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EXPANSION OF SOYBEAN FARMING INTO DEFORESTED AREAS IN THE AMAZON BIOME IN MATO GROSSO, PARÁ AND RONDÔNIA STATES: THE ROLE OF PUBLIC POLICIES AND THE SOY MORATORIUM

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WORKING PAPER SERIES Nº 2020-12

DEPARTMENT OF ECONOMICS, FEA-USP
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Abstract:

In the 1990s and 2000s, soybean farming grew sharply, particularly in states located in Brazil's mid-west region. To curb deforestation, the Federal Government implemented the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon Region (PPCDAm). At the same time, soy-buying companies and Civil Society Organizations implemented the Soy Moratorium. This paper focused on the major role of these initiatives in decreasing soybean farming in areas deforested after 2006 and on their importance in achieving this result. We considered rich database deforestation, soybean planted area, and other critical explained variables, and used spatial panel models to a balanced database of 287 municipalities over eight years. The results confirm that lower deforestation rates in the biome laid the foundation for reducing soybean farming in the Amazon biome. However, since 2008, when the Soy Moratorium was launched, there was a structural decline in this relationship, and new plantations began to represent a small percentage of newly deforested areas. The soybean production chain is modern and organized in regional hubs and that its growth stems from stable institutional conditions in municipalities and their surroundings, as well as from the availability of skilled labor and credit. Therefore, government programs to reduce deforestation made room for specific private actions focused on soybean farming that created a new environment for agricultural expansion in line with Brazilian law and environmental commitments. The Soy Moratorium reinforced this new order, and this production chain became a case study on public and private governance, given its importance in reducing soybean farming in deforested areas after the cut-off date.

Keywords: Agriculture, Amazon Biome, Deforestation, Soy Moratorium

JEL Codes: Q1, Q5, C23,

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Abstract

In the 1990s and 2000s, soybean farming grew sharply, particularly in states located in Brazil's mid-west region. To curb deforestation, the Federal Government implemented the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon Region (PPCDAm). At the same time, soy-buying companies and Civil Society Organizations implemented the Soy Moratorium. This paper focused on the major role of these initiatives in decreasing soybean farming in areas deforested after 2006 and on their importance in achieving this result. We considered rich database deforestation, soybean planted area, and other critical explained variables, and used spatial panel models to a balanced database of 287 municipalities over eight years. The results confirm that lower deforestation rates in the biome laid the foundation for reducing soybean farming in the Amazon biome. However, since 2008, when the Soy Moratorium was launched, there was a structural decline in this relationship, and new plantations began to represent a small percentage of newly deforested areas. The soybean production chain is modern and organized in regional hubs and that its growth stems from stable institutional conditions in municipalities and their surroundings, as well as from the availability of skilled labor and credit. Therefore, government programs to reduce deforestation made room for specific private actions focused on soybean farming that created a new environment for agricultural expansion in line with Brazilian law and environmental commitments. The Soy Moratorium reinforced this new order, and this production chain became a case study on public and private governance, given its importance in reducing soybean farming in deforested areas after the cut-off date.

Key words: Agriculture; Amazon Biome; Deforestation; Soy Moratorium.

Introduction

Soybean farming in Brazil grew fast both in terms of area and production. As shown in Table 1, the growth between 2000 and 2005 was unprecedented. The planted area increased by about 8.8 Mha in the country, and almost 5.0 Mha only in Mato Grosso state, the region with land areas belonging to the Cerrado (savannah) and Amazon biomes and bordering the states of Pará and Rondônia, both in the Amazon biome.

Table 1 – Soybean planted area and production in Brazil (in 1,000 units)

Variable (10^3)	1990	1995	2000	2005	2010	2015
Planted area (ha)	9,742.50	10,663.20	13,969.80	22,749.40	24,181.00	33,176.90
Production (tons)	15,394.50	23,189.70	38,431.80	55,027.10	75,324.30	95,630.90

Source: National Food Supply Company (CONAB 2016).

This growth led to job creation, poverty reduction, and increased income in producing states, particularly in Mato Grosso (Weinhold et al. 2013; Richards et al. 2015). On the other hand, the expansion of soybean farming in environmentally sensitive areas and the lack of detailed information triggered reactions such as a campaign launched by Greenpeace called “Eating Up the Amazon” (Greenpeace 2006a).

This campaign linked meat consumption on the European continent to deforestation in the Amazon biome and to demand for soy for pressuring importing companies to impose trade restrictions on soybean grown in Brazil. Soy Moratorium (SoyM) helped to avoid these restrictions. SoyM is an initiative implemented in 2006 by companies affiliated to the Brazilian Association of Vegetable Oil Industries (ABIOVE) and to the National Association of Grain Exporters (ANEC) for the purpose of dissociating the expansion of soybean farming in deforested areas by not buying or financing soybean crops in deforested areas after July of that year (ABIOVE 2006;

Greenpeace 2006b, 2007). Specifically related to financing actions, the SoyM initiative counted on the participation of the largest agricultural credit institution in Brazil (ABIOVE 2010a).

The SoyM initiative was implemented by monitoring major soybean producing municipalities using remote sensing techniques (Rudorff et al. 2011, 2012). Initially scheduled to last two years, the initiative was successively renewed until 2016, when it became a permanent action (Greenpeace 2008, 2009a, 2010, 2012, 2014; ABIOVE 2009a, 2016a; BRASIL 2012). The reports confirmed that less than 1% of the areas deforested over that period were used for growing soybeans, suggesting that the sectoral initiative has been successful (Greenpeace 2008; ABIOVE 2009b, 2010b, 2011, 2012, 2013, 2014, 2015, 2016b). The main consequence was the rapid recognition and approval from European customers, including importing companies, consuming industries, and retail chains (ABIOVE 2010c; The European Soy Consumer Group 2010, 2011).

It is also important to highlight the strengthening of public governance in the Amazon biome after almost four decades of increasing international pressure on the Brazilian government and increased domestic awareness of the issue, especially as slash-and-burn practices increased in the late 1980s (Lago 2009). This scenario led to significant initiatives to curb environmental degradation, including the creation of the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) (MMA 2013a), systematic surveys conducted under the Amazon Deforestation Calculation Program (PRODES) (INPE 2015a), and the Plan for the Prevention and Control of Deforestation in the Legal Amazon Region (PPCDAm), which structured State actions around Land and Territorial Planning, Environmental Monitoring and Control, and Promotion of Sustainable Productive Activities (IPEA et al. 2011; MMA 2013b).

The significant drop in annual deforestation rates recorded between the 2002-2004 and 2012-2014 periods (INPE 2015b) was seen as resulting from public governance actions and coordinated sectoral actions (Assunção et al. 2013a, 2015; Risso 2013). However, the joint adoption of public and private policies led to heated debates on the role and effectiveness of each of these actions in reducing deforestation in general and, more specifically, in reducing the share of soybean farming in newly cleared land areas (Macedo et al. 2012; Boucher et al. 2014; Gibbs 2014; Gibbs et al. 2014; Nepstad et al. 2014; ABIOVE 2017). The issue grew in importance as it stirred debates on how to curb indirect deforestation caused by other production chains, such as that of biofuels (Morton et al. 2006; Fargione et al. 2008; Searchinger et al. 2008; Barona et al. 2010; Lapola et al. 2010; Arima et al. 2011; Macedo et al. 2012), and also on which other production chains are being pressured to follow the model adopted for soybean farming, such as cattle ranching (Greenpeace 2009b; Gibbs et al. 2015).

