CLIMATE CHANGE, AGRICULTURE AND LIVESTOCK INTENSIFICATION IN BRAZIL: THE BORLAUG HYPOTHESIS

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ABSTRACT

This paper analyzes the economic impacts of productivity gains in the Brazilian agriculture to reduce deforestation and domestic greenhouse gas (GHG) emissions, as proposed by Borlaug Hypothesis. For this, it was used a Computable General Equilibrium (CGE) model, tailored to include a module of land-use change and GHG emissions. The simulations were carried out through three policies, whose shocks were applied on livestock, agriculture, and both sectors aggregately. The results show that productivity gains can effectively "save" land and thus avoid the deforestation of areas of native vegetation, as established by Borlaug Hypothesis. In addition, the policies promoted the reduction of GHG emissions, especially in the Amazon and Cerrado biomes, with no adverse effects on the Brazilian economy and has improved income distribution reducing price goods to low income households. Finally, this research constitutes a step forward in the study of land-use change and its integration to GHG emissions into a CGE model framework, showing the role of productivity as an alternative for reducing deforestation and increasing, or at least, preserving agricultural production. However, productivity gains, albeit effective in reducing emissions and deforestation, may have lower effects if they are not combined with other policies.

Keywords: Deforestation; Greenhouse gas emissions; Productivity; CGE model.
Classification JEL: C68, D58, Q15, Q24, Q34, Q54

RESUMO

Este artigo analisa os impactos econômicos de ganhos de produtividade na agricultura brasileira, tendo em vista a redução do desmatamento e das emissões domésticas de gases de efeito estufa (GEE), conforme proposto pela Hipótese de Borlaug. Para isso, utiliza-se um modelo de equilíbrio geral computável (EGC), adaptado com um módulo de mudanças do uso da terra e emissões de GEE. As simulações foram realizadas através de três políticas, cujos choques foram aplicados sobre a pecuária, agricultura e em ambos os setores de forma agregada. Os resultados mostram que ganhos de produtividade podem efetivamente "poupar" terras e, portanto, evitar desmatamento, como indicado pela Hipótese de Borlaug. Ainda, as políticas promoveram a redução das emissões domésticas de GEE, especialmente nos Biomas Amazônia e Cerrado, sem gerar efeitos adversos sobre a economia brasileira e contribuíram para uma melhor distribuição de renda, ao reduzir os preços dos bens às famílias de menor renda. Assim, este trabalho contribuiu com o estudo das mudanças no uso da terra e sua integração às emissões de GEE, no arcabouço dos modelos EGC, ao evidenciar o papel da produtividade como alternativa para redução do desmatamento e aumento, ou pelo menos, manutenção dos níveis de produção agrícola. Contudo, ganhos de produtividade, embora efetivos na redução de emissões e do desmatamento, podem ter seus efeitos reduzidos se esses não forem combinados com outras políticas.

Palavras-chave: Desmatamento, Emissões de gases de efeito estufa, Produtividade, Modelo EGC.
Área Anpec 11: Economia Agrícola e do Meio Ambiente.

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1 Introduction

Brazil has emerged as a major agricultural producer in the international scenario. Such recognition stems from its agricultural dynamism, which has been a key strength of its economy. From 1994 to 2011, for example, the average share of agriculture in GDP was 24.6 percent, which when disaggregated shows

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that agriculture alone accounted for 17.1 percent, while livestock accounted for 7.1 percent, over the same period (CEPEA, 2014).

The positive performance of the agricultural sector led to a positive balance of trade for Brazil. Over the past 20 years, agribusiness accounted, on average, for 40.4 percent of all its exports. This result is in sharp contrast with the weak performance of other export sectors, particularly industrial sectors. In 2013, for example, the Brazilian trade balance amounted to US$ 2.6 billion, while the balance of agribusiness totaled US$ 82.9 billion, showing the importance of this sector to the country's economy (BRASIL, 2014).

Agriculture also has a bearing on the well-being of the population due to variations in its purchasing power. In Brazil, such variations are mainly captured by the IPCA, which is a price index that measures the official inflation in the country. Almost 22 percent of this index is made up of food and beverage items, which are subject to crop fluctuations that affect domestic prices (IBGE, 2012).

Agricultural expansion is, therefore, a key element for expanding the national economy, especially on a stable basis. Over decades, such expansion has been based on land incorporation. Between the Brazilian Agricultural Censuses of 1995/96 and 2006, for example, the total area occupied by crops grew by 20 percent, from 50.1 million hectares (Mha) to 59.8 Mha, while planted pasture areas grew from 99.6 Mha to 101.4 Mha over the same period (IBGE, 2014a).

In a regional context, crops areas grew mainly in the mid-west (+63.9%), north (+37.3%), and northeast (+29%) regions of Brazil. Livestock, in turn, grew only in the north (+39.3%) and northeast (+26.9%) regions. The latter regions and the mid-west stood out in reducing native vegetation areas in agricultural establishments by -23.6%, -8.1%, and -9.6%, respectively (IBGE, 2014a).

Presently, the agricultural sector faces the challenge of continuing to grow at the same pace in a scenario of land supply constraints. Such restriction refers to the conversion of native vegetation areas for other uses, especially in the Amazon and Cerrado biomes, located in regions where agriculture has expanded over recent decades – the north, northeast and mid-west regions of Brazil.

The difficulties imposed on land clearing for cattle farming and crops in Brazil's center-north resulted from national efforts to reduce deforestation in the Cerrado and Amazon biomes with the aim of reducing domestic GHG emissions, causing productivity gains to emerge as important alternative for the Brazilian agriculture growth. Conversely, productivity increases in agriculture would allow production to grow without clearing new areas – the Borlaug effect (BORLAUG, 2002).

This article has as objective to analyze the economic impacts of productivity gains in the Brazilian agriculture. Besides, policy effects on land allocation and GHG emissions were also evaluated, through a CGE model tailored for the Brazilian economy with a land-use module that captures heterogeneity related to different land types and biomes.

This study is organized in four sections, besides this introduction. The first one analyzes the evolution of agricultural productivity in Brazil. The second one presents the methodology and the empiric strategy of this study. In the third one the results are discussed. The last one presents the final remarks.

2 Agricultural productivity in Brazil

Productivity is a recurrent issue in economics due to its implications for economic growth and development, as well as for the well-being of the population. Food security and deforestation, therefore, are important issues underlying increases in agricultural productivity. Borlaug (2002) stated that if the yield of grain production in 1950 had remained at the same level in 2000, around 1.2 billion hectares would be necessary to ensure the same production level in the latter period, against the 660 million hectares being used nowadays. This relation between increases in agricultural productivity and a decreasing demand for new land is referred to as the "Borlaug Hypothesis".

Following Borlaug's argument, Stevenson et al. (2011) analyzed the impacts of adopting new technologies in connection with land-use change, focusing on Brazil and Indonesia. The Brazilian case was evaluated using a CGE model that considers the effects of increases in productivity in soybean crops. The results support the Borlaug Hypothesis, as productivity gains reduced the area occupied by soybean crops by 300,000 hectares, at the same time that it increased forest and pasture areas by 0.1% and 0.13 %, respectively.

