University of São Paulo
“Luiz de Queiroz” College of Agriculture

Essays on land-use change and greenhouse gas emissions in Brazil

Jonathan Gonçalves da Silva

Thesis presented to obtain the degree of Doctor in Science. Area: Applied Economics

Piracicaba
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Jonathan Gonçalves da Silva
Bachelor in Science in Economics

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versão revisada de acordo com a resolução CoPGr 6018 de 2011

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CONTENTS

RESUMO

Ensaios sobre as mudanças do uso da terra e emissões de gases de efeito estufa no Brasil

Este trabalho analisa as mudanças do uso da terra e florestas no Brasil, com ênfase no desmatamento e nas emissões de gases de efeito estufa (GEE). Mais especificamente, avaliam-se: (i) como a literatura especializada realiza a integração entre as mudanças do uso da terra e emissões de GEE no arcabouço dos modelos de equilíbrio geral computável (EGC); (ii) os principais impactos em termos econômicos e de emissões, de políticas de redução do desmatamento. Para isso, esta tese foi dividida em três ensaios independentes. O primeiro ensaio, de caráter teórico, avalia as principais contribuições para a integração das mudanças do uso da terra às emissões de gases de efeito estufa em modelos EGC. O segundo ensaio, é um estudo empírico sobre os impactos econômicos do desmatamento zero no Bioma Amazônia. O terceiro ensaio, analisa as implicações de ganhos de produtividade na agropecuária sobre a alocação de terras, emissões de GEE e economia brasileira. Os principais resultados evidenciam as dificuldades para a integração das mudanças do uso da terra às emissões de GEE, bem como a efetividade do controle do desmatamento na Amazônia em reduzir as emissões nacionais, apesar de impor perdas à economia e intensificar as desigualdades regionais. Já os ganhos de produtividade na agropecuária, também reduziram as emissões domésticas, mas, sem impactar negativamente a economia. Porém, tais efeitos são limitados, uma vez que expiram com os ganhos de produtividade.

Palavras-chave: Uso da terra; Gases de efeito estufa; Modelos EGC

ABSTRACT

Essays on land-use change and greenhouse gas emissions in Brazil

This study evaluates the land use changes and forests in Brazil, focusing on deforestation and its greenhouse gas emissions (GHG). More specifically, it analyses: (i) how the specialized literature integrates land-use changes to GHG emissions into a computable general equilibrium (CGE) framework; and (ii) the economic impacts of halting the deforestation. For this purpose, this study was divided into three independent essays. The first essay is theoretical, and evaluates the state of the art of the integration between land-use change and GHG emissions into CGE models. The second essay, is an empirical study about the economic impacts of zero deforestation in the Amazon Biome. The third essay, evaluates the implication of productivity gains in agriculture on land allocation, GHG emissions and the Brazilian economy. The results highlight the difficulties to integrate land use to its GHG emissions, as well as the effectiveness of the deforestation control in the Amazon to reduce national emissions, although it imposes losses to the economy and boosts regional inequalities. Finally, productivity gains in agriculture in turn, also may reduce the domestic emissions, but with no adverse impacts on the economy. However, such effects are limited, as they expire with the productivity gains.

Keywords: Land use; Greenhouse gases; CGE models

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LIST OF ABBREVIATIONS

AEZ – Agro-Ecological Zone

CEPEA – Centro de Estudos Avançados em Economia Aplicada (Center for Advanced Studies on Applied Economics)

EPPA – The Emissions Prediction Policy Analysis Model

FARM – The Future Agricultural Resources Model

IBGE – Instituto Brasileiro de Geografia e Estatística (Brazilian Insitute for Geography and Statistics)

IMAGE – The Integrated Model to Assess the Global Environment

INPE – Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research)

GHG – Greenhouse gases

IGSM – Integrated Global System Model

IPCA – Índice de Preços ao Consumidor Amplo (Expanded Consumer Price Index)

IPCC – Intergovernmental Panel on Climate Change

GTAP – Global Trade Analysis Project

MNP – Milieu en Natuur Planbureau (The Netherlands Environmental Assessment Agency)

MPSGE – Mathematical Programming System for General Equilibrium

OECD – Organisation for Economic Co-operation and Development

USDA – United States Department of Agriculture

WRI – World Resources Institute

1 INTRODUCTION

The capacity of agriculture to generate income, employment and a positive trade balance are features that make it a strategic sector for the Brazilian economy. Between 1994 and 2011, this sector contributed, on average, 24.6% of the Brazilian GDP. Over the same period, agriculture alone accounted for 17.1% of GDP, while the share attributed to livestock was 7.1% (CENTRO DE ESTUDOS AVANÇADOS EM ECONOMIA APLICADA - CEPEA, 2014).

Agriculture has therefore turned Brazil into a major player in the global food market. Currently, the country is a major producer of coffee, orange juice, soybean, cotton, beef, sugar, and ethanol, among other products. As a result, the United States Department of Agriculture - USDA (2014) stated that the role of Brazilian agriculture as a major player in the global context will be a lasting one, especially in the areas of grain and beef cattle production. Such success in agriculture is due, among other factors, to public incentives (especially in the 1960s and 1970s), productivity gains, and land availability. The latter allowed agricultural expansion in its extensive form, characterized by land incorporation. It made it possible for crops and pastures to expand into new regions.

