural sector and the policy itself. First, restrictions on forest fires are not directly mentioned as a requirement for the design of rural credit in resolution 3545/2008. Second, the fires that occur on rural properties can be controlled by the producers themselves, as a necessary mechanism for land management. In other words, if producers use fire for land preparation, and given that this database does not distinguish between controlled and uncontrolled fires, it is expected that a credit constraint will not have major effects on fires.

It is also important to highlight that resolution 3,545/2008 restricts access to rural credit to rural producers who do not prove the absence of environmental irregularities, upon presentation of supporting documentation. Thus, compliance with good environmental practices became a necessary condition for the financing of agricultural activities in the Amazon Biome, as of 2008. Given these facts and considering the low effect of resolution 3545/2008 on forest fires obtained in the estimates , it is possible to suggest that the main cause of fires in the Amazon Biome does not stem from the agricultural activities that can be financed.

Tabela 6: Treatment effects according to time and group.

	Before	**After**	**After - Before**
First identification strategy			
Control	-6.2230	-4.8890	1.3340
Treatment	-6.2230	-4.9841	1.2389
Treatment - Control	0.0000	-0.0951	-0.0951
Second identification strategy			
Control	0.0000	1.0620	1.0620
Treatment	0.7193	1.6095	0.8902
Treatment - Control	0.7193	0.5475	-0.1718

Source: Own elaboration.

It is important to highlight that resolution 3,545/2008 provides for the reduction of forest fires at a low economic cost, since its implementation and execution consists only of demanding that rural producers prove compliance with good environmental practices on their properties when contracting the rural credit. Therefore, resolution 3545/2008 has a low demand for public resources for its implementation, resulting in a policy of high economic efficiency with positive results in the fight against forest fires in the Amazon Biome.

It is also important to highlight that the basic text of resolution 3,545/2008 requires rural producers to present proof that they are complying with good environmental practices only when contracting rural credit. In other words, the resolution does not address the obligation to continue compliance with good environmental practices after contracting the rural credit, except in the case of recurrence in contracting the credit, in which case the rural producer is obliged to prove again compliance with the environmental legislation in force in the resolution. This fact can directly contribute to the relatively low value of the coefficient of the differences-in-differences model, since, considering that the rural producer can obtain access to rural credit and not need another loan, the environmental requirements of resolution 3545/ 2008 no longer needed to be fulfilled.

According to studies by Crowley *et al.* (2009) and Lin, Wijedasa & Chisholm (2017), fires have a benefit and a cost for the economic activities of the agricultural sectors. The benefits are usually associated with the ease of preparing the land for cultivation, while the costs usually stem from the loss of land productivity. Thus, it is possible to state that, if the economic benefit of forest fires is greater than the benefit of obtaining rural credit, rural producers in the Amazon Biome will have greater incentives to use fire in agricultural practices, which can reduce the effect of resolution 3545/2008 on forest fires. In this sense, if the objective of the Brazilian environmental authorities is to reduce the number of fires in the Amazon Biome, central planners must seek to increase the benefits arising from rural credit for rural producers in this location.

4.3 Placebo analysis

For the construction of the placebo analysis, it was considered that the treatment took place in March 2006, when the command of the Ministry of Economy in Brazil was changed, consequently changing the composition of the National Monetary Council. Thus, this change could represent a variation in the rural credit policy in Brazil, without considering, however, the restrictions imposed by resolution 3,545/2008. With this, a placebo analysis was built from a database that has monthly information from January 2005 to January 2008.

The Tabela 7 shows the results of the placebo estimates. As in the estimation of real data, the models with fixed month effect, municipality fixed effect and month and municipality fixed effect were estimated. Analyzing the results of the coefficient β_3, it is possible to observe that the estimate was statistically insignificant for all specifications. This result indicates that it is not possible to reject the null hypothesis that the treatment effect on the treated is null, when considering the placebo analysis database.