Gasques et al. (2012) also analyzed the effects of several policies on the productivity of Brazilian agriculture. In that study, the total factor productivity (TFP) index was estimated, revealing a high productivity growth rate in domestic agriculture, which grew by 5.69 percent in the 2000-2011 period. That index is justified by lower subsidies being granted to the sector and its increasing efficiency, which place Brazil in the group of countries with the highest productivity growth rate in agriculture, supporting the results of other studies, such as that by Fugile (2010).

Martha Jr. et. al. (2012) also studied productivity, but focusing on the Brazilian cattle farming industry. In that study, the expansion observed in the agricultural frontier is associated with an increase in livestock production, especially in 1950-1975. Nonetheless, in the following period, the dynamism of the agricultural sector was associated with productivity gains, which amounted to about 3.6% and 6.6% per year in 1975-1996 and 1996-2006, respectively. Finally, the authors conclude that with no productivity gains and other land saving actions, such as investment in technology and in improving livestock, the Brazilian livestock industry can only grow by incorporating new land.

The relative consensus around increases in agricultural productivity in Brazil contrasts with discussions on the magnitude of such increases. According to the OECD (2011), Brazil ranks first in the global ranking of agricultural productivity, which grew by 1.87% in 1961-2007 and 3.63% in 2000-2007. The growth recorded in developed countries amounted to only 1.48% and 0.86% over the same periods.

The USDA (2014) also shows that Brazil is the country with the highest agricultural productivity growth, of 4.03%, followed by China, with a rate of 3.05% – both of which are higher than those registered in OECD countries. These developing and East European countries accounted for an average increase in the productivity of global agriculture from 1.65% in 1999-2000 to 1.84% in 2001-2009.

The specialized literature, then, supports the argument that agricultural productivity is on the rise worldwide, especially in developing countries. Thus, Brazil stands out for its high productivity growth, although there is no consensus on the magnitude of such growth. As a result, the argument for using productivity gains to reconcile the trade-off between agriculture/livestock growth, deforestation, and GHG emissions, all of which are addressed in this article, is reinforced.

3 Methodology

This article uses a computable general equilibrium model of Brazil, TERM-BR, to analyze the relation between productivity gains and land clearing. It is a multiregional and bottom-up model, tailored for regional and interregional analyses whose structure uses national results as aggregations of regional results (HORRIDGE, 2012).

The TERM-BR model has been applied mainly to study how specific policy shocks may affect Brazil, such as the economic impacts of fiscal policies (SANTOS, 2006), climate shocks on agriculture (MORAES, 2010), and the intensification of biofuel production and consumption (SANTOS, 2013), among others. The model was modified to cope with the goal of this study, including a land use module, following the advances made by Ferreira Filho and Horridge (2014). However, we took a step further and matched land-use changes to their GHG emissions.

Finally, in this study there are 36 commodities and industries, 15 Brazilian regions and/or states, 10 households and labor grades, and 2 margins (trade and transport). The core database is the 2005 Brazilian input-output table, presented in Ferreira Filho (2010). Additionally, the model includes three dynamic-recursive mechanisms: (i) a flow-stock relation between investment and capital stock, which assumes a one-year gestation lag; (ii) a positive relation between investment and profit rate; and (iii) a relation between wage increases and regional labor supply. These mechanisms as a whole allowed for a plausible base scenario for the future to be built.

3.1 TERM-BR production structure

In the TERM-BR production structure producers choose an optimal combination of primary and intermediary factors to minimize their costs subject to a production function whose structure is a composite of several “nested” Constant Elasticity of Substitution (CES) functions.

Figure 1 shows TERM-BR production structure, which is organized in four distinct levels and represents the production of several goods and services in the economy. At the top of the figure, quantities of final goods and services in each region and sector are determined by a Constant Elasticity of Transformation (CET) function, which induces production in favor of goods whose relative prices have increased.

At the next level, from top to bottom, intermediary goods (both domestic and imported goods) are combined with primary factors and taxes using a Leontief function, which combines the aforementioned elements in fixed proportions; in other words, primary factors and other inputs are complementary in the process of producing goods and services.

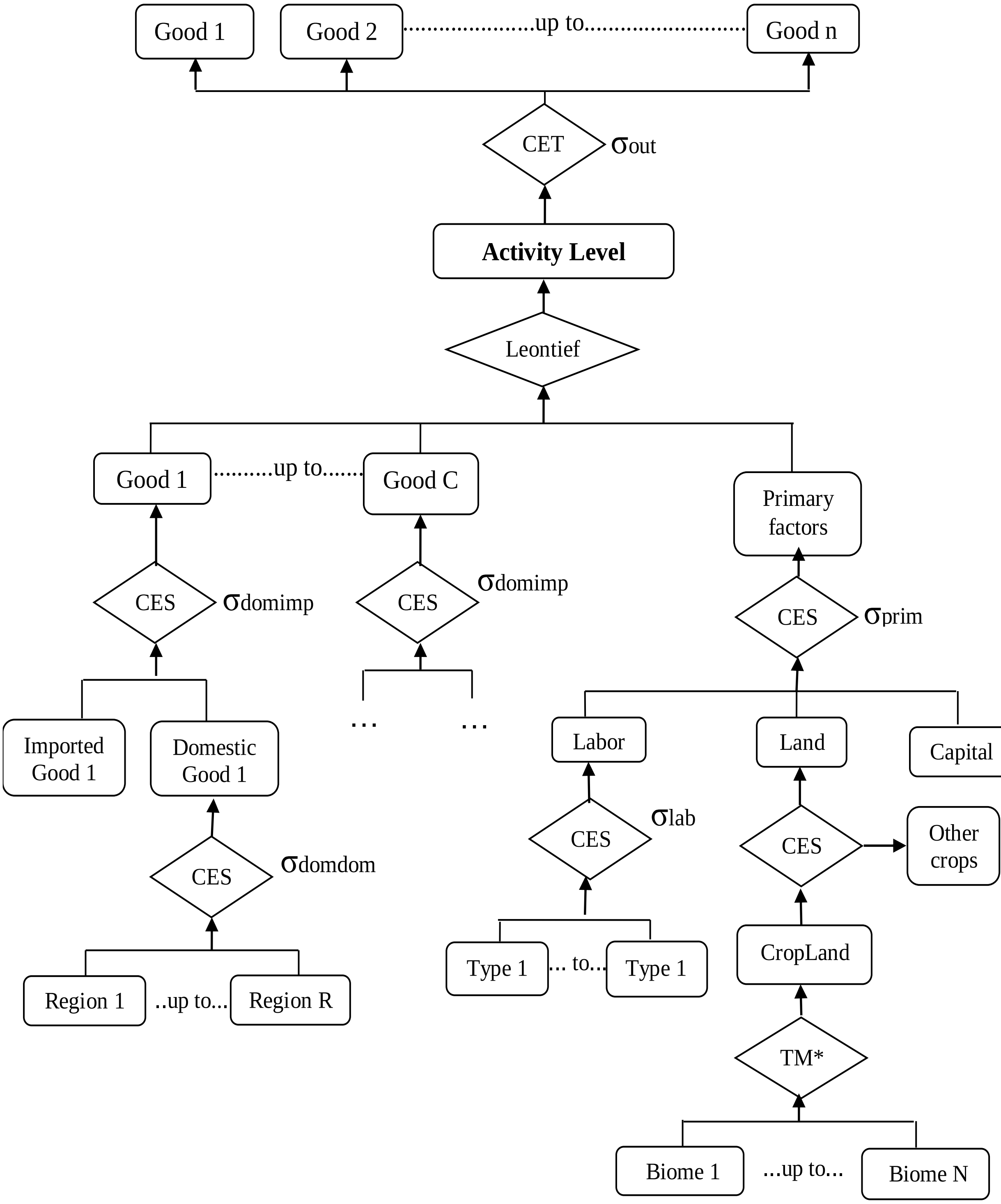

Figure 1 - TERM-BR nesting production structure
Source: Adapted from Horridge (2012)
* Transition Matrix (TM)

At the third level, composite inputs are combined through a CES functions, with particular Armington's elasticities of substitution. That is, goods from different sources are considered imperfect substitutes of each other. Still at the same level, primary factors (land, capital and labor) are also combined using a CES function, driven by an elasticity of substitution σprim.