The 2006 Agricultural Census shows that livestock activity benefited largely from land incorporation, since about 160 million hectares (Mha), i.e. 48.1% of all Brazilian agricultural establishments consist of pastures. Furthermore, in the intercensal period pasture areas grew by 10.3%, especially in Brazil's north region. Croplands, in turn, despite their smaller area, corresponding to less than half of the land occupied by pastures or 63 Mha, grew by 21.9% between 1995 and 2006. Such growth is concentrated in two regions, the mid-west (+103.7%) and the north (+15%) regions (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE, 2014).

The specialized literature associates agricultural expansion to another ongoing phenomenon in countries such as Brazil, namely, deforestation. Several authors, such as Margulis (2003), Simon and Garagorry (2005), Morton et al. (2006), Hargrave and Kis-Katos (2013), among others, have evaluated this relationship. Despite using distinct methodologies, all of those studies agree that this is a complex phenomenon in its causes and consequences.

In Brazil, estimates show that, up to 1980, 300,000 km² of native vegetation had been deforested in the Legal Amazon region, or 6% of its biome. In the 1980s and 1990s, more than 280 thousand km² of forests gave way to other activities, a process that became more intense in the following period. In the early 2000s, for example, the accumulated deforested area amounted to 670 thousand km². That was when deforestation in the Amazon region reached its peak (BRASIL, 2013a).

Nonetheless, after years of significant and almost continuous growth, deforestation began to drop in the mid-2000s. The deforested area in the Legal Amazon region declined by 79%, from 27.772 km² in 2004 to 5.843 km² in 2013 (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2014).

The reduction in deforestation in Brazil did not lessen its responsibility in relation to the adverse effects of climate change, resulting from decades of GHG emissions. The relationship between deforestation and GHG emissions is the result of the share of land-use change and forestry in Brazil's total emissions[1], 57% in 2005 and 22% in 2010. Besides, in 2005, almost 75% of all domestic of carbon dioxide emissions was caused by land-use change, mainly deforestation (BRASIL, 2013b).

Nonetheless, most domestic emissions resulting from land-use change and forestry were generated in the largest Brazilian biomes, the Amazon and Cerrado regions. Together, they accounted for 68.3% of all net domestic CO_2 emissions in 2005, while other biomes such as the Atlantic Forest and the Caatinga, Pantanal, and Pampa regions accounted for 6.3%, 3%, 1.3%, and 0%, respectively, meaning that they were responsible for only 10.6% of all emissions (BRASIL, 2010).

In regional terms, both emissions and land-use change are concentrated in the north and mid-west regions, mainly in an area comprising the states of Rondônia, Mato Grosso, Pará, and Tocantins. This region is referred to as the "Deforestation Arch" and it concentrates the Brazilian municipalities with the highest deforestation indices, meaning that they are a priority target for controlling the clearing of new areas and reducing GHG emissions domestically.

Therefore, policies to curb deforestation and, consequently, emissions in a large country such as Brazil should consider the specificities of the regions and biomes in question. For example, one hectare of forest in the Amazon Biome may have 213 tons of carbon, whereas the same hectare in the Cerrado region may have just 78 tons of carbon (BRASIL, 2010). Hence, policies applied to different biomes and/or regions tend to generate distinct results, mainly in terms of emissions.

[1] In CO_2e, i.e. carbon dioxide equivalent, is a standard unit for measuring emissions from various greenhouse gases. It expresses the impact of each GHG in terms of the amount of CO_2 with the same potential of warming.

In addition, limiting new land supply with the aim of reducing deforestation and GHG emissions can slow down Brazil's agricultural growth and adversely affect food security as well. Besides, soybean and sugarcane, two important temporary crops for Brazil due to their strategic role in energy policies, would also be adversely affected by land constraints.

Brazilian agriculture has therefore to face the challenge of increasing food in a scenario of an increasing demand for commodities, mostly in the developing world. Furthermore, it has to reconcile food and biofuel production, without harming the former and avoiding price increases. Finally, this sector must continue to expand, but without increasing deforestation and, consequently, GHG emissions.

Considering what was mentioned above, this thesis analyzes the economic impacts of policies to reduce deforestation and GHG emissions in Brazil through an economic model tailored to deal with land-use changes and resulting emissions. More specifically, the following issues are considered: (i) how these topics are treated in the specialized literature; (ii) what are the main economic impacts of reducing deforestation and alternative policies such as those designed to increase productivity gains in agriculture.

This thesis is divided into three independent essays. The first essay, of a theoretical character, evaluates some contributions to the integration of GHG emissions and land-use change into a computable general equilibrium (CGE) framework. The second one is an empirical study about halting deforestation in the Brazilian Amazon area, which was done through a new version of a CGE model tailored to represent land use and GHG emissions endogenously. The third essay analyzes the impacts of productivity gains in agriculture on land allocation, GHG emissions, and the Brazilian economy at large. In this study, we also deal with deforestation reduction, but through a possible land saving effect triggered by productivity gains in agriculture, as suggested by the Borlaug Hypothesis (BORLAUG, 2002).

Therefore, this study takes a step forward in discussing land allocation and GHG emissions in Brazil. First, by analyzing how the specialized literature deals with this issue. Second, in a quantitative way, through the development and application of a land use and emission module coupled to a CGE model, which permits the implementation of specific policies by region and/or biome. Finally, this study can support the evaluation of social costs related to deforestation control, highlighting which sectors, products, and agents will benefit from or be harmed by the implementation of such policies.