In this scenario, new proposals to curb deforestation are being discussed, such as those of zero deforestation in the Amazon region (Greenpeace 2015) and forest compensation and recovery (Azevedo et al. 2015). Therefore, policies designed to foster more intense livestock production, combined with actions to discourage the conversion of forests into pastures, have grown in importance (Bowman et al. 2012; Cohn et al. 2014), as pastures cover most of the crop area being used in Brazil (IBGE - Instituto Brasileiro de Geografia e Estatística 2006, p. 175). It has also become more important to promote a better understanding of the costs of implementing a zero deforestation policy (De Souza Ferreira Filho et al. 2015).

This paper analyzes the effectiveness of the Soy Moratorium in Brazil and contributes to the literature on the topic in two main ways. First, it uses a database originally developed for this study. Second, it introduces spatial econometrics techniques to conduct the analysis. This is the first time that this methodological approach is adopted to analyze this problem in Brazil. It will make possible to determine the individual effect of sectoral actions and public policies on reducing deforestation in the Amazon biome to grow soybeans as well as to evaluate the effectiveness of each of these actions.

Literature review

Improved remote sensing techniques and the use of geographic information systems (GIS) significantly improved the results of territorial analysis by crossing data on deforestation, land use, and other relevant variables. Besides, there was a considerable increase in the availability of PRODES data in 1988, of data produced by the Real-Time Deforestation Detection System (DETER) (Diniz et al. 2015) in 2004, and of data from land use mapping projects (TerraClass) (Almeida et al. 2016) and from the Mapping of Forest Degradation in the Brazilian Amazon Region (DEGRAD) in 2008 (INPE 2008).

Several studies using econometric methods sought to isolate the determinants of conversion of native forests from a large number of explanatory variables obtained from agricultural censuses and other surveys (de Espindola et al. 2012; Hargrave and Kis-Katos 2013). According to the authors, the variables most commonly correlated with deforestation are the following ones: proximity to highways, urban areas, and public infrastructure works; the existence of wood extraction or mining activities; availability of agricultural credit and expansion of agricultural activities; edaphoclimatic conditions (climate, soil quality); the presence of rural settlements; indicators of social or technological aspects (farm size, mechanization, etc.); and legal certainty (conflicts over land and lack of property deeds). Following a different line of investigation, the importance of deforestation inhibitors, such as conservation units and indigenous territories, was also considered.

The main econometric studies on the causes of deforestation are summarized in **Table 2**:

Table 2 - Literature review of studies on the causes of deforestation

Studies	**Methods**	**Significant variables**
(de Espindola et al. 2012)	SLM	Distance from infrastructure, land reform settlements, and indigenous lands
(Hargrave and Kis-Katos 2013)	FD, GMM	Commodity prices, environmental fines, and embargoes
(Pfaff 1999; Cropper et al. 2001; Etter et al. 2006)	Probit, logit	Protected areas, distance from infrastructure, and local climate and soil characteristics
(Andam et al. 2008; Pfaff et al. 2015a, b)	PSM	Public protected areas
(Arima et al. 2014; Andrade 2016)	PSM, Dif-in-Dif	List of priority municipalities of the ministry of Environment (MMA)
(Laurance et al. 2002; Kirby et al. 2006; Vera-Diaz et al. 2009)	GIS minimum transportation cost	Distance from infrastructure and urban centers
(Aguiar et al. 2007)	SLM	Distance from urban areas, distribution centers, agrarian framework, and indigenous lands
(Pfaff et al. 2007)	Logit	Distance from infrastructure
(Weinhold and Reis 2008)	OLS	Distance from infrastructure

Studies	Methods	Significant variables
(Mendonça et al. 2012)	SVAR and cluster analysis	Land use, mainly use of pasture
(Rodrigues-Filho et al. 2015)	ARIMA	Stability of public administration staff
(Verburg et al. 2014)	Land Use Simulator	Percentage of the area allocated to Legal Reserves and protection of Conservation Units
(Araujo et al. 2009)	FE Panel	Indicators of legal uncertainty over land ownership and distance from highways
(Brown et al. 2016)	SLM and SEM FE Panel	Distance from infrastructure, rural population, and indicators of legal uncertainty over land ownership
(Richards et al. 2014)	SLM FE Panel	Agricultural prices and profitability, land prices, and distance
(Faria and Almeida 2016)	SLM and SDM FE Panel	Production of agricultural goods and extraction of ores, legal uncertainty over property rights, type of rural property (owned, leased, or settlements), presence of government-protected areas and indicators of climatic conditions

It can thus be seen that the spatially complex character of deforestation stands out in the reviewed literature. Some works place greater emphasis on market aspects, such as transportation prices and infrastructure, while others attribute greater relevance to socioeconomic issues such as the presence of rural settlements or farm size. A third group focused its analysis on public policy actions. Therefore, the complexity of the analysis suggests the need for using a model designed to address all relevant variables simultaneously to avoid omission bias, and that takes into account the temporal and spatial autocorrelation of the data.

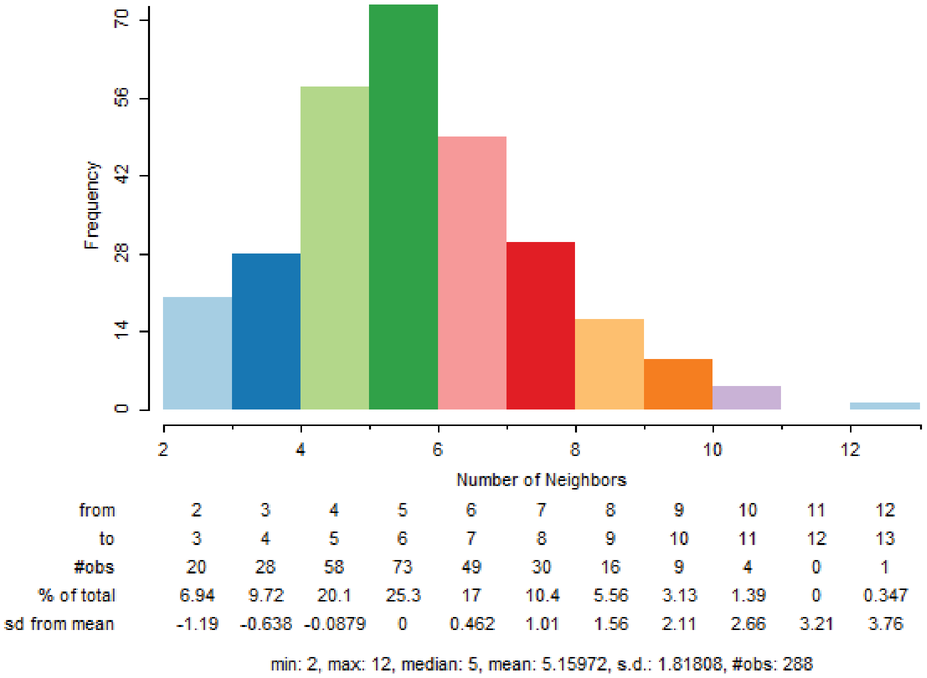
Objective

The objective of this paper is to determine the influence and effectiveness of the Soy Moratorium and of some public policies adopted as part of the Plan for the Prevention and Control of Deforestation in the Legal Amazon Region (PPCDAm) in reducing the relative share of the area planted with soybeans in deforestation actions recorded between 2004 and 2011. In addition, it is intended to investigate whether the restrictions imposed on expanding soybean farming into forest areas in the Amazon region ended up becoming an incentive to increasing productivity above the regional average in municipalities under the Soy Moratorium restriction.