At the last level, a labor composite is defined through a CES function which combines different types of skills and classifies them according to regional wages, a proxy for skills. Finally, at the last level other inputs are also represented by CES functions, which are a composite of domestic goods from several regions.

3.2 Household demands

Households choose the optimal consumption bundles by maximizing a utility function of the Klein-Rubin (or Stone-Geary) type, subject to a budget constraint. This utility function (Klein-Rubin) is often used in CGE models because it allows for subsistence and luxury goods to be disaggregated. With the maximization of the utility function, a demand equation system is generated that is referred to as Linear Expenditure System (LES). It describes each good as a linear function of total expenditure and of the prices of all goods, so the resulting equations are homogeneous of zero degree in prices and income. Figure 2 shows consumption possibilities for households, considering the maximization of the Klein-Rubin utility function.

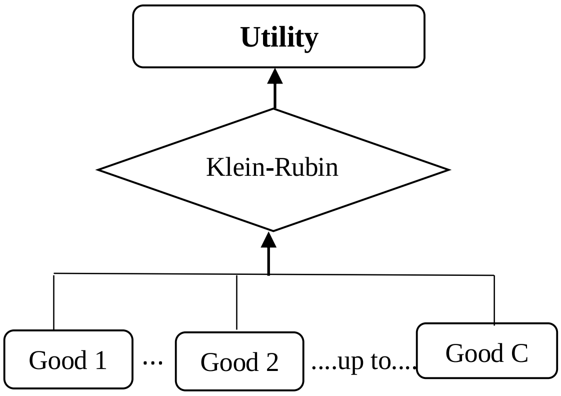

Figure 1 - Household demand structure in the TERM-BR model.
Source: Santos (2006).

Regional CGE models are connected by the trade in goods, which is supported by large interregional trade matrices that register each commodity by region of origin and destination, transported values (related to domestic and imported goods), and margins associated with trade and transportation.

3.3 Land-use changes and GHG emissions module

Land use changes and forests are treated endogenously through a transition matrix approach, calibrated with data from the Brazilian Agricultural Censuses of 1995/96 and 2006. The transition matrix shows the land use dynamic in a specific region (r) at two points in time – an initial (i) and the final one (f). Table 1 shows four land use categories: crop (cr), pasture (pt), plantforest (pt), and unused (un). The last one represents all areas not being used for agricultural purposes, such as forests, grasslands, urban areas, rivers, lakes, and reservoirs, among others. In other words, the “unused” category represents areas of native vegetation and is used as a proxy for evaluating deforestation.

Table 1 - Transition matrix for region r.

$LAND\ USE\ (p,q)$	$CROP_f$	$PASTURE_f$	$PLANTFOREST_f$	$UNUSED_f$	$TOTAL_f$
$CROP_i$	$(cr,cr)_{i,f}$	$\cdots$	$\cdots$	$(cr,un)_{i,f}$	$\sum_f (p,cr)_i$
$PASTURE_i$	$\cdots$	$(pt,pt)_{i,f}$	$\cdots$	$\cdots$	$\cdots$
$PLANTFOREST_i$	$\cdots$	$\cdots$	$(pf,pf)_{i,f}$	$\cdots$	$\cdots$
$UNUSED_i$	$(un,cr)_{i,f}$	$\cdots$	$\cdots$	$(un,un)_{i,f}$	$\cdots$
$TOTAL_i$	$\sum_i (cr,q)_{i,f}$	$\cdots$	$\cdots$	$\cdots$	$\sum_i \sum_f (p,q)$

Source: Prepared by the author

The elements of the main diagonal represent land use that remains under the same category, while the off-diagonal elements represent land conversion between the four land categories under consideration. For example, $(pt, cr)_{i,f}$ corresponds to the amount of pastures (pt) in the initial period (i) that were converted into crops (cr) in the final period (f). Summing over the column ($TOTAL_f$) gives the total for each category in the initial period, whilst summing over lines ($TOTAL_i$) gives the total in the final period. The transition matrix can be expressed in share form, as in Ferreira Filho and Horridge (2012, 2014) representing Markov probabilities, which are modeled as a function of land rent values, as shown by Equation 1.

$$S_{pqr} = \mu_{pr}.L_{pqr}.P_{qr}^{\alpha}.M_{qr} \qquad (1)$$

where (the r subscript denoting region/biome zones):
$S_{pqr} =$ share of land type p that becomes type q in region/biome r
$\mu_{pq} =$ a slack variable, adjusted to ensure that $\sum_q S_{pqr} = 1$;
L_{pqr} = a constant of calibration = initial value of S_{pqr}
P_{qr}^{α} = average unit rent earned by land type q
α = a sensitivity parameter, with value is set to 0.28
M_{qr} = a shift variable, initial value 1

The sensibility parameter "α" was set at 0.28 in order to give a normal representation of deforestation in the historical period. If land rents in crop areas increase, the rate of conversion of pastures into crops will also increase. Furthermore, to represent the conversion rate of the "Unused" category, a fictitious rent was employed based on a regional CPI (FERREIRA FILHO; HORRIDGE, 2014).

Land use changes and forests, as well as their GHG emissions, were represented in the new version of the TERM-BR model using observed data. Such representation employs transition matrices as calibrated with satellite imagery provided by the Brazilian National Institute for Space Research.

The new transition matrices also constitute an advance in relation to the former version of the model, as they incorporate a new dimension into the TERM-BR model, the Brazilian biomes, namely, Amazon (rainforest), Cerrado (savannah), Atlantic Forest (tropical forest), Pantanal (wetlands), Caatinga (semi-arid), and Pampa (grasslands), as show in Figure 3.

Figure 3 - Brazilian biomes.
Source: Adapted from (IBGE, 2014b).

The biomes capture the heterogeneity associated with different types of soil, weather, and carbon content, similarly to the idea of the Agro Ecological Zones (AEZs) developed by the Global Trade Analysis Project (GTAP)[3]. Besides, those differentials of soil, vegetation, and weather are accurately represented by biomes as compared to similar structures widely used for studying physical aspects of land use change.

The new dimension, then, captures different GHG emissions associated with the same land use category, but in distinct biomes. The conversion of "Unused" areas (which represent areas of native vegetation) into pastures, for example, leads to the release of different amounts of carbon dioxide in the Amazon and Cerrado biomes.

The new version of the TERM-BR model was developed in two stages with a module based on new information on land use and emissions. First, it was built from transition matrices by Brazilian biome and state. At this stage, it used satellite imagery, as noted before, which were disaggregated into polygons, biomes, municipalities, and GHG emissions for the whole country[4].