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2 LAND-USE CHANGE AND GREENHOUSE GAS INTEGRATION INTO A COMPUTABLE GENERAL EQUILIBRIUM FRAMEWORK

Abstract

This essay analyzes the state of the art of the integration between GHG emissions and land-use change into a computable general equilibrium (CGE) framework. For this purpose, two main approaches were considered. The first one is represented by individual models adapted to deal with land-use change and emissions, such as the GTAP-AEZ and FARM models. The second approach refers to integrated systems such as the EPPA-IGSM and IMAGE-LEITAP systems, which are part of larger systems that generate and use data for their respectively structures. Moreover, the Brazilian case was analyzed through the TERM-BR model, which is similar to the models considered in the first approach. In the individual modeling, land heterogeneity is incorporated through AEZs, while integrated models, in general, use data generated by other sub-models, which facilitate the integration and exchange of information. Finally, the challenge of both approaches is that of detailing the terrestrial system accurately and capturing its economic implications. In addition, to represent such complex phenomenon as land-use change and its emissions, other important issues should be incorporated by modeling, such as GHG removals and the assignment of values for unused land, which is not a simple task and has been requiring an increasing amount of time in studies.

Keywords: Land heterogeneity; Greenhouse gases; CGE models

2.1 Introduction

Greenhouse gases[2] play an important role in supporting life on Earth. This is done through the absorption of part of the solar radiation, which keeps the temperature at appropriate levels for the survival of all species. However, over time and with human action, this natural process and climatic conditions have changed worldwide. As a result, the international community turned to this phenomenon to look for ways to contain and mitigate its adverse effects.

Therefore, GHG emissions and their sources were analyzed and the burning of fossil fuels and industrial processes were identified as the main global emitters. Nonetheless, some countries, especially Brazil and Indonesia, stood out for their emission profile, predominantly associated with land-use change and forests. These sources account for 17% of all GHG emissions worldwide (INTERGOVERMENTAL PANEL ON CLIMATE CHANGE - IPCC, 2007).

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[2] CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrous oxide), HCFs (hydrofluorocarbons), PFCs (perfluorocarbons), SF_6 (sulfur hexafluoride), among others.

It is worth highlighting that emissions from land-use change and forests are those related to deforestation, the clearing of native areas for agriculture, and burning practices, among other sources. In 2011, Brazil was ranked seventh among the greatest GHG emitters due to these emissions, which when land-use change and forestry are included increase from 1,131.10 million metric tons of dioxide carbon equivalents ($MtCO_2e$) to 1,419.10 $MtCO_2e$, corresponding to 25.5% more emissions (WORLD RESOURCES INSTITUTE - WRI, 2014).

Thus, to reduce its domestic GHG emissions, the Brazilian government turned to deforestation, because of its contribution to the total emitted domestically and to its capacity to lead to a smooth transition to a low-carbon economy. Furthermore, deforestation control does not require major sacrifices from industry or structural changes in the economy. However, in a large country like Brazil, where critical issues such as agrarian reform, agricultural production, environmental preservation, land-use change, and forests have to be addressed, which can be problematic.

Therefore, to evaluate the costs and benefits of reducing emissions a model is required that combines land-use changes, economic variables, and GHG emissions, apart from also considering distinct regions, some of which can be large, as in the Brazilian case.

Thus, this essay analyzes the state of the art of the integration between GHG emissions and land-use change and forests into the CGE framework, focusing on economic aspects, database treatment, and some results achieved.

For this purpose, this essay is divided into four sections, apart from this introduction. The first and the second sections are devoted to evaluating the international literature related to this subject. In the third section, the Brazilian contribution to this problem is analyzed. Finally, the last section is devoted to final remarks and proposing some directions for future research.

2.2 Modeling land-use change and emissions in the international context

Land-use change and forests and their links to GHG emissions constitute a new research area, especially in the economic arena, which is at the cutting edge of knowledge. This complex and interdisciplinary branch of study poses several challenges to research, such as the need for harmonizing databases from different sources, developing concepts, and considering a broad spatial dimension.

Furthermore, it is noteworthy that the causes and consequences of climate change are global. Nonetheless, a given area, even in the same country, may have different types of soil, vegetation, weather, biomes and, consequently, distinct carbon contents. Such heterogeneity related to land and GHG emissions should be incorporated into the analysis and is a part of the issues encompassed by this field of study.

In spite of being a recent topic in the literature, several studies have advanced in the representation of land use and its GHG emissions, such as those by Stavins (1999), Plantinga and Mauldin (2001), Kerr et al. (2003), Lubowshi et al. (2006), and Gouvello et al. (2010), which used an econometric approach for this purpose. Mention must also be made of the contributions of Havlík et al. (2011), Sohngen and Mendelsohn (2007), and Sands and Kim (2008), who used partial equilibrium models. However, despite the efforts of these authors to integrate land-use change and forests to GHG emissions[3], this subject was not exhausted.

We therefore evaluate major and recent contributions in the economic context, focusing on the achievements of CGE models, as noted before. Furthermore, these models have made it possible for a comprehensive analysis of production and prices to be made, besides being suitable for studying policy shocks on specific regions.

Following Peterson and Van der Werf (2009), two main approaches to land-use change and its GHG emissions were considered in a CGE framework. The first one distinguishes land types and incorporates the heterogeneity related to different types of land using climatic zones, as has been done using the GTAP-AEZ (HERTEL et al., 2008) and FARM (WONG; ALAVALAPATI, 2003) models. The second one derives land information from external land use models and/or use that information in integrated systems such as the IMAGE (MILIEU EN NATUUR PLANBUREAU - MNP, 2006) and EPPA (PALTSEV et al., 2005) models.