Methodology and database

We took advantage of spatial econometrics techniques due to the characteristics of the subject under study and of the databases that were used (LeSage and Pace 2009, pp. 25–32). Spatial lags are treated using a spatial weight matrix that describes the spatial arrangements between units and must be previously defined by the econometrist (Elhorst et al. 2014, pp. 5–34).

Still, from a methodological point of view, we opted for competition between Queen-type neighborhood matrices and by order of q-neighbors. However, the choice q-neighbors number will depend on the result of the Akaike (AIC) tests (Stakhovych and Bijmolt 2009). As indicated by the connectivity histogram[1] (**Figure 1**), this should be done with matrices made up of 5-10 neighbors:



from	2	3	4	5	6	7	8	9	10	11	12
to	3	4	5	6	7	8	9	10	11	12	13
#obs	20	28	58	73	49	30	16	9	4	0	1
% of total	6.94	9.72	20.1	25.3	17	10.4	5.56	3.13	1.39	0	0.347
sd from mean	-1.19	-0.638	-0.0879	0	0.462	1.01	1.56	2.11	2.66	3.21	3.76

min: 2, max: 12, median: 5, mean: 5.15972, s.d.: 1.81808, #obs: 288

Figure 1 - Connectivity histogram of the analyzed municipalities

Spatial modeling also allows for estimating direct effects/impacts (on the spatial unit itself) and indirect effects/impacts (on neighboring units) (LeSage and Pace 2009; Elhorst et al. 2014, p. 22). In this paper, the recommendation to start with the SLX model was followed, as it is the simplest one and it allows for using non-spatial techniques (Halleck Vega and Elhorst 2015, p. 360), and GNS models were discarded, as their parameters are weakly identified (Elhorst et al. 2014) and they "tend to eliminate each

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[1] GeoDa software version 1.8.16.4.

other or to become insignificant and, as a result, this model is not useful for choosing between SDM and SDM models" (Halleck Vega and Elhorst 2015, p. 347).

Regarding panel data estimation, the Hausman test can be applied to decide between the fixed-effect (FE) or random-effect (RE) model. However, for cases where the data represent all spatial units, the FE method may be the most suitable one (Elhorst et al. 2014, pp. 53–57). Therefore, the panel model will be estimated using fixed effects for the SDM and SDEM models, and the one yielding the highest figure in this test is chosen. In this paper, the full model used is given by **equation (1)**[2]:

$$\Delta \mathrm{APS}_{m,t} = \mu_m + \tau_t + X_{m,t-1}\beta + WX_{m,t-1}\theta + \Delta AD_{m,t-3}\zeta + \Delta AD_{m,t-2}\varsigma + u \qquad (1)$$

where APS is the area planted with soybeans, AD is the deforested area, m is the municipality, t is the year, q is the number of lags, μ and τ are the specific effects on space and time, β, θ, ζ and ς are the parameters to be estimated, X are the above-mentioned controls, W is the matrix of spatial weights, and u is the error term. We choose to apply 2 and 3 lags for the deforested area, and 1 lag for the other variables.

Database

Municipalities fully or partially located in the Amazon biome in the states of Mato Grosso, Pará and Rondônia were analyzed (**Figure 2**). These municipalities represent the frontier for the expansion of soybean farming (**Figure 3**) and because they are located in the region where the actions to fight deforestation are focused on.

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[2] Matlab software version R2015a (8.5.0.197613) for Windows.

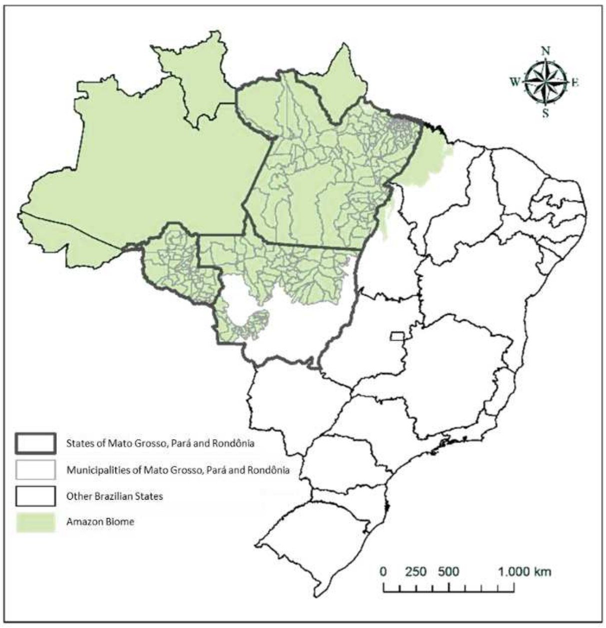

Figure 2 - Map of the analyzed municipalities

Source: Prepared by Joel Risso, whom I thank for authorizing me to use it.

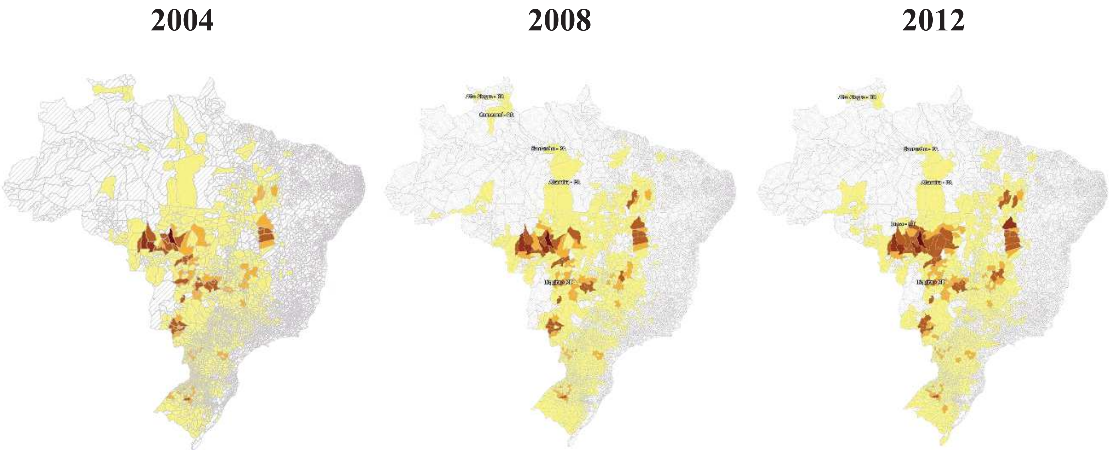

Figure 3 - Evolution of the area planted with soybeans by municipality in Brazil (2004, 2008 and 2012)

Source: Chartograms prepared based on data available in the IBGE/SIDRA database (IBGE - Instituto Brasileiro de Geografia e Estatística 2016).