The first version of the transition matrices follows the format shown in the Second Brazilian Inventory of Anthropogenic Emissions by Sources and Removals by Sinks of Greenhouse Gases (BRASIL, 2010), with the exception of the regional dimension. At the second stage, the transition matrices built by state and biome were aggregated again under the CAT set, which considers 15 land use categories. Such categories were also aggregated in 4 broader categories, following model' structure, which was done under the new set ALNDTYPE, as showed in Table 2.

[3] More details can be found in Lee (2004).
[4] For more details, see Brasil (2010).

Table 2 – Mapping of land use categories.

Land categories	Disaggregated categories (old)	Broader categories (new)
FNM	Non-managed forests	Unused
FM	Managed forests	
Fsec	Secondary forests	
CS	Forests with selective timber extraction	
GNM	Non-managed fields	
GM	Managed fields	
Gsec	Secondary fields	
S	Urban areas	
A	Rivers and lakes	
Res	Reservoirs	
O	Other uses	
NO	Non classified areas	
Ac	Crops	Crop
Ref	Reforestation	PlantForest
Ap	Planted pastures	Pasture

Source: Prepared by the author.

The number of land use categories of the former model remains, but as noted before a new dimension Biome (Amazon, Cerrado, Caatinga, Atlantic Forest, Pampa, and Pantanal) was created to capture the heterogeneity of land use and GHG emissions between different regions (r) of the country. Besides, land use change was traced to its GHG emissions and the transition matrices can be interpreted through a hypothetical example:

- TRANS0 (“Non-managed forest”, “Pasture”, “MtGrosso”, “Amazon”) = 100 hectares of non-managed forests in the initial period converted into pasture in the final period in the Amazon Biome in Mato Grosso state;
- EMIS0 (“Non-managed forest”, “Pasture”, “MtGrosso”, “Amazon”) = 100 hectares of Non-managed forest converted into Pastures in the state of Mato Grosso in the Amazon Biome emit 100 gigagrams of carbon dioxide equivalent (CO_2 eq.);
- YTRANS2 (“Unused”, “Crop”, “Bahia”, “Cerrado”) = 50 hectares of Unused areas in the initial period converted into crops in the Cerrado Biome of Bahia state.

Figure 4 shows the data flow adopted for building the module of land use change and GHG emissions. The initial area matrix (TRANS0), after being aggregated into 4 broad categories, was annualized (YTRAN) following the model’s temporal structure.

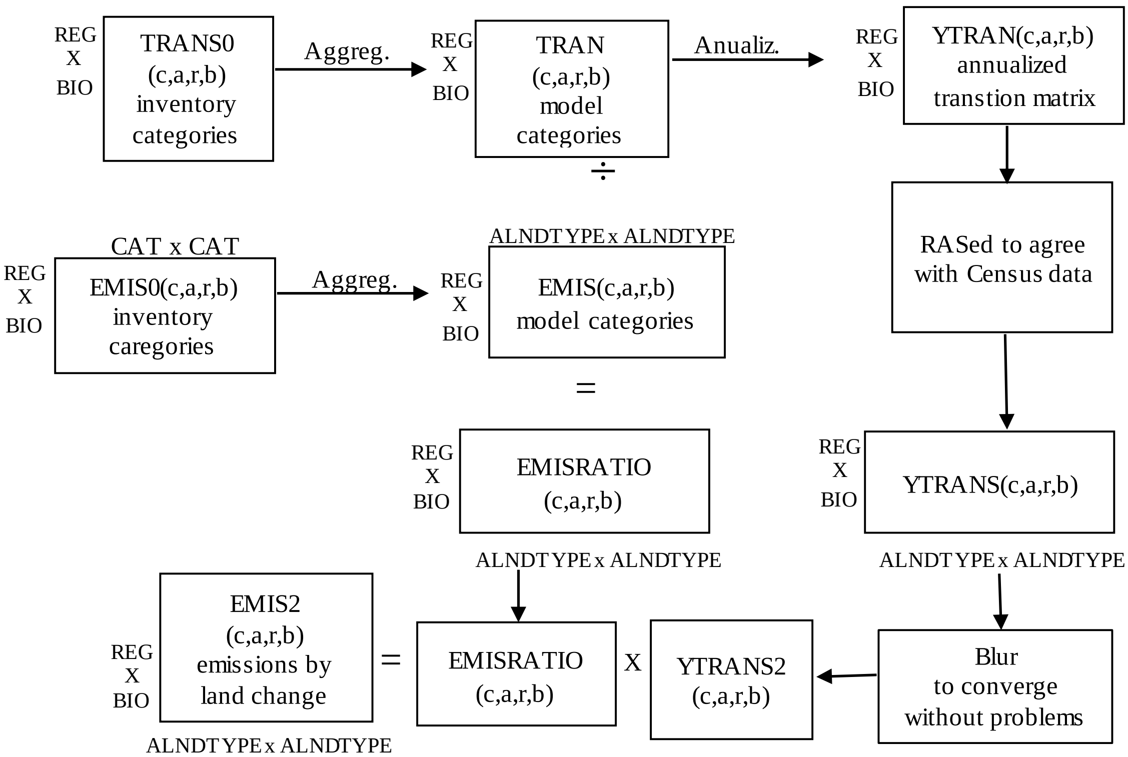

Figure 4 - Treatment of data on land-use change and emissions.
Source: Prepared by the author.

The RAS mathematical method was then applied to the resulting transition matrix to ensure that the totals matched the data from the Brazilian Agricultural Census. Thus, any area discrepancies between different data sources were solved. Furthermore, all data were analyzed using the GEMPACK software (HARRISON; PEARSON, 1996). As a result, the new transition matrices were assigned to GHG emissions, considering each land use category. Then, the emissions by hectare ratio (EMISRATIO) was applied to area data (YTRANS2) and the amount of GHG was obtained for each land use category, according to the biome and region under consideration. Figure 5 shows the new land supply and demand structure in the model with the new dimension, biome, incorporated into it.

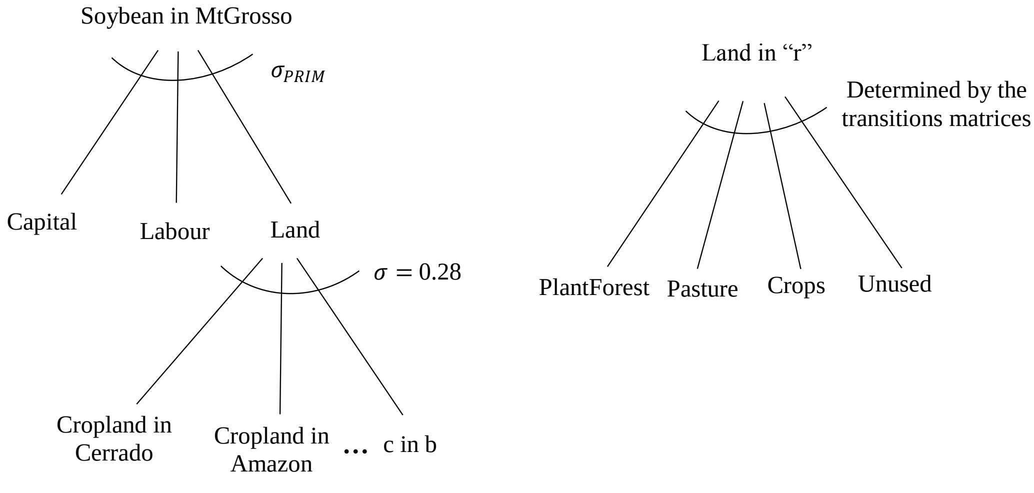

Figure 52 - Land supply (right-hand side) and demand (left-hand side) of the TERM-BR model.
Source: Prepared by the author.