2.2.1 GTAP models

The GTAP-AEZ (LEE, 2004; HERTEL et al., 2008) model is a CGE model capable of representing different land types, their use, and GHG emissions. It follows the standard model structure and database of the GTAP (HERTEL, 1997), incorporating all theoretical framework developed by this research group. Such representation, based on the pioneering work of Darwin et al. (1995, 1996), uses climatic and agronomic information to deal with

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[3] For more details see Hertel, Rose and Tol (2009) and Peterson and Van der Werf (2009).

land use through AEZs, which in turn supply the model with information about different land types, productivities, and climatic zones, among other inputs.

The different land types are represented in the model through a broad database (LEE et al., 2009) that includes information on land cover and use, carbon stocks, and other GHG-related information integrated into a GTAP database. Monfreda et al. (2008) and Ramankutty (2011) were responsible for the development of this global database. It contains information about pastureland and cropland that was combined with data from several agricultural censuses, as well as with land cover satellite images.

Lee (2004) highlights that 18 AEZs, 6 harvest periods, and 3 climatic zones (tropical, temperate and boreal zones) were considered, which were divided into 0.5 degree (latitude by longitude) grid cells, as shown in Figure 1.

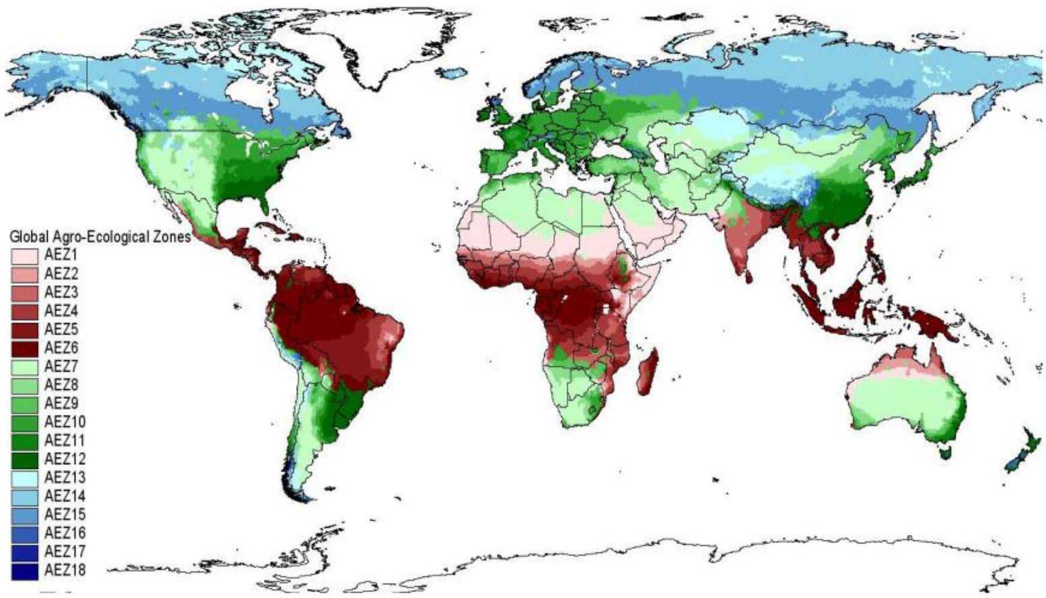

Figure 1 - Global map of the 18 AEZs
Source: Lee (2004)

Land located in a certain AEZ is considered similar in terms of soil and climatic characteristics, which capture the heterogeneity related to different land types. Therefore, through the new database (with climatic information), GHG emissions were integrated into land-use changes and forests and incorporated into the CGE framework, giving rise to the GTAP-AEZ model (HERTEL et al., 2008, 2009; LEE, 2004).

In the GTAP-AEZ model, land allocation is governed by a constant elasticity of transformation (CET), so different land types are considered imperfect substitutes by their owners. First, they decide to allocate land between 3 cover types (cropland, forest and grazing land), considering their relative returns. Then, allocation is carried out among several types of crops, which is also done considering the return on each crop (GOLUB; HERTEL; SOHNGEN, 2007).

Furthermore, the GTAP-AEZ model has a national production function for each commodity and the AEZs are inserted in this structure as inputs. Thus, there is a production function for each land use sector in every AEZ considered. As noted by Lee (2004), the production function for corn, for example, is different in each AEZ. So land is mobile within crops, livestock, and forestry sectors, but not across AEZs. Such representation captures the idea that some activities can only be carried out under certain climatic conditions in terms of soil and moisture.

Figure 2 shows the production structure of the rice sector in AEZ2, which is analogous to other commodities and AEZs. Rice production (PDR_AEZ2) only employs land from AEZ2 and is associated with methane emissions (CH_4), which are considered proportional to the harvested area. Moreover, fertilizer use in that sector is associated with nitrous oxide (N_2O) emissions (LEE, 2004).