Caption (colors indicate strips of areas planted with soybeans in the municipality in hectares):

Color	From	To
🟨	1	50,000
🟧	50,001	100,000
🟫	100,001	300,000
🟫	300,001	500,000
🟥	500,001	1,000,000
//////	Absence of data	

This region comprises a set of 287 municipalities, according to the 2010 IBGE grid map. To carry out a simultaneous analysis of the main elements seen as relevant for analyzing the relationship between deforestation and agriculture, municipal information for the 2004-2011 period (8 years) was gathered for a balanced panel referring to:

- **Revenues:**
  - Average soybean price;
  - Dummy for the presence of soy crushing plants;
- **Credit:** amount of official rural credit granted for agricultural and livestock undertakings;
- **Sectoral policies:**
  - Dummies for the municipalities monitored by the Soy Moratorium multiplied by the percentage of areas deforested before 2006;
  - Expanse of the area under the financing restrictions imposed by the Soy Moratorium.
- **Costs:**
  - Average wages of workers engaged in agricultural, livestock, and forestry activities;
  - Prices of mineral diesel S500 (which are relevant for the composition of production costs, as they are used in agricultural machinery) multiplied by the minimum distances between the area planted with soybeans and the municipality. If soybeans were not grown in a specific municipality or year, we considered the centroid of the deforested area in the municipality and the main outlets for goods to the domestic or export market, as shown in **Table 3**.

Table 3 - Outlets for agricultural products

STATE	Municipality	Longitude	Latitude	Type of grain terminal
MT	Rondonópolis	-54.6684658	-16.5203111	Railway terminal
PA	Marabá	-50.0169512	-5.6298065	Railway terminal
PA	Santarém	-54.7376730	-2.4153440	River port terminal
RO	Porto Velho	-63.9135040	-8.7459640	River port terminal
TO	Porto Nacional	-48.4966925	-10.5443517	Railway terminal

- **Deforestation:** data on total deforestation and with soybean farming per year calculated based on data from the PRODES Project. The former comprises clear-cut deforestation. Soybean growing in deforested areas per year was, in turn, analyzed using a methodology based on remote sensing of time series of MODIS sensor images (Risso 2013);
- **Economic activity:**
  - Nominal municipal GDP;
  - Trade Openness Index.
- **Public policies:**
  - IBAMA area under environmental embargo;
  - Dummy for municipalities where the Federal Police carried out environmental operations resulting in arrests;
  - Dummy for municipalities included in the priority list of the ministry of Environment (MMA) for actions against deforestation.
- **Legal uncertainty:** dummy for the occurrence of land conflicts reported by the Pastoral Land Commission.

The process of building the database for this study involved a great effort to compile public information available in widely scattered agencies with competence related to the subject of deforestation in the Amazon region. In this respect, it was necessary to make this information compatible for the same geographic and time unit, and in relation to the latter, it was essential to consider that soybeans are sown at different times of the year in the different Brazilian regions (between October and June), and for this reason the lag period had to be carefully chosen to avoid endogeneity problems.

Table 4 shows a complete list of the sources used in this study, while **Table 5** shows the descriptive statistics of the variables. In addition to these variables, slope dummies were applied to variables VAD, QAI, Psoja and SalMed with figures from 2008, the year in which flyovers of areas under the Soy Moratorium began to be carried out. The intention was analyzing some parameters change as a result of the adoption of this private sectoral policy. The remaining slope dummies were excluded from the model due to their high correlation with the original variable.

Table 4 - List and description of the variables used in the model

Variable	Description	Unit	Source
Year	Soybean harvest year	..	-
VAPS	Variation in the area planted with soybeans	10^4 ha	INPE
VAD	Variation in the total planted area deforested	10^4 ha	INPE
D_IndSoja	Intercept dummy for the presence of soybean industrial plant	..	ABIOVE
D_MS	Intercept dummy for monitoring under the Soy Moratorium	..	ABIOVE
D_MunPrior	Intercept dummy for official monitoring	..	Ministry of Environment (MMA)
D_PF	Intercept dummy for the presence of environmental operations of the Federal Police	..	Ministry of Justice (MJ)/Federal Police Department (DPF)

Variable	Description	Unit	Source
D_CPT	Intercept dummy for the occurrence of land conflicts	..	Pastoral Land Commission (CPT)
MS_CAR	Area of farms under purchase and financing restrictions imposed by the signatories of the Soy Moratorium	10^5 ha	Greenpeace
QAI	Number of Infraction Notices	..	MMA
Aemb	Embargoed area in the municipality	10^4 ha	MMA
Psoja	Average farmer soybean price	R$/kg	IBGE
SalMed	Nominal wages of tractor drivers	10^3 R$	Ministry of Labor and Employment (MTE)
Reb	Number of head of cattle	..	IBGE
CredAg	Official credit granted for agriculture	10^6 R$	Central Bank of Brazil (BCB)
CredPec	Official credit granted for cattle-raising	10^6 R$	BCB
IDD	Index of the minimum distance between a municipality in and export outlets multiplied by the average resale price of diesel	R$/month	Author
PIBm	Municipal GDP at current prices	10^6 R$	IBGE
AbertCom	Municipal trade openness index	..	*

Note: numeric data does not apply. *Prepared based on foreign trade data from the ministry of Industry and Foreign Trade and Services, municipal GDP as calculated by the Brazilian Institute for Geography and Statistics (IBGE), and annual R$/USD commercial exchange rate as calculated by the Central Bank of Brazil.

Table 5 - Descriptive statistics of the variables used in the model

Variable	n	Average	Standard deviation	Median	Minimum	Maximum
VAPS	2,583	0.055	0.317	0.000	-2.268	4.912
VAD-2	2,583	0.578	1.193	0.168	0.000	16.908
VAD-3	2,583	1.894	5.299	0.273	0.000	71.101
D_IndSoja-1	2,583	0.004	0.062	0.000	0.000	1.000
D_MS-1	2,583	0.038	0.186	0.000	0.000	0.985
MS_CAR-1	2,583	0.003	0.042	0.000	0.000	0.914
D_MunPrior-1	2,583	0.044	0.205	0.000	0.000	1.000
D_PF-1	2,583	0.041	0.198	0.000	0.000	1.000
D_CPT-1	2,583	0.270	0.444	0.000	0.000	1.000
QAI-1	2,583	0.020	0.046	0.006	0.000	1.108
Aemb-1	2,583	0.032	0.181	0.000	0.000	4.792
Psoja-1	2,583	0.434	0.127	0.417	0.209	0.850
SalMed-1	2,583	0.541	0.330	0.540	0.002	3.126
Reb-1	2,583	1.588	1.832	1.079	0.000	20.224
CredAg-1	2,583	0.591	2.068	0.066	0.000	26.650
CredPec-1	2,583	0.452	0.673	0.211	0.000	7.764
IDD-1	2,583	0.731	0.326	0.744	0.030	1.813
PIBm-1	2,583	0.277	0.978	0.089	0.004	18.801
AbertCom-1	2,583	0.068	0.227	0.000	0.000	3.022
D*VAD-3	2,583	0.433	0.655	0.000	0.000	14.037
D*Psoja-1	2,583	0.209	0.244	0.000	0.000	0.850
D*SalMed-1	2,583	0.279	0.327	0.000	0.000	1.597
D*AbertCom-1	2,583	0.033	0.159	0.000	0.000	2.562

Note: The number following the variables indicates time lag.