At the end of the stages described, a new model suitable for handling land use and its GHG emissions endogenously emerged. Consequently, land (re)allocation was promoted through the four broad categories and transition matrices according to the biome and region, governed by a constant elasticity of transformation (CET) function.

Table 3 shows GHG emissions distributed by biome and land use category. In the initial database, cattle farming is the main emitter of GHG in Brazil, especially in the Amazon and Cerrado regions, which is a major indication of the locus of domestic emissions and of key activities for curbing the ongoing deforestation process in Brazil.

Table 3 - Emissions of converting Unused lands in other uses, by Biome, in gigagrams of carbon dioxide (initial database).

Land use	Amazon	Cerrado	Caatinga	MAtlantica	Pampa	Pantanal	**Total**
Crop	118,799	146,693	23,509	4,481	0	1,383	**294,866**
Pasture	891,264	165,451	27,913	91,285	1	11,829	**1,187,743**
PlantForest	1,337	2,076	-25	289	0	0	**3,678**
UNUSED	-173,462	-14,652	-4,770	2,427	-122	-366	**-190,945**
Total	**837,939**	**299,569**	**46,627**	**98,481**	**-121**	**12,847**	**1,295,342**

Source: Model's database.

Therefore, the TERM-BR model can analyze patterns of occupation of the Brazilian territory considering the main economic activities in each sub-region and the expansion of the agricultural frontier, associating them to GHG emissions. Furthermore, the model can indicate alternatives for the Brazilian agriculture in terms of reallocating economic activities with the aim of increasing agricultural production and reducing deforestation and GHG emissions.

3.4 Scenarios

The shocks implemented in this article take into account a number of stylized facts in the Brazilian economy, such as: (i) the lower productivity of livestock in the agricultural frontier as compared to other regions of the country; (ii) the high productivity of Brazilian agriculture, especially in frontier regions, where advanced production methods have been employed in crops such as soybean, cotton, among others. Productivity in livestock sector, then, still has room to increase at a faster rate than agriculture in Brazil. The shocks implemented are the following:

- **Policy 1**: increasing primary livestock productivity by 2 percent over 6 years, 2015-2020, but only in agricultural frontier regions;
- **Policy 2**: increasing primary agricultural productivity by 1.5 percent over 6 years, 2015-2020, in all regions;
- **Policy 3**: the previous two policies together.

In both cases, the effects of the policies are permanent. Besides, the effect of a productivity increase in only frontier livestock (Policy 1) was considered separately from the shock on agriculture (Policy 2) and then the two were aggregated under Policy 3. Through this procedure, we can identify if productivity gains in livestock alone are sufficient to curb the deforestation process, as well as to reduce GHG emissions.

3.5 Model closure

The model's closure and main features are:

- Real wage change drives the movement of labor between regions and activities (but not between labor categories). Total labor supply increases, according to official projections by IBGE.
- Capital accumulates between periods following the dynamic investment rule. Furthermore, capital stock is updated through the new capital price, e.g. the start-of-period price.
- Regional consumption follows labor income. Moreover, regional real government spending demand follows regional real household demand.
- The domestic GDP price index is chosen as the *numeraire*. Other prices should thus be interpreted as relative to the GDP price index.

- The national balance of trade is fixed as a percentage of real GDP.
- We divided the regions of the model into two groups: Land-constrained (LndUsed, where agricultural land is consolidated) and Frontier (region where land is available for expanding agriculture), as shown in Figure 6. Regions where deforestation is on the rise can be separated and specific policies applied to them.

Figure 6 - Frontier (green) and Land-constrained (yellow) regions of the model.
Source: Prepared by the author.

4 Results

Table 4 shows the results of the main macroeconomic variables cumulated in 2005-2035. As expected, the productivity increase in agriculture was positive for the Brazilian economy, once it boosted the country's growth by up to 0.51 percent in the broader scenario, which considers productivity gains both in agriculture and livestock (Policy 3).

Table 4 - Policy deviations: macro variables (real values): total growth cumulated in 2035.

Cumulative % growth	Househ.	Invest.	Gov.	Exports	Imports	GDP	Employ	Real wage	Capital Stock
Policy 1	0.08	0.19	0.08	0.11	0.09	0.11	0.00	0.13	0.16
Policy 2	0.38	0.51	0.38	0.31	0.26	0.40	-0.01	0.63	0.48
Policy 3	0.46	0.71	0.46	0.42	0.36	0.51	-0.01	0.76	0.65

Source: Model results

The scenario of productivity gains only in livestock in the frontier region (Policy 1) also generated positive results, highlighting the influence of that activity on the Brazilian economy. In this case, GDP increased by 0.11%, affecting other major variables such as household consumption (+0.08%) and government spending (+ 0.08%). Thus, all policies led to an increase in investment due to a reduction in the price of capital, whose effects on the capital stock only began to be felt in the post-2021 period, as capital is a rigid variable in the short run.

In productive terms, the policies boosted agricultural output, as expected. Policy 1, for example, benefited production in other regions of Brazil (LndUsed), notably when rice and cotton crops are considered, as shown in Table 5. It is also worth mentioning that cattle farming shifted to frontier regions (+8.9%), which may explain the increase observed in crops in non-frontier regions as a result of more land becoming available.

Table 5 - Agricultural output variation, cumulative percent change in 2005-2035 (policy deviation).

agricxtota	Policy 1		Policy 2		Policy 3	
	Frontier	LndUsed	Frontier	LndUsed	Frontier	LndUsed
Rice	0.5	0.2	2.9	7.5	3.4	7.7
Corn	2.4	0.0	1.9	3.3	4.4	3.3
Wheat	0.6	0.3	3.0	4.3	3.5	4.6
Sugarcane	0.3	0.2	1.0	2.3	1.3	2.6
Soybean	0.1	0.3	9.7	10.0	9.8	10.3
Other agric	0.2	0.1	1.7	3.2	1.9	3.3
Cassava	0.4	0.2	0.7	5.3	1.2	5.5
Tobacco	0.2	-0.1	2.8	4.5	3.0	4.4
Cotton	0.1	0.3	2.9	0.1	3.1	0.4
Citrus fruits	0.2	0.3	-0.1	3.9	0.1	4.2
Coffee	0.2	0.4	11.1	11.7	11.3	12.1
Forestry	0.3	0.2	2.5	5.0	2.8	5.2
Meat cattle	8.9	-4.4	1.0	0.8	10.1	-3.7
Milk cattle	-0.1	0.8	0.8	0.9	0.7	1.7

Source: Model results

Thus, under policies 1 and 3, the shift of cattle farming to frontier regions and the growth of crops in traditional agricultural regions were boosted, as noted before. Such movements were enhanced by an increase in agricultural productivity in the rest of the country (LndUsed), as indicated by the results of policies 2 and 3. These policies reinforce the role of the agricultural frontier as a productive hub, as indicated by the growth of meat cattle (+10.1%) and of agriculture as a whole, in this case represented by an increase in the production of soybean (+9.8%) and corn (+4.4%).