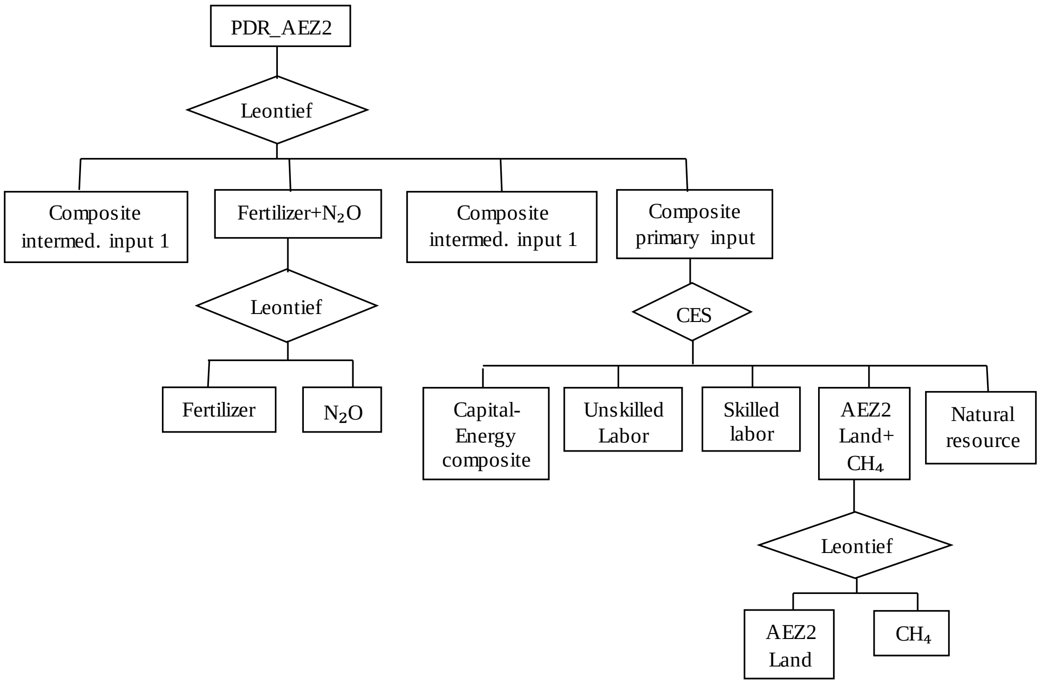

Figure 2 - Paddy rice production structure in AEZ2
Source: Lee (2004)

Finally, the GTAP-AEZ model has been mainly used for studying climate policies, as in Golub, Hertel and Sohngen (2007), Hertel et al. (2009), and Golub et al. (2010) who analyzed the effectiveness of a tax policy in reducing carbon dioxide emissions. However, it is worth noting that using broad AEZs, albeit useful for modeling large regions, can hide important phenomena underlying the land-use change process, such as, for example, deforestation and dynamic emissions and their spillover effects, especially in large countries such as Brazil.

2.2.2 The FARM model

The FARM (DARWIN et al., 1996, 1999) is a CGE model developed by the Economic Research Service (ERS) of the USDA in the mid-1990s to evaluate the impacts of global climate on agriculture. This model associates climatic conditions to land and water inputs, as well as to production and trade worldwide.

The FARM's components are connected through two main structures, one of which is environmental and the other economic in nature. The former is generated through a geographic information system (GIS), which aggregates climatic variables to land and water resources, considering a 0.5 by 0.5 degree grid scale. Thus, the environmental structure, through GIS, uses several databases about climatic regions, native vegetation, and land use. Moreover, in each region land is divided into 6 climatic classes based on "length of the growing season" that capture differentials of productivity between land classes, similarly to the GTAP-AEZ model (DARWIN, 1999; WONG; ALAVALAPATI, 2003).

The economic structure is in turn a CGE model, as noted before, developed from a standard GTAP database and model. It is governed by the interaction between climate, population, technology, and consumer preferences. In addition, it is in the FARM's CGE structure that the connections between sectors and regions are established. It is also where important characteristics such as competitive markets and constant difference of elasticities (CDE) in representations of consumer demands, among other factors, are highlighted (HERTEL, 1997).

The FARM model incorporates land heterogeneity as follows: i) considering the "length of the growing season"; ii) assuming that land supply derives from constant elasticity of transformation (CET) functions. Such functions play an important role, as they capture land competition between economic sectors, besides allowing for rent differentiation based on its use. Thus, land can be allocated between sectors according to prevailing economic conditions while maintaining intrinsic productivity, as shown in Figure 3.

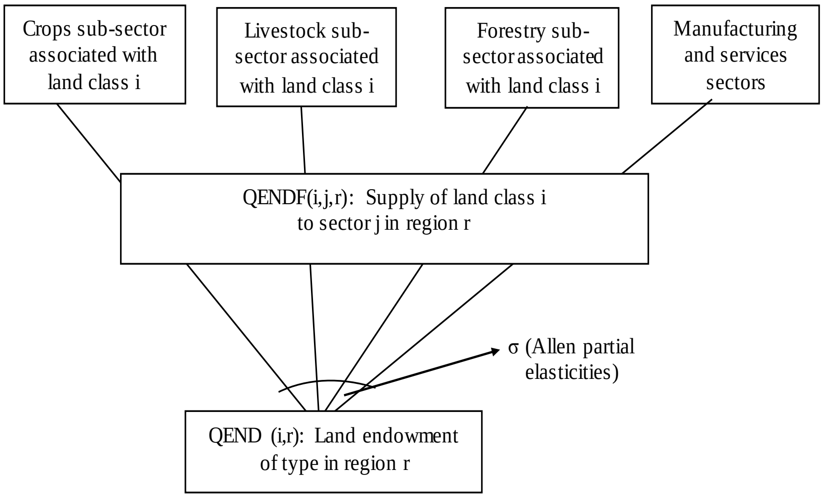

Figure 3- Land supply in the dynamic FARM model.
Source: Wong and Alavalapati (2003).