However, it was not possible to incorporate a lot of information into the model due to collinearity problems, as in the case of the population and municipal GDP variables. Other information items were not suitable for inclusion in the model because they lacked an adequate history for analyzing panel data, as in the case of indicators related to the land regularization program.

Thus, the variables that were chosen meet the necessary requirements of exogeneity for estimating panel data consistently and efficiently and are presented in **Table 6.** This is a symmetrical table, and it also shows the correlation between these variables. It can be seen that there are no indications of severe multicollinearity problems between the variables:

Table 6 - Correlation between the variables used in the model

	VAPS	**VAD-2**	**VAD-3**	**D_IndSoja-1**	**D_MS-1**	**MS_CAR-1**	**D_MunPrior-1**	**D_PF-1**	**D_CPT-1**	**QAI-1**	**Aemb-1**	**Psoja-1**	**SalMed-1**	**Reb-1**	**CredAg-1**	**CredPec-1**	**IDD-1**	**GDPm-1**	**AbertCom-1**	**D*VAD-3**	**D*psoja-1**	**D*SalMed-1**	**D*AbertCom-1**
VAPS	1.00																						
VAD-2	0.05	1.00																					
VAD-3	0.09	0.34	1.00																				
D_IndSoja-1	0.00	-0.03	-0.02	1.00																			
D_MS-1	0.21	-0.04	-0.06	0.18	1.00																		
MS_CAR-1	0.05	-0.02	-0.02	0.01	0.35	1.00																	
D_MunPrior-1	0.13	0.12	-0.02	-0.01	0.27	0.21	1.00																
D_PF-1	-0.02	0.07	-0.03	0.05	0.10	0.14	0.04	1.00															
D_CPT-1	0.01	0.24	0.10	0.03	-0.01	-0.01	0.05	0.11	1.00														
QAI-1	0.04	0.26	0.08	0.05	0.11	0.03	0.19	0.26	0.19	1.00													
Aemb-1	0.02	0.25	0.03	-0.01	0.08	0.04	0.30	0.02	0.06	0.23	1.00												
Psoja-1	0.02	-0.02	-0.19	0.04	0.20	0.04	0.18	0.00	0.02	0.08	0.06	1.00											
SalMed-1	0.25	0.01	0.39	0.03	0.11	0.06	0.10	-0.03	0.04	0.05	0.04	-0.07	1.00										
Reb-1	0.00	0.47	0.20	-0.03	0.02	0.00	0.28	0.11	0.24	0.24	0.32	0.09	0.08	1.00									
CredAg-1	0.24	-0.01	-0.02	0.46	0.26	0.11	0.05	0.07	0.03	0.05	0.00	0.08	0.15	-0.03	1.00								
CredPec-1	0.03	0.21	0.03	0.09	0.10	0.05	0.24	0.11	0.12	0.18	0.26	0.11	0.09	0.71	0.14	1.00							
IDD-1	0.07	-0.13	-0.17	0.06	0.16	0.05	0.11	0.03	-0.24	-0.04	0.06	0.04	0.07	-0.05	0.10	0.06	1.00						
GDPm-1	-0.01	0.02	-0.02	0.08	0.04	0.02	0.05	0.26	0.08	0.41	0.01	0.02	0.04	0.04	0.10	0.08	-0.04	1.00					
AbertCom-1	0.03	-0.01	-0.02	0.10	0.04	0.00	0.01	0.01	0.06	0.04	0.00	0.00	0.05	-0.01	0.16	0.05	-0.04	0.21	1.00				
D*VAD-3	0.00	0.25	0.03	-0.01	0.08	0.07	0.41	0.08	0.11	0.23	0.51	0.07	0.09	0.42	-0.01	0.33	0.01	0.07	0.00	1.00			
D*psoja-1	0.03	-0.18	-0.24	0.08	0.29	0.10	0.29	0.03	-0.06	0.04	0.15	0.40	0.24	0.06	0.05	0.18	0.28	0.08	0.02	0.31	1.00		
D*SalMed-1	0.04	-0.19	-0.23	0.08	0.27	0.12	0.28	0.05	-0.07	0.03	0.14	0.28	0.31	0.07	0.07	0.21	0.31	0.08	0.03	0.32	0.93	1.00	
D*AbertCom-1	0.05	-0.05	-0.06	0.16	0.10	0.02	0.07	0.00	0.04	0.02	0.02	0.06	0.07	0.01	0.18	0.08	0.04	0.20	0.67	0.07	0.22	0.23	1.00

Note: The number following the variables indicates time lag.

Figure 4 shows that a significant part of the Brazilian Legal Amazon region is covered by non-forest areas, which are mostly found in the states of Mato Grosso, Tocantins and Maranhão, and by spots of them in the states of Roraima and Amapá. These areas are mainly characterized by the typical savanna vegetation (Cerrado biome), which is characterized by a forest-field ecotone, as its tree and shrub biomass decreases gradually according to the soil conditions and to the effects of slash-and-burn practices (Ross 2011, pp. 180–181).