Tabela 7: Results of placebo estimates.

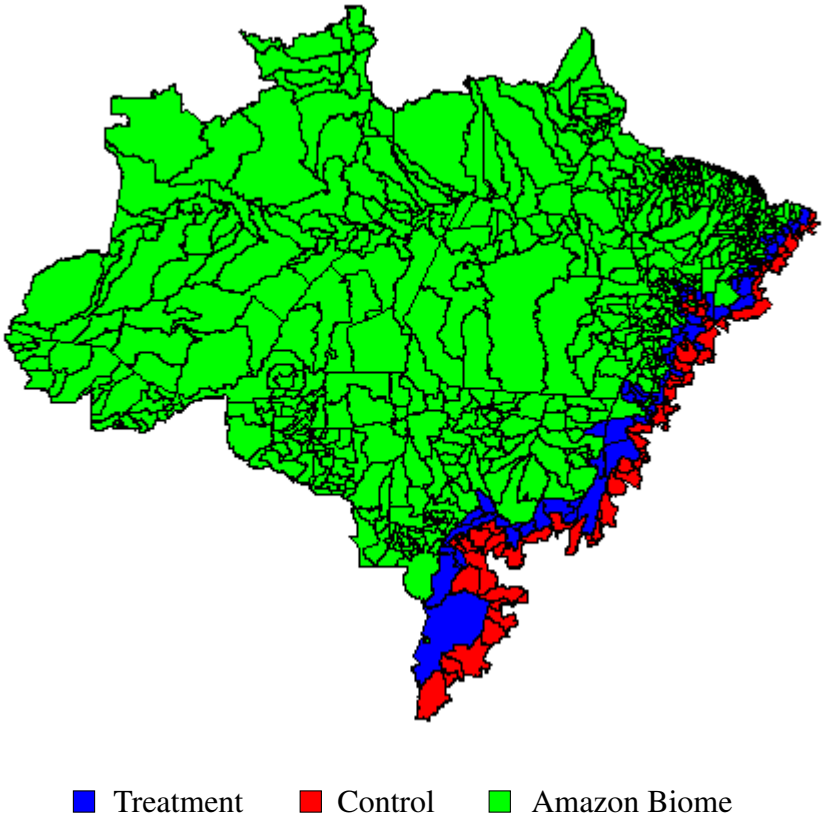
	Fixed effect municipality	**Fixed effect Month**	**Fixed effect municipality and month**
First identification strategy			
α	1009.0000*	289.7000*	343.9000*
β_1	0.4263*	-0.0230*	-0.2185*
β_2	0.0525	0.0993	0.1456
β_3	-0.0445	-0.0335	-0.0531
R^2 ajustado	0.3622	0.5780	0.6431
Second identification strategy			
α	564.8000*	161.5368*	1790.1000*
β_1	0.2074*	-24.6682*	-0.2376*
β_2	-1.7180*	0.2087*	-0.6908*
β_3	0.0356	0.0050	-0.03111
Adjusted R^2	0.3199	0.5380	0.6273

Source: Own elaboration.

The estimates from the placebo analysis serve as a basis for the assertion that the negative effect of the difference-in-differences model coefficient can be attributed to the implementation of resolution 3545/2008. This is because the coefficient that measures the effect of resolution is no longer statistically significant. Therefore, the placebo test contributes to the robustness of the results presented in the differences-in-differences model, confirming that resolution 3545/2008 contributed to the reduction of fire outbreaks in the Amazon Biome.

To test the robustness and corroborate the placebo test, an estimate was prepared in which those municipalities located immediately outside the Amazon Biome that are located within the national territory are considered treated, that is, the municipalities that are on the border of the Amazon Biome, however, they do not belong to the biome. To form the control group for these observations, the municipalities bordering the treatment group that do not belong to the Amazon Biome were considered. The intention of this identification strategy for the placebo test is to consider as treated those municipalities that have great similarity to the municipalities of the Amazon Biome, but which, however, belong to another biome, and to compare them with similar municipalities outside the Amazon Biome. The details of this strategy can be viewed in Figura 4.