In the model, each land class comprises 11 commodity-producing sectors, 8 of which are related to manufacturing and services, while the remaining 3 are related to land use (crops, livestock and forestry) and correspond to a specific type of land. For example, land class LC1 comprises crops, livestock and forestry categories of sector 1, as well as other non-farm sectors. Thus, these land classes are associated with different ecosystem mixes, at the same time that they include a variety of uses and product mixes (WONG; ALAVALAPATI, 2003).

Therefore, the FARM extended structure to represent land-use change has become an important tool to study policy shocks, especially climatic ones, like Darwin (1999) and Wong and Alavalapati (2003) did. The former states that the effects of global climate change can be positive, since countries take advantage of opportunities such as new land that becomes available for agriculture as a result of temperature increases. The latter, in turn, used a dynamic version of the FARM model to simulate the impacts of reforestation scenarios on economic sectors within and without the U.S. However, they concluded that policy effects on the American economy are small, especially for land-intensive sectors.

Finally, the constraints of both models can contribute to changes in land use and their emission representation. In the FARM case, more work is required to integrate physical aspects into a CGE framework, since changes in the demand for land are not derived from optimizing the behavior of the agents, but rather from bioclimatic models, as noted by Michetti (2012). The GTAP-AEZ model, in turn, can be incorporated into the AEZs, provided that data about productivity is observed, instead of using assumptions about it in the agricultural representation. Avetisyan et al. (2008) noted that a broader AEZ disaggregation would improve the representation of regions/countries, but such task tends to be limited by computational costs, one of the chief constraints in land modeling.

2.3 Integrated systems

2.3.1 EPPA model

EPPA (PALTSEV et al., 2005; BABIKER et al., 2001) is a dynamic-recursive, multiregional, CGE model developed at MIT to study the world economy, GHG emissions, and climate policies.

The EPPA model projects economic variables (GDP, energy use, consumption, among others) and emissions of GHG and other air pollutants from fossil fuel burning, industrial processes, and agricultural activities. This model uses the GTAP database and information about GHG emissions from other sources. It is part of the IGSM (SOKOLOV et al., 2005) – a structure composed of several sub-models designed to analyze human interactions with the climate system – that is used to study global climate change and its economic and social consequences.

The IGSM structure has three main components: an economic component, represented by the EPPA model, a climatic component, and another component for terrestrial ecosystems. The latter, which is called “Global Land System Framework” (SCHLOSSER et al., 2007) comprises three sub-models: the Community Land Model (CLM), the Terrestrial Ecosystems Model (TEM), and the Natural Emissions Model (NEM). These sub-models generate forecasts about changes in terrestrial ecosystems, as well as emissions of carbon dioxide, methane, nitrous oxide, and other gases resulting from this process. The terrestrial module is coupled to the EPPA model, which generates GHG projections associated with human activities.

In the EPPA model, global economic performance is obtained recursively through simulations within a range of 5 years, from 2000 to 2100. In addition, production and consumption structures are represented by nested elasticity of substitution (CES) functions and, in special cases, by Cobb-Douglas and Leontief functions. The model is written in the GAMS software and solved using the MPSGE interface developed by Rutherford (1999).

In the EPPA standard version (PALTSEV et al., 2005; BABIKER et al., 2001) the agricultural sector has only one land category, which is used as a specific input. Gurgel, Reilly, and Paltsev (2007) disaggregated the agricultural sector into crops, livestock, and forestry, while dividing land into 5 categories (cropland, pastureland, harvested forest land, natural grassland, and natural forest land). Each land type is a renewable resource whose quantities can be altered through conversion to other land types or discarded to a non-land use category.

Thus, land use representation in the model is carried out through a multi-product production function with a fixed coefficient, which considers forestry product (wood and other forestry products) as a perfect substitute for the forestry sector output, as shown by the dashed line in Figure 4.

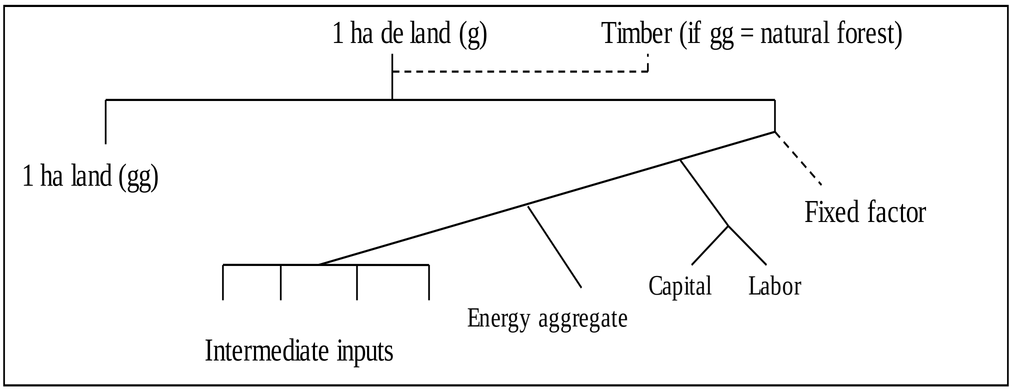

Figure 4 - EPPA land conversion structure
Source: Gurgel, Reilly and Paltsev (2007)

The EPPA model adopts two approaches to deal with the fixed factor represented in Figure 4. The first one, referred to as the “Pure Conversion Cost Response” (PCCR) model, does not consider the fixed factor, so it does not impose any constraints for converting native vegetation areas into areas for other uses. The second approach, the so-called “Observed Land Supply Response” (OLSR) model, considers the fixed factor, allowing for the parameterization of the substitution elasticity between the fixed factor and other inputs to represent the observed land supply response.