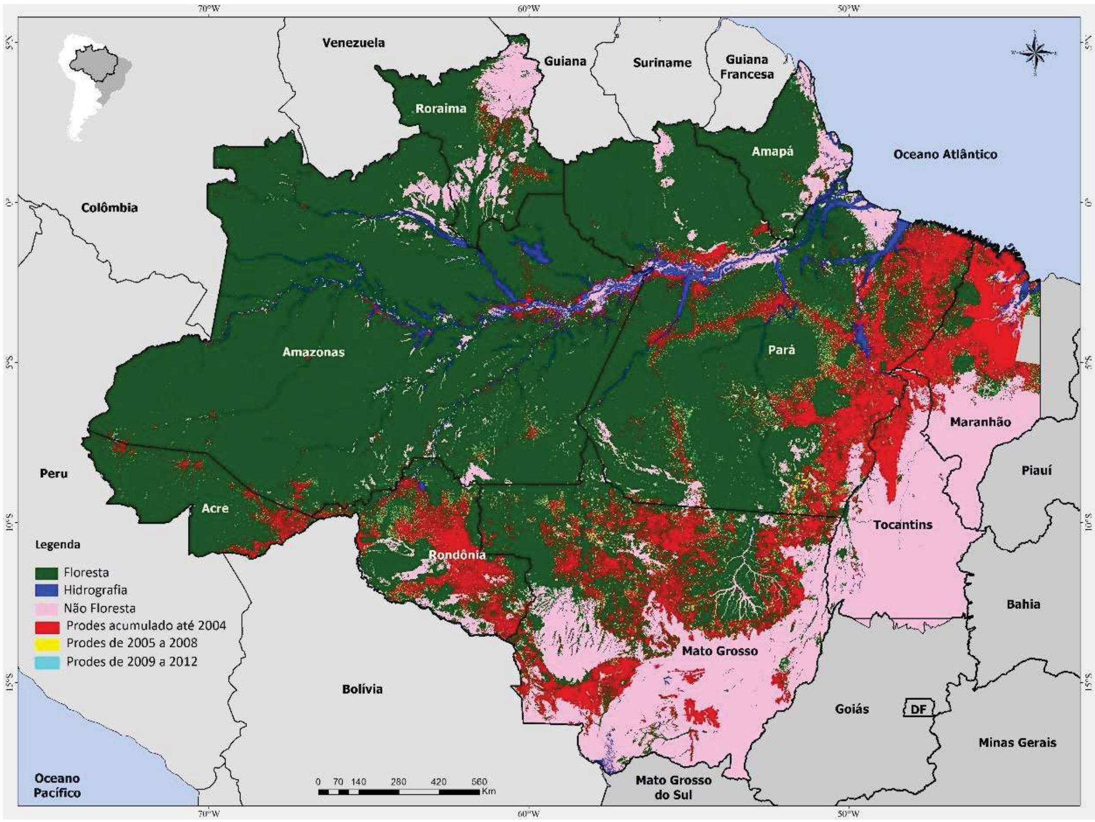

Figure 4 - Map of clear-cut deforestation in the states making up the Brazilian Legal Amazon region according to PRODES data (accumulated up to 2004, 2005-2008, 2009-2012).

Source: Prepared by INPE researcher Marcos Adami.

However, the Legal Amazon region is mostly made up of forest areas, which is "a generic term for a type of formation in which trees are the dominant element, forming a canopy" (Ross 2011, p. 155). In the specific case of the region analyzed in this study, it is an Amazon tropical rainforest. **Figure 4** also shows that a large part of the surface area of the Brazilian Legal Amazon region comprises a vast hydrographic network with watercourses and bodies that distinguish it from other Brazilian regions. It also shows that most deforestation events in the area were recurrent until 2004, but they were even more intense between the years 2005 and 2008. In the following four-year period, a reduction in annual rates is noticeable due to the lower presence of polygons falling under this category.

Results and Discussion

Competition between spatial matrices resulted in the choice of a matrix made up of 9 neighbors as the one that best described the data generating process. Given these considerations, **Table 7** shows the results of the models estimated by routines in Matlab software (Halleck Vega and Elhorst 2015). **Table 8** shows their main statistics, and it was seen that the SDEM model was the best one to explain variations in the area planted with soybeans in the Amazon biome. Space and time fixed effects were subtracted in these estimations.

Table 7 - Results of the models

Model	**OLS**		**SLM**		**SEM**		**SLX**		**SDM**		**SDEM**	
Variable	**Coef.**	**T-statistic**	**Coef.**	**T-statistic**	**Coef.**	**T-statistic**	**Coef.**	**T-statistic**	**Coef.**	**T-statistic**	**Coef.**	**T-statistic**
VAD-2	-0.01	-1.169	-0.01	-1.266	-0.013	-1.485	-0.012	-1.353	-0.013	-1.476	-0.013	-1.495
VAD-3	0.003	1.728 *	0.001	0.897	0.004	2.678 ***	0.004	2.328 **	0.005	3.196 ***	0.004	2.778 ***
D_IndSoja-1	-0.243	-2.402 **	-0.169	-1.805 *	-0.092	-0.971	-0.235	-2.334 **	-0.155	-1.624	-0.199	-2.04 **
D_MS-1	0.023	0.65	0.006	0.184	-0.007	-0.172	-0.035	-0.849	-0.007	-0.192	-0.001	-0.034
MS_CAR1	-0.373	-2.841 ***	-0.199	-1.661 *	-0.08	-0.634	-0.189	-1.417	-0.105	-0.83	-0.153	-1.201
D_MunPrior-1	0.078	2.349 **	0.048	1.582	0.062	1.969 **	0.069	2.04 **	0.063	1.981 **	0.062	1.94 *
D_PF-1	-0.038	-1.36	-0.036	-1.393	-0.015	-0.56	0.003	0.104	-0.007	-0.25	-0.023	-0.848
D_CPT-1	0.001	0.043	0.007	0.525	0.008	0.579	-0.006	-0.448	0.002	0.129	0	0.013
QAI-1	0.048	0.279	0.049	0.306	0.052	0.333	0.024	0.141	0.027	0.169	0.05	0.303
Aemb-1	0.008	0.21	0.002	0.057	0.006	0.181	0.013	0.351	0.006	0.165	0	0.001
Psoja-1	0.004	0.033	0.014	0.311	-0.03	-0.327	-0.034	-0.237	-0.032	-0.239	-0.031	-0.241
SalMed_ag-1	0.167	5.688 ***	0.081	4.18 ***	0.09	3.341 ***	0.075	2.45 **	0.059	2.034 **	0.076	2.742 ***
Reb-1	0.049	3.205 ***	0.024	1.731 *	0.024	1.54	0.016	0.969	0.019	1.181	0.02	1.281
CredAg-1	0.003	4.292 ***	0.001	1.771 *	0	0.429	0	0.367	0	-0.122	0	0.49
CredPec-1	0.001	0.938	0.001	0.946	0.002	1.323	0.002	1.26	0.002	1.619	0.002	1.599
IDD-1	-0.059	-0.556	-0.049	-0.653	-0.173	-1.092	-0.19	-0.552	-0.341	-1.046	-0.38	-1.171
PIBm-1	0.008	0.539	0.001	0.106	0.003	0.246	-0.002	-0.172	0	0.024	0.003	0.22
Abert_com-1	-0.041	-0.652	-0.041	-0.715	-0.054	-0.94	-0.038	-0.629	-0.044	-0.758	-0.029	-0.485
D*VAD-3	-0.041	-3.413 ***	-0.025	-2.271 **	-0.028	-2.278 **	-0.026	-1.871 *	-0.025	-1.931 *	-0.026	-2.052 **

Model	OLS		SLM		SEM		SLX		SDM		SDEM	
Variable	Coef.	T-statistic	Coef.	T-statistic	Coef.	T-statistic	Coef.	T-statistic	Coef.	T-statistic	Coef.	T-statistic
D*Psoja	-0.03	-0.163	0.03	0.464	0.079	0.753	-0.145	-0.692	-0.154	-0.778	-0.16	-0.858
D*SalMed_ag-1	-0.053	-0.721	-0.027	-0.544	-0.011	-0.167	-0.069	-0.865	-0.036	-0.482	-0.05	-0.693
D*AbertCom-1	0.013	0.297	0.011	0.263	0.006	0.155	0.03	0.689	0.018	0.426	0.015	0.358
W*VAD-2							-0.006	-0.313	0.003	0.152	0	0.011
W*VAD-3							-0.01	-4.276 ***	-0.008	-3.441 ***	-0.009	-2.803 ***
W*D_IndSoja-1							-1.545	-5.299 ***	-1.022	-3.69 ***	-1.335	-4.051 ***
W*D_MS-1							0.251	3.555 ***	0.137	2.048 **	0.16	1.648 *
W*MS_CAR1							-2.632	-8.626 ***	-1.213	-4.154 ***	-1.345	-3.241 ***
W*D_MunPrior-1							0.011	0.124	-0.039	-0.484	0.03	0.278
W*D_PF-1							-0.182	-2.697 ***	-0.163	-2.536 **	-0.306	-3.517 ***
W*D_CPT-1							-0.011	-0.31	-0.022	-0.646	-0.035	-0.755
W*QAI-1							-0.309	-0.68	-0.265	-0.618	-0.087	-0.155
W*Aemb-1							-0.184	-1.61	-0.128	-1.187	-0.18	-1.358
W*Psoja-1							-0.043	-0.283	-0.005	-0.034	-0.011	-0.069
W*SalMed_ag-1							0.205	5.048 ***	0.045	1.161	0.171	3.017 ***
W*Reb-1							0.056	1.577	0.011	0.321	0.035	0.738
W*CredAg-1							0.017	9.568 ***	0.009	5.019 ***	0.01	4.116 ***
W*CredPec-1							-0.003	-0.81	-0.003	-0.949	-0.003	-0.777
W*IDD-1							0.185	0.501	0.357	1.021	0.36	0.935