Prices were also affected by the policies, as shown in Figure 7. It presents the results of Policy 3, the broadest one, dividing the consumers into 10 income ranges[5] (POF1 to POF10).

[5] POF1 ranges from 0 to 2 minimum wages, POF2 from 2+ to 3, POF3 from 3+ to 5, POF4 from 5+ to 6, POF5 from 6-8, POF6 from 8-10, POF7 from 10-15, POF8 from 15-20, POF9 from 20-30, and POF10 above 30 minimum wages. The minimum wage in Brazil in 2005 was around US$150.00, considering US$1.00 = R$ 2.00

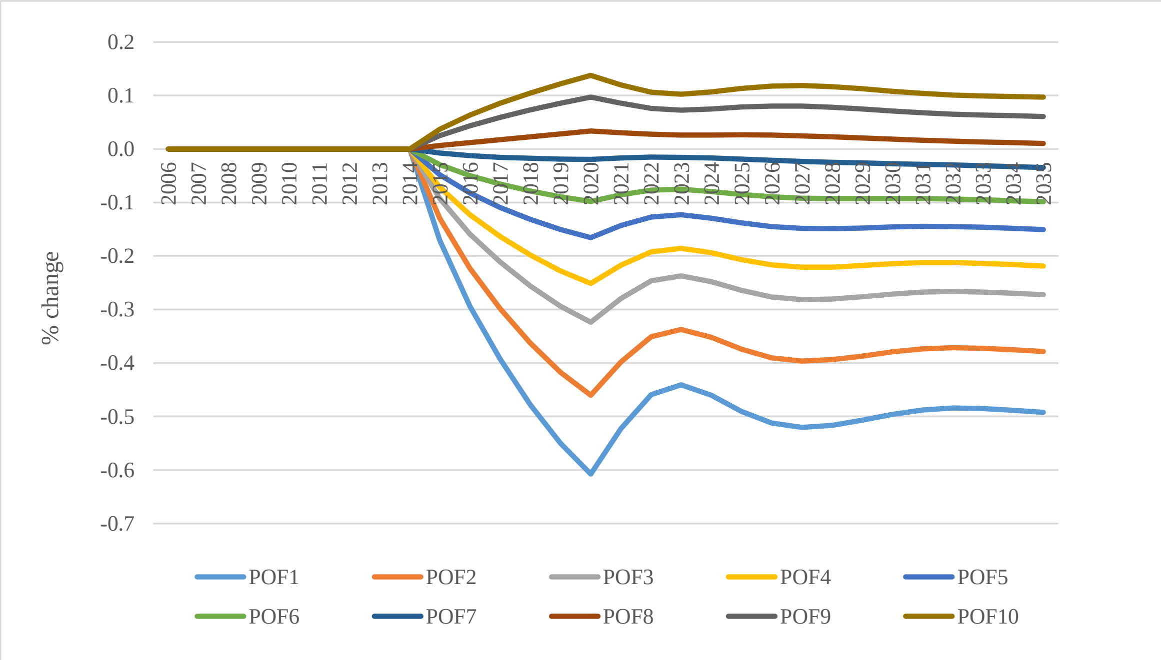

Figure 7 - Policy 3: consumer price index by household income, cumulative percentage change in 2005-2035 (deviations). Source: Model results.

The policies improved income distribution, especially Policy 3 (aggregate of policies 1 and 2) by reducing consumer prices for the POF1-POF5 income ranges, which represent consumers with the lowest incomes. Moreover, the productivity gains observed in the agricultural frontier spread their effects by reducing prices in other regions of the country. For example, in RestNE (Ceará, Rio Grande do Norte, Paraíba, and Sergipe) and PernAlag (Pernambuco and Alagoas), two of the least developed regions of Brazil, prices were also affected.

Table 6 shows the impact of productivity gains in terms of land prices. As expected, land prices dropped in almost all scenarios, except in that of Policy 2. In this case, the increase in productivity in crops did not lead to a reduction in the prices of pasturelands, as occurred with Policy 1, whose shock on livestock effectively reduced the prices of cropland.

Table 6 - Rental agricultural land price, cumulative percent change in 2005-2035 (policy deviation).

pagrland	Policy 1		Policy 2		Policy 3	
	Frontier	LndUsed	Frontier	LndUsed	LndUsed	LndUsed
Crop	-0.4	-0.1	-8.7	-12.3	-9.0	-12.4
Pasture	-5.1	-10.5	2.2	2.4	-3.0	-8.3
PlantForest	-1.2	-0.9	-15.6	-18.2	-16.5	-19.0

Source: Model results

The effects of Policy 1 spread to other regions (LndUsed) beyond the agricultural frontier, where the shock was applied. These effects were brought about by an increase in land supply resulting from productivity gains in livestock in the frontier region. The main difference of these results, also showed by Policy 3, was the magnitude of the drop in prices.

Policy 2, in turn, signals something different for pastures. In this case, the price of pasturelands increased, since there were no changes in livestock productivity and this activity continues to be land-intensive, especially in the Amazon and Cerrado biomes, as shown in Table 7.

Table 71 - Land use variation due to productivity shocks, cumulative percent change 2005-2035 (policy deviations).

Policy 1						
qlndbrd1_d	Amazon	Cerrado	Caatinga	Atlantic Forest	Pampa	Pantanal
Crop	1.05	0.58	0.20	0.13	0.06	3.15
Pasture	-0.13	-0.52	-0.40	-0.18	-0.08	-0.28
PlantForest	1.31	0.43	0.96	0.33	0.29	1.49
Unused	0.00	0.03	0.09	0.08	0.01	0.07
Policy 2						
qlndbrd1_d	Amazon	Cerrado	Caatinga	Atlantic Forest	Pampa	Pantanal
Crop	-4.68	-1.57	-0.88	-0.23	-0.12	-4.12
Pasture	0.56	1.00	0.39	0.20	0.15	0.32
PlantForest	-4.45	-1.79	-4.22	-0.98	-1.02	-5.32
Unused	0.00	0.08	0.03	-0.01	0.03	0.00
Policy 3						
qlndbrd1_d	Amazon	Cerrado	Caatinga	Atlantic Forest	Pampa	Pantanal
Crop	-3.70	-1.00	-0.69	-0.09	-0.05	-1.07
Pasture	0.44	0.49	-0.01	0.02	0.08	0.05
PlantForest	-3.22	-1.36	-3.27	-0.66	-0.73	-3.88
Unused	0.00	0.11	0.12	0.07	0.03	0.07

Source: Model results.

In Policy 1, the productivity shock reduced pasturelands in all the considered biomes, but it did not impose constraints on the growth of crops and native vegetation areas. On the contrary, it can increase land supply for those activities. In Policy 2, productivity gains in crops curbed the clearing of forests and fields in the Amazon (stable), Cerrado (0.08%), and Caatinga (0.03%) biomes, as expressed by the variation in the "Unused" category, which was close to zero. Despite the small magnitude of those results, they highlight the livestock-deforestation relationship through the growth of cattle farming in areas of natural vegetation, especially in the Amazon Biome. Nevertheless, under Policy 2, the livestock-deforestation relationship was controlled by productivity gains in agriculture that made more land available for expanding livestock activities.