In the PCCR approach, land conversion is carried out by comparing revenues and costs. For this purpose, values were assigned to land use, according to the national statistics. However, for land with no values, the methodology developed by Gurgel, Reilly and Paltsev (2005) was used, which assigns values to non-used land.

Therefore, land is analyzed in economic and physical terms. However, the model adopts a “strong” assumption, employing variations in land prices in the U.S. and in other regions to calculate the elasticity used to represent the observed land supply response. Finally, with land use and its GHG emissions incorporated by the model, it has been used in several studies of policy shocks, such as in analyses of future land use scenarios associated with energy policies (HALLGREN; SCHLOSSER; MONIER, 2012) to evaluate the effects of cellulosic biofuel production on future GHG emissions (GURGEL et al, 2012), with the aim of analyzing the impacts of an emission reduction policy on the Brazilian economy (SILVA, 2010), among others.

2.3.2 The IMAGE-LEITAP model

The IMAGE (MNP, 2006) was developed in the late 1980s by researchers of the National Institute for Public Health and the Environment of the Netherlands to analyze the effects of climate change, and it was one of the first integrated climate assessment models.

The IMAGE model comprises other sub-models, such as MIT’s IGSM model, which explore the interaction between natural and human systems. According to Strengers (2001), the IMAGE model was not widely applied to economic analysis because of its simple representation of agriculture and other sectors. Nonetheless, this limitation was addressed by combining the IMAGE and the LEITAP models. The latter is a version of the GTAP standard model (HERTEL, 1997), which improved the representation of economic and environmental aspects under analysis.

The new IMAGE-LEITAP model (EICKHOUT et al., 2008) has a sophisticated demand structure that reflects the level of substitution between different land types and supply curves to represent the land conversion and abandonment process. The GTAP standard version (LEITAP) represents land allocation through a CET structure, assuming that several land types are imperfect substitutes, but can substitute each other, as shown in Figure 5.

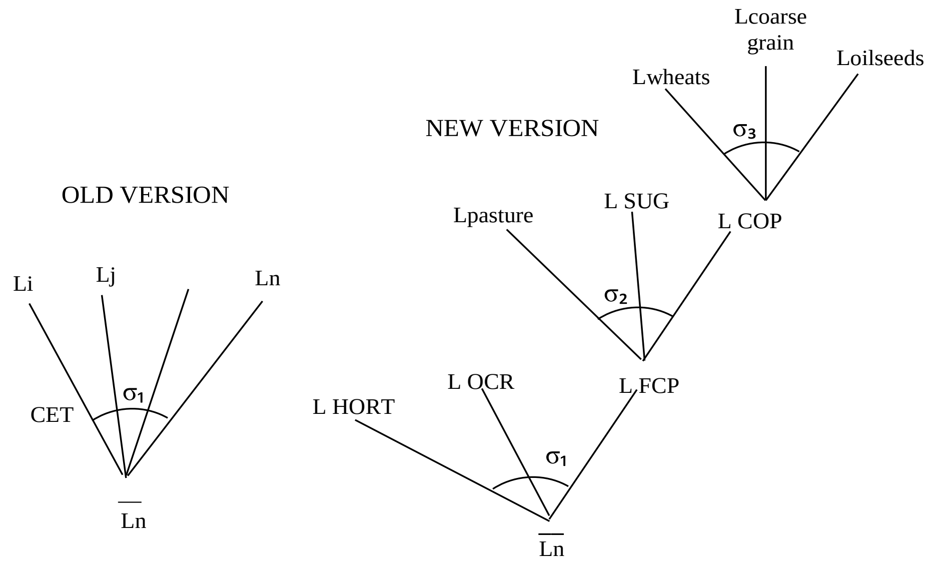

Figure 5- Land allocation tree in the extended version of GTAP
Source: Eickhout et al. (2008)

The structure represents land allocation and was extended considering the degree of substitution between several land types. This structure distinguishes different land types through three nested CET structures. Besides, the model covers several land use types with different levels of substitution between several crops.

In the lower nest, a constant elasticity of transformation is observed between horticulture (HORT), other cultures (OCR), and field crops and pastures (FCP). The transformation is governed by the elasticity of transformation σ_1. The FCP group is also an aggregated CET for Cattle and Raw Milk (both of which are Pastures), Sugar Cane and Beet (SUG), and the group of Cereal, Oilseed, and Protein Crops (COP). In this nest, the elasticity of transformation is σ_2. In the bottom nest, in turn, land transformation is carried out through the elasticity σ_3. Thus, the substitution degree may vary between nests. Some agronomic characteristics are captured. And, in general, it is assumed that $\sigma_3 > \sigma_2 > \sigma_1$, implying that it is easier to change land allocation within the COP group, while that allocation is not easy outside the COP group (EICKHOUT et al., 2008).

In the IMAGE model, climate change is simulated endogenously. Changes in the energy system and in land use led to GHG emissions, which are connected to carbon cycle and atmospheric chemistry models. The Terrestrial Environment System (TES) computes emissions from land-use change, natural ecosystems, agricultural systems, and carbon dioxide exchanges between land and the atmosphere. These sub-models project GHG concentrations that lead to climate change. Using the information generated by the IMAGE model and used in the LEITAP model, environmental aspects can be included in economic analyses (EICKHOUT et al., 2008).