Model	OLS		SLM		SEM		SLX		SDM		SDEM	
Variable	**Coef.**	**T-statistic**	**Coef.**	**T-statistic**	**Coef.**	**T-statistic**	**Coef.**	**T-statistic**	**Coef.**	**T-statistic**	**Coef.**	**T-statistic**
W*PIBm-1							-0.021	-0.544	-0.02	-0.56	-0.001	-0.032
W*Abert_com-1							0.004	0.022	0.059	0.346	0.159	0.769
W*D*VAD-3							-0.008	-0.251	0.017	0.55	-0.003	-0.078
W*D*Psoja							0.236	1.037	0.162	0.754	0.278	1.111
W*D*SalMed_ag-1							-0.092	-0.845	-0.009	-0.086	-0.105	-0.689
W*D*AbertCom-1							0.124	0.986	0.067	0.56	0.043	0.309

Note: significance of the parameters at 10% (*), 5% (**) and 1% (***). The number following the variables indicates time lag.

Table 8 - Statistics of the models

Model	Fixed effects	SLM	SEM	SLX	SDM	SDEM
R^2	0.04	0.55	0.39	0.16	0.56	0.45
Likelihood log	7.83	273.43	266.74	94.17	311.51	304.55
AIC	28.35	-500.86	-487.48	-100.35	-533.03	-519.09
Moran's I statistic (probability)	0.28 (0.00)			0.53 (0.00)		
LM $\rho = 0$ (prob.)				1,621.80 (0.00)		
Robust LM $\rho = 0$ (prob.)				2,167.44 (0.97)		
LM $\lambda = 0$ (prob.)				2,295.64 (0.00)		
Robust LM $\lambda = 0$ (prob.)				3,541.27 (0.00)		

Table 7 summarizes the comprehensive set of variables that was analyzed simultaneously in this study, especially when spatial lags are incorporated using the SLX, SDM, and SDEM models. **Table 8** shows in turn that there are indicators of the existence of spatial correlation based on Moran’s I statistic of a value equal to 0.28 for the fixed-effect model. These spatial residues remain in the SLX model, in which Moran’s I statistic is one of 0.53. Based on the SLX model, LM and robust LM statistics are applied, which indicate the models with spatial correlation in errors as the most appropriate. The choice of the SDEM model was due to the lower value of the LM statistic.

The results show a positive relationship between the variation in the area planted with soybeans and that observed in the deforested area three years earlier (VAD-3). They are consistent with the cycle of consolidation of soybean crops, which follows the phases of deforesting areas, removing tree stumps, sowing an intermediate crop to prepare the soil (rice, for example), and then growing soybeans. From a spatial point of view, the competition observed between municipalities with the largest available area (W*VAD-3) should also be pointed out, since the increased deforestation rates seen in neighboring municipalities reduced the variation in the area planted with soybeans in the central municipality.

However, the slope dummy (D*VAD-3) shows that after 2008 there was a reversal in this trend as soybeans ceased to be grown in newly deforested areas and new soybean farms began to be established in older deforested areas. This result is in line with Risso’s conclusions (Risso 2013) and with the annual reports of the Soy Moratorium and they corroborate the effectiveness of this initiative to reduce soybean farming in deforested areas after the cut-off date.

An increase in the area planted with soybeans was also observed in the central municipality when neighboring municipalities were placed under the purchase and financing restrictions adopted by the signatory companies of the Soy Moratorium (W*MS_CAR-1 and W*D_MS-1). Therefore, a more effective control in a locality can generate incentives for growing soybeans in its surroundings, possibly in already deforested areas, as a means to dodge the restrictions imposed by the Soy Moratorium.

The results also showed a negative relationship between the presence of processing plants and of soybean farms in the municipality and in its neighboring municipalities (D_IndSoja-1 and W*D_IndSoja-1). This result was interpreted as a further indication of the effectiveness of the Soy Moratorium, as this reduction was recorded in the portion located within the Amazon biome, while the total area in these municipalities increased over the same period.

Soybean farming is a highly mechanized and capital-intensive activity in all stages, from sowing to harvest. Due to these features, soybean growing is a demanding activity in terms of training the employees in charge of operating the required equipment to ensure the least possible losses and the quality of the product in line with international standards. For this reason, based on the premise that the average wage (SalMed and W*SalMed) reflects productivity, and since this variable is correlated with the skills required from soybean workers, it can be concluded that its positive sign indicates that soybean farming tends to grow in regions with greater availability of skilled workers. If this relationship is valid in the municipality and in its surroundings, continued increase in production and the ensuing demand for labor lead to a virtuous regional cycle of income and employment.

Concerning public policies, special mention should be made of the coefficients related to the implementation of the list of priority municipalities for fighting deforestation (D_MunPrior-1) and to Federal Police operations (W*D_PF-1).

About the former, the positive coefficient indicates that the strong restrictions and controls imposed on municipalities included in that list of the ministry of Environment have been effective in reducing deforestation, as already highlighted in the literature review, apart from generating incentives for better use of areas cleared for agriculture.

The negative coefficient related to Federal Police operations in neighboring municipalities indicates that the variation observed in soybean growing had a strong impact on reducing deforestation and on opening up new areas in the surroundings of a region. Among the policies adopted under the PPCDAm plan for controlling deforestation, the most successful ones were those related to commands and control, including in this case operations of the Brazilian Institute for the Environment (IBAMA) and of the Federal Police, as well as the monitoring work carried out by the Department of Transportation and Terminals (DETER) (Assunção et al. 2013b). It appears, therefore, that fighting the causes of deforestation through Federal Police actions has also had a bearing on reducing new soybean plantations in the Amazon biome.

These results describe the growth dynamics of soybean farming based on structural and long-term elements, including workers' training, the possibility of establishing secure contractual relations between farmers and purchasing companies, and credit granting. The strong concentration of soybean crops in production hubs in the north region of Mato Grosso state is also indicative of externalities linked to the exchange of knowledge and information among farmers, which is fundamental for reducing costs and increasing productivity. These elements played a key role in promoting the development of soybean farming in Brazil despite economic adversities and the poor quality of the storage and transportation infrastructure.