It is worth highlighting that cattle farming is seen as the main trigger of deforestation. Thus, when livestock expansion is controlled through, for example, productivity gains, there is no spillover effect of deforestation to the other biomes. In other words, Borlaug' Hypothesis is fully met, as in policies 1 and 3. However, when such activity is neglected, as in Policy 2, there is a sort of "leakage" and deforestation is displaced to other biomes, meaning that Borlaug's Hypothesis is only partially met.

In Policy 3, the increasing productivity of both livestock and agriculture can lead to mixed and/or overlapping results. This is what happened in the Cerrado region, where the broader shock of productivity (agriculture + livestock) led to a reduction in both crop and livestock areas, as shown in Figure 8.

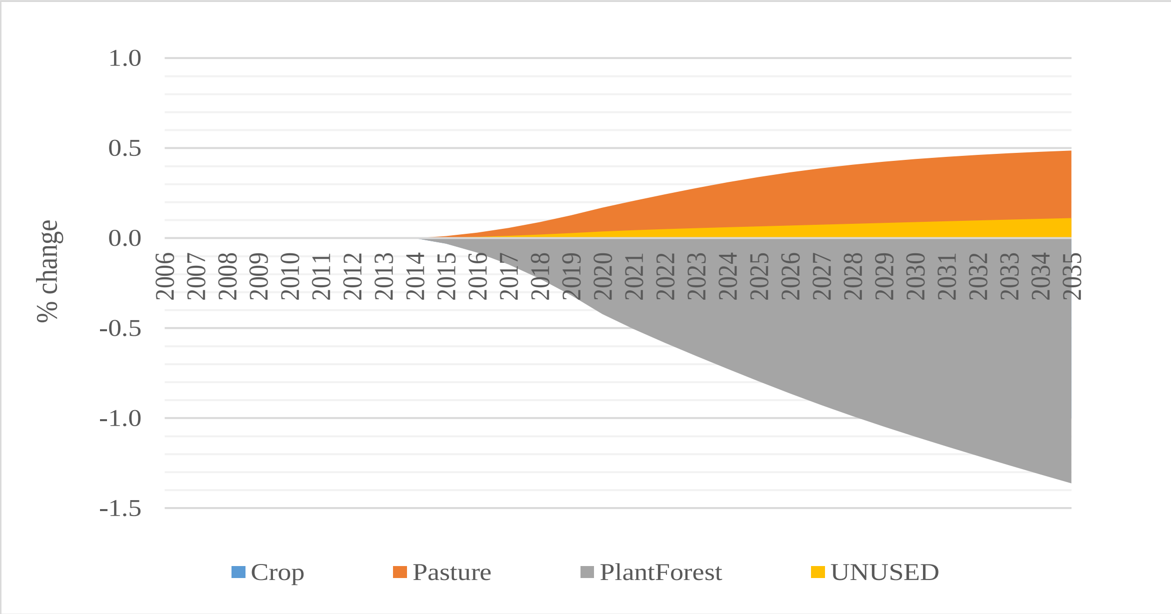

Figure 8 - Policy 3: land use variation in the Cerrado region as a result of a productivity shock, cumulative percent change in 2005-2035 (deviations).
Source: Model results.

Decreasing land reallocation and deforestation rates were key for reducing domestic GHG emissions. This result should be considered not only from the perspective of avoided emissions, but also from that of removals generated in native vegetation areas. Figure 9, for example, shows how productivity gains in livestock (Policy 1) can be an important tool for slowing down domestic emissions. In this case, productivity increases tend to decrease land conversion rates, especially those of conversion into pastures, thus reducing GHG emissions. Those effects are more intense in the Amazon Biome, which has the largest amount of carbon accumulated above and below the soil in relation to other biomes.

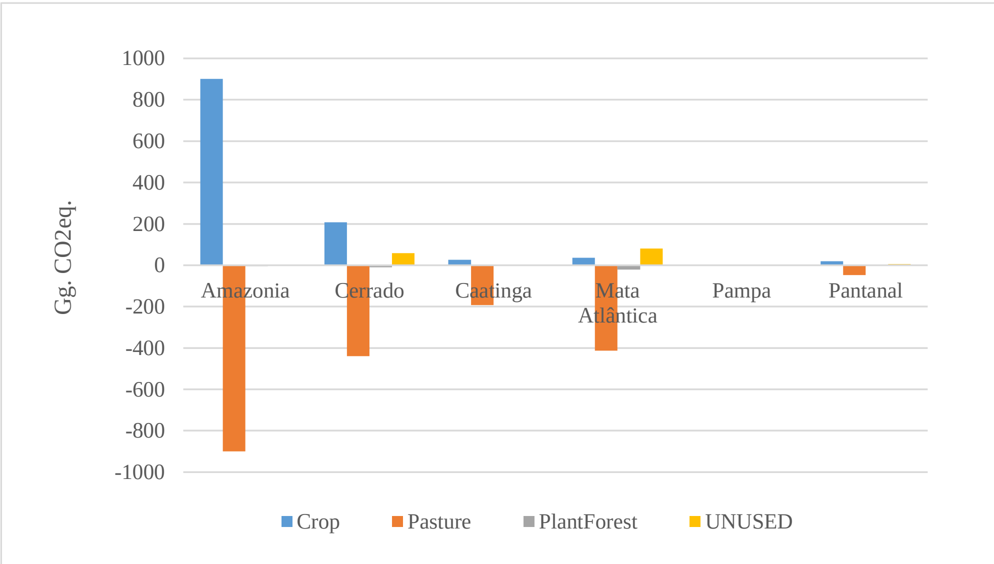

Figure 9 - Policy 1: land use emissions in Brazil by biome, in gigagrams of carbon dioxide equivalent cumulated in 2035 (deviations from the baseline).
Source: Model results.

Cerrado Biome in turn, accounted for the greatest reduction in GHG emissions. This was due to the absence of constraints on land expansion, as well as to the proximity between the Cerrado and Amazon biomes, which made it possible for cattle farming to move from the former to the latter, incorporating land and releasing GHG. Furthermore, productivity increases in crops tend to boost the growth of crop areas, which explains the reduction in emissions from crops that occurred under Policy 2, as shown in Figure 10.