Figura 4: Identification strategy for the robustness of the placebo test.



Source: Own elaboration.

The estimations were made considering fixed effects of municipality and time. The results of these procedures are shown in Tabela 8. Note that the coefficient demonstrating the difference of differences (β_3) cannot be considered statistically different from zero, in all three estimates performed. Although the coefficients β_1 and $\beta 2$ are statistically different from zero in the estimates where the municipality fixed effects are considered, these results only indicate that there is some response in the treatment and/or control groups before and/or after of the validity of resolution 3545/2008, not implying, however, in a significant difference in the average number of forest fires between the treatment and control groups before and after the mentioned intervention.

The vertical intercept of the estimate was also statistically different from zero in the estimates in which the fixed effects of month and municipality are considered separately. This result shows that the number of fires has a non-zero average in the control group before the implementation of resolution 3545/2008. When only the fixed effects of the municipality are considered, the coefficient β_1 also has a value statistically different from zero, indicating that there is also a non-zero mean for the fires in the control group after the intervention studied here. The results of the coefficients obtained in the estimates also suggest that there is a non-zero average for the number of fires in the treatment group, both before and after the implementation of resolution 3545/2008. However, despite these values being statistically different from zero, they are the same for both groups before and after the intervention, which shows that resolution 3545/2008 was not responsible for causing significant changes in fire outbreaks between municipalities that make up the two groups considered in the estimate in question.

In view of these findings, it is possible to state that there are no statistically significant differences in the intervention studied here on fire outbreaks in the two groups considered in this placebo test. This evidence provides evidence that resolution 3545/2008 did not generate significant effects on the number of fires outside

the Amazon Biome. As a consequence, this result reinforces the reliability of the difference-in-differences model estimates and the aforementioned conclusions that there is a statistically significant response towards the reduction of fire outbreaks in the Amazon Biome as a result of the implementation of resolution 3545/2008.

Tabela 8: Robustness test for placebo.

	Fixed effect Municipality	**Fixed effect Month**	**Fixed effect Municipality and month**
α	-6,8253*	-4,9890*	1,9620
β_1	-0,4667*	1,8930	1,5370*
β_2	1,5235*	0,0287	1,4610*
β_3	-0,0507	0,0421	-0,0171
Control variables	Yes	Yes	Yes
Adjusted R^2	0,3180	0,5225	0,5965

Source: Own elaboration

5 Conclusions

The objective of this article was to verify the effect of the implementation of a policy of restriction of access to rural credit on forest fires in the Brazilian territory, delimited by the Amazon Biome. For this, a panel of monthly data was used with information available between January 2005 and December 2020. The econometric results were obtained through difference-in-difference models with municipal and time fixed effects, which allowed measuring the effect of the treatment in the municipalities served by the policy.

The results found are robust and allowed us to conclude that the restrictions on access to rural credit, imposed by resolution 3,545/2008, were responsible for the reduction of forest fires in the Amazon Biome from the period in which the policy was implemented until the end of the coverage period of that study. Although this effect is relatively small, it is important to emphasize that this result occurs at a low economic cost for the public sector, which allows us to infer that resolution 3545/2008 contributes to the reduction of fires in the Amazon Biome in an economically efficient way.

In terms of policy implications, evidence indicates that rural credit conditioning is an effective policy instrument in combating forest fires. Thus, an expansion of this policy to other regions of the country can be suggested.

This reduction in forest fires provided by Resolution 3545/2008 suggests that, possibly, other variables were indirectly affected by the restriction of access to rural credit. Thus, it is possible to suggest potential effects of Resolution 3545/2008 in the health sector, with regard to greenhouse gas emissions, in addition to several other effects which can be tested in future research.

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