Unlike other studies on the causes of deforestation, this study sought to specifically analyze the growth in soybean farming in the Amazon biome and its relationship with deforestation. For this reason, macroeconomic variables (PIBm-1 and AbertCom-1) linked to deforestation were included, whose coefficients were not significant. This result may be because deforestation is a more complex process and one that takes place on a different scale from that of the occupation of areas for soybean farming in the Amazon biome. It can be therefore deduced that macroeconomic activity has no direct bearing on soybean farming, as it follows structural variables, as already highlighted above. No direct relationship between variables related to livestock production (Reb and CredPec) and increased soybean farming was observed either.

The increase in soybeans planted area explained by deforestation taken place at a rate of 0.004, that is, at the rate of 40 hectares for every 10,000 hectares of deforested area. The policies implemented under the PPCDAm plan between 2004 and 2011 had negative effects on the variation observed in the deforested area in the municipalities, as they reduced it from about 9,300 hectares/year to 4,300 hectares/year. This reduction resulted in a slowdown in soybean farming calculated at 20 hectares/year per municipality. As of 2008, the implementation of the Soy Moratorium had the average effect of slowing down soybean farming to 26 hectares/year for every 10,000 hectares of deforested area per municipality. This effect, which was felt in an area of about 4,300 hectares/year, resulted in an average slowdown in soybean farming of about

120 hectares/year per municipality. Therefore, considering that the policies implemented under the PPCDAm plan had effects over an 8-year period and that the Soy Moratorium yielded effects for 4 years, it is estimated that the former and the latter avoided soybean farming in about 45,100 hectares and 138,400 hectares, respectively, showing that the Soy Moratorium played a key role in slowing down the rate of expansion of soybean farming. This result, observed in the light of reports issued by the Soy Moratorium, allows us to conclude that the sectoral policy had the desired effect of reducing the expansion of soybean farming in areas of native vegetation.

To investigate whether the SoyM restriction imposed on the expansion of the soybean planted area created an incentive to increase yield above the average in the municipalities under the monitoring imposed by the Soy Moratorium we considered the evolution of soybean yield. Only municipalities with soybeans in every year in the 2002-2011 were included. On average, the subset analyzed accounted for 59.21% of the total production in the biome.

For choosing between the fixed or random effects panel models, the Hausman test was applied, whose null hypothesis is the premise that the random effects model is the correct one and that, for this reason, it is also the most efficient. However, if the unobservable random term is correlated with the explanatory variables, the fixed effects model will be consistent and the null hypothesis should be rejected.

Hausman's H statistic follows a Chi-Square distribution with M degrees of freedom, where M is the number of variables with variation over time, as they are the only ones that can be estimated using the fixed effects model (Cameron and Trivedi 2005, p. 718). In this case, the calculated statistic was $H = 300$ with 20 degrees of freedom and p-value $<2 * 10^{-16}$. Therefore, the null hypothesis was rejected and the estimation was carried out using fixed effects panel models related to the municipality. The Breusch-Godfrey test was also applied, whose statistic was BG = 60 with 9 degrees of freedom and p-value = $4 * 10^{-9}$, indicating serial correlation.

The model was estimated using the Feasible Generalized Least Squares (FGLS) panel estimation methodology to control for heteroscedasticity and serial correlation, as shown in **equation (2)**:

$$\mathrm{Produt}_{m,t} = \mu_m + \mathrm{Produt}_{m,t-1} + Price_{m,t}\theta + X_{m,t-1}\beta + \varepsilon \tag{2}$$

where Produt is the average soybean yield, Price is the average soybean price in the municipality, X refers to the control variables, m is the municipality, t is the year, μ_m is the specific effect of space, α, β and θ are parameters, and ε is the error term.

In this case, there was a change in magnitude and significance with the inclusion of dummies for year, but only results related to control variables will be presented in **Table 9.** In this model, a decision was made to use the soybean price in the current year instead of yield based on the understanding that the local price is exogenously determined (it depends on the international market, on the exchange rate, and on the transportation cost) and reflects more appropriately the profitability expected by farmers for purchasing inputs:

Table 9 - Results of the models

Variable	Coefficient	T-statistic
Produt-1	0.036	0.90
Price	-0.015	-1.06
Aemb-1	0.000	1.09
SalMed-1	0.003	0.67
CredAg-1	0.000	2.83 ***
IDD-1	0.048	0.42
D_MS-1	-0.001	-0.37
D_IndSoja-1	-0.009	-1.33
D_PF-1	0.003	0.96
Multiple R^2	0.554	

Note: Significance of parameters at 10% (*), 5% (**) and 1% (***). The number following the variables indicates time lag.

It should be noted that after controls are included, yield is mainly related to the granting of agricultural credit, which is a determining factor in the decision of farmers to buy more inputs, make investments and improve their farm, and opt for better technological packages. However, no relationship between agricultural productivity and the Soy Moratorium was observed. The same can be said of the public policy variables for reduced deforestation.

Conclusions

Public and private actions in soybeans planted areas have moved in the same direction in recent years. Our main objective was to assess the effectiveness of each policy, trying to disentangle their weight on the expansion of planted areas.

The results suggest that the soybean production chain has been increasing as a result of structural elements related to legal certainty, credit, and its relationship with the other links in the chain. As a capital- and skilled labor-intensive activity, soybean farming depends on stable conditions to generate a virtuous growth cycle.

While initially the area planted with soybeans increased in newly deforested areas, as time went by public and private actions significantly changed this growth pattern. The decline in deforestation rates and strict control on the use of new areas entailing high risk of embargoes and fines have become impediments to an investment-intensive crop.

Likewise, the results suggest that the Soy Moratorium, an initiative that imposed substantial restrictions on purchasing soybeans and financing its farming in deforested areas after July 2006, has reinforced a new trend in the production chain toward growing soybeans in older converted areas. To achieve these results, it relied on the availability of a high stock of underutilized pastures suitable for conversion to cropland.

Public and sectoral initiatives reinforced and complemented each other, the former as key elements for defining a new order for agricultural expansion and exploitation of arable land and the latter as necessary elements for establishing specific policies for Brazil's largest cultivated crop. Their effects can also be felt in other production chains looking for ways to adapt themselves to new consumer requirements.

Therefore, the fall in deforestation rates laid the necessary foundation for implementing the Soy Moratorium. By creating a new awareness in society of the dynamics of opening up new areas, it ensured the success of the sectoral initiative in further slowing down the expansion of soybean farming in the Amazon biome. Given the above-described scenario, it was seen that public governance initiatives played a key role in reducing the expansion of soybean farming in the Amazon biome. The sectoral actions taken after 2008 played a preponderant role in slowing down the encroachment of soybean crops into deforested areas as seen until July 2006 and their expansion in already deforested areas, in line with this new dynamic.

Finally, it should be mentioned that the Soy Moratorium did not influence the average soybean yield. As mentioned above, this is a capital-intensive crop linked to a modern, exportoriented production chain whose growth depends on structural elements related to long-term expectations. In this regard, soybean yield is mostly determined by the availability of resources for farmers to invest in the best technological packages to introduce continuous improvements.

As a complex phenomenon, deforestation reflects local economic, social, and environmental conditions, as well as the effectiveness of the State's presence in the region. On several occasions, analyzing this phenomenon is difficult due to the lack of data in the required frequency and spatialization. Last but not least, the evolution of spatial econometrics techniques has significantly changed the way data is handled. Using these techniques jointly with remote sensing tools with socioeconomic data will likely promote a better understanding of the causes of deforestation.

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