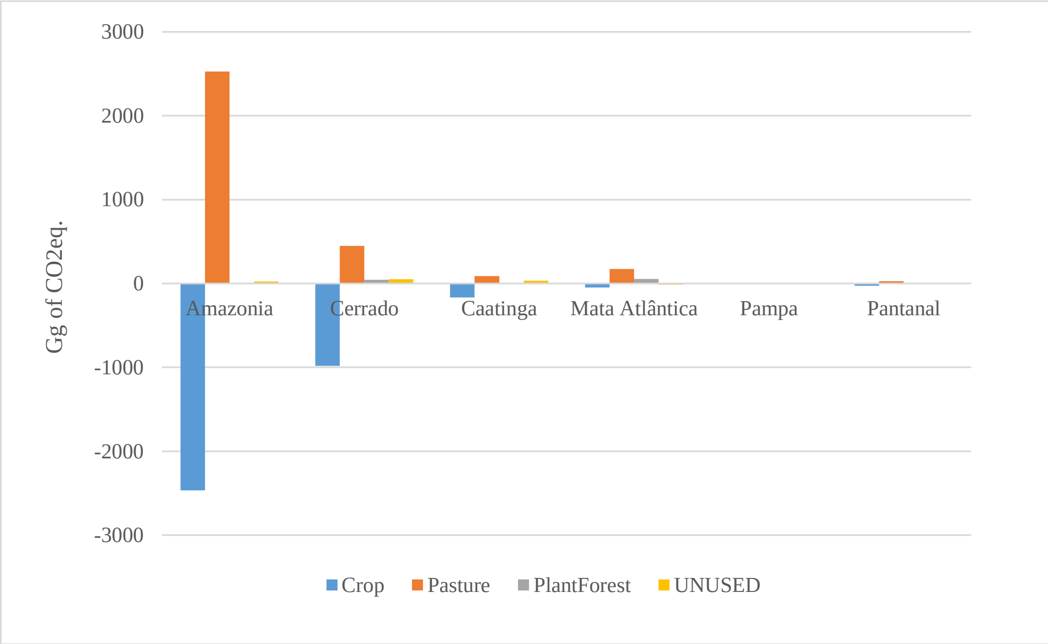

Figure 10 - Policy 2: land use emissions in Brazil by biome, in gigagrams of carbon dioxide equivalent, cumulated in 2035 (deviations from the baseline).
Source: Model results.

Under Policy 3, as noted before, the results may be mixed and/or overlapping. This happened in terms of land allocation and GHG emissions. Figure 34, for example, shows the representative case of emissions from the Cerrado Biome, where shocks on agriculture and livestock were combined, reducing crop and pasture areas. This effect also affects emissions from the Cerrado region, which follow the behavior of crop and pasture areas, as shown in Figure 11.

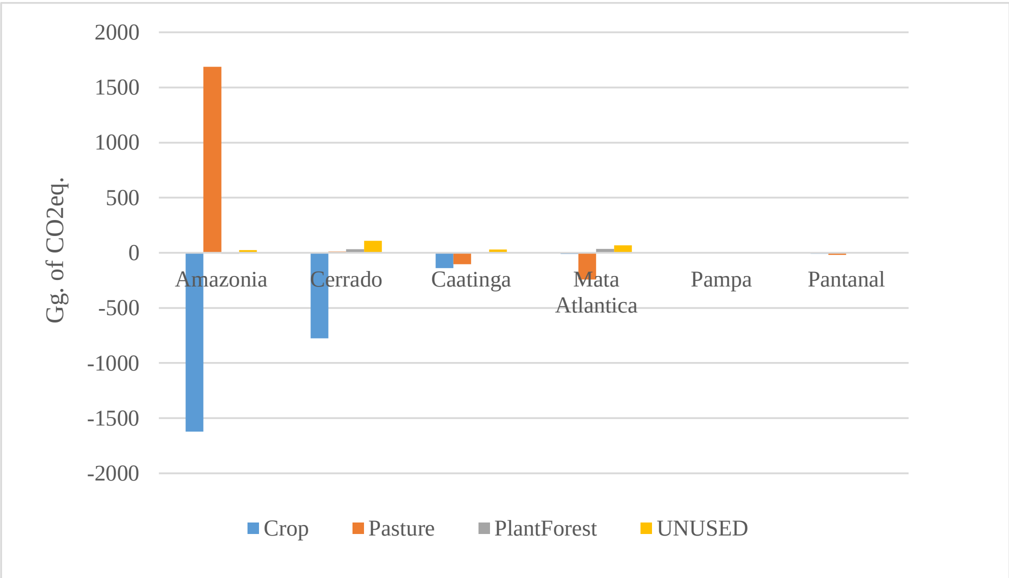

Figure 113 - Policy 3: emissions by biome, in gigagrams of carbon dioxide equivalent, cumulated in 2035 (deviations from the baseline).
Source: Model results.

Table 8 shows the efficiency of Policy 3 – which is the combination of the policies 1 and 2 – in curbing GHG emissions. Thus, emissions by source in the initial (2005) and final (2035) periods were considered. In addition, the shares of each source in total emissions from Brazil were also considered.

Table 8 - Policy 3: total emissions and shares, by source, in the initial and final periods.

EMIT	2005		2035	
	Gg. CO2eq.	Share (%)	Gg. CO2eq.	Share (%)
Mining	113,665	5.4	253,277	10.9
Gasoline	32,705	1.5	66,568	2.9
Gasalcohol	9,449	0.4	20,499	0.9
Oil fuel	139,591	6.6	323,059	13.9
Petrochemicals	15,364	0.7	37,160	1.6
Activity	479,533	22.6	1,076,730	46.2
LUC	1,329,081	62.7	552,437	23.7
Total	2,119,387	100.0	2,329,730	100.0

Source: Model database (2005) and results (2035).

In the initial period, emissions related to land-use changes accounted for 62.7% of total emissions from the country, or for 1,329,081 gigagrams of dioxide carbon equivalent (Gg. of CO2eq.). However, under Policy 3, such total drops by more than half, by -58.4%, which corresponds to 552,437 Gg. of CO_2 eq. Thus, productivity gains in agriculture as a whole (crop + livestock) are an important tool to curb deforestation and reduce domestic GHG emissions. Furthermore, it does not impose constraints on other economic sectors, for example, on the industrial sector, apart from benefiting the climate.

Finally, the policies were effective in promoting economic and environmental gains. However, these achievements tend to vanish as the productivity effects fade away and more technology becomes necessary to promote them again. This is not a trivial task, especially in a country with high productivity rates in agriculture. Thus, this sector must consider other alternatives to keep growing, such as, for example, that of promoting shifts to new regions where land is still available, as in the northeast, where almost half the native vegetation (Caatinga) was deforested in the past.

5 Final remarks

This article analyzed the impacts of productivity gains in agriculture on the economy, land use changes, and GHG emissions. The results show that the policies considered here can “save” land and thus avoid more deforestation, as stated by Borlaug’s Hypothesis. In addition, the policies managed to reduce GHG emissions from all Brazilian biomes, especially from the Amazon and Cerrado biomes.

Increases in agricultural productivity benefit the country as a whole, as a result of their positive macroeconomic effects, such as higher consumption, production and investment levels and GDP growth. In addition, income distribution was enhanced by lower prices for the poorest households.

It is worth highlighting how the policies were efficient in reducing deforestation and emissions in the Cerrado and Amazon biomes, according to the shock considered. The effects of the Borlaug Hypothesis, although suitable for Brazil, may vary according to the biome and activity (livestock or agriculture) under analysis, and in some cases they can be strengthened, as in the Cerrado region under Policy 3.

Finally, this study took a step forward in studying land use change and its integration into GHG emissions in a CGE model, as tailored to the Brazilian case. The role of productivity gains was demonstrated as an alternative for reducing deforestation and increasing, or at least preserving, the growth of agricultural production. However, the results show that the effects of the policies are limited if they are focused on productivity with no other alternatives for agriculture, since productivity gains tend to fade away. In this regard, other issues should be considered as part of the solution for the trade-off between agriculture and deforestation. A good alternative is to turn to other previously deforested regions that are suitable for agriculture, such as Brazil’s northeast region, which would reduce the pressure on forested areas.

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