Issues related to climate change are projected by the IMAGE model in a long-run scenario, up to 2100, which is suitable for studying the impacts of policy shocks. Furthermore, it covers a wide range of factors related to direct and indirect stress caused by human activities on natural systems. The model considers 24 regions, besides data on climate and land use, geographically represented through a 0.5 by 0.5 degree grid scale (PETERSON; VAN DER WERF, 2009; MICHETTI, 2012).

Therefore, the IMAGE resources to represent land use and GHG emissions have turned it into an important tool to study climate policies, as in Bouwman et al. (2002), who evaluated carbon dioxide concentrations in the atmosphere as a result of land cover and climate pattern changes. Another example is the study of the effects of reductions in beef consumption on land use and GHG emissions carried out by Bouwman et al. (2009).

Nevertheless, it was in Eickhout et al. (2008) that the LEITAP model was coupled with the IMAGE model, generating a detailed representation of economic sectors, especially agriculture, and of the productivity of different land types. The results achieved highlight the role of land availability as a determining factor to explain economic and environmental effects of climate shocks. Moreover, the authors emphasized that land supply, used as an endogenous element, would increase agricultural demand as a result of a possible land price reduction in the sector under analysis.

In addition, special mention should be made of the similarity between the EPPA and the IMAGE-LEITAP model, which belongs to integrated systems applied to studying the climate. These models are a composite of several sub-models that provide information about ecosystems, especially terrestrial ones, and generate data on GHG emissions from land-use change and forests. As a result, both models use information from other components of the system to which they belong as inputs.

Peterson and Van der Werf (2009) highlight that using information from large integrated systems gives us important insights as a value added created by the connection of such sub-models. However, observed data can also give us insights, as in individual models. This is so because simple observation of reality can be useful for the analysis.

Finally, the role of integrated modeling deserves highlighting as one of the most promising avenues for studying climate and land use changes. First, because it is difficult to obtain data about terrestrial dynamics and other physical aspects to integrate them into economic models. Second, because the rapid development of computing has facilitated data connection and generation, as required by interdisciplinary studies such as those on climate change.

2.4 Modeling land-use change and ghg emissions in Brazil

In Brazil, in an economic context, land-use change and its GHG emissions were studied by Santos (2013) and Ferreira Filho and Horridge (2012, 2014), both using the CGE model TERM-BR, which was adapted to the study of climatic policies and their impacts on the Brazilian economy.

The TERM-BR is an inter-regional, multi-period, bottom-up model, i.e. national results are driven by regional results. Apart from an annual recursive-dynamic structure, which consists basically of three mechanisms or relation between: investment and capital stock, investment and rate of profit, and wage growth and regional labor supply.

An important feature of TERM-BR is its ability to handle a greater number of regions and sectors, comparing to other CGE models. Ferreira Filho and Horridge (2012, 2014), for example, considered 15 Brazilian regions, 38 sectors, and 10 household types and labor grades. Santos (2013) in turn, uses 27 regions/states, 41 products, 41 industries, and 4 final users.

The latter study, analyzed the impact of increase production and the use of biofuel on the Brazilian economy. For this, it was linked GHG emissions to the economic variables of the TERM-BR model, like fuels, activities, and final demand. The resulting theoretical module equates data from different sources, the National Inventory of Greenhouse Gases and the Brazilian Input-Output Table, following Ferreira Filho e Rocha (2008) and Adams, Horridge and Wittwer (2003).

The link between emissions and their sources was done, for example, following the proportion of fuel used, as reported in the I-O table. Thus, the emissions of burning fuels are attached to gas and oil extraction, coal, gasoline, and gasalcohol, oil fuel, diesel, and other products from oil refining. The final demand in turn, was linked to households’ consumption and governmental expenditure. The disaggregated Brazilian I-O table allowed the distribution of the remaining emissions to intermediary consumption and activities.

However, the emissions related to land-use change and forestry were not accounted, as such sector is not represented in the Brazilian I-O table. Thus, Santos (2013) moved forward in representing the GHG emissions related to the Brazilian economy, but without one of the major emission sources, namely, land-use changes and forestry.

Ferreira Filho and Horridge (2014) in turn, advanced in represent land-use change, through a new approach. First, they improved the TERM-BR model, modeling agriculture and land use separately in each 15 Brazilian regions, following IBGE data, which consider 3 types of agricultural land use, Crop, Pasture, and Plantation Forestry.

In each region, the area of Crop in a current year is pre-determined, according to IBGE data. However, the model allows a given Crop area to be re-allocated among other crops, following the CET-like rule:

$$A_{jr} = \lambda_r . K_{jr} . R_{jr}^{0.5}$$

where A_{jr} is the area of crop land in region r used for industry j, and $R_{jr}^{0.5}$ is the unit of land rent earned by industry j. K_{jr} is a constant of calibration, while a slack variable λ_r adjusts so that:

$\sum_j A_{jr} = A_r =$ pre-determined area of cropland.

Such strategy is also used to distribute Pasture areas between Beef and Diary uses, while Forestry has only one use. Besides, the model considers a land use category, called Unused, which represents all areas not used in agriculture, like native forests, urban areas, grasslands, reservoirs, lakes and roads. Thus, changes in Unused are considered as a proxy for deforestation.

The model allows land to move between the different types of land use (Crop, Pasture, Plant Forest, and Unused), for example, Pasture areas in the initial year can be converted into Crops in a second period. Such movements are represented by transition matrices, as shown in Table 1.

In the transition matrix, the row labels refer to land use at the start period, while column labels refer to final period. The elements of the main diagonal represent land use that remains in the same category, while the off-diagonal elements represent land conversion between the four categories under analysis. For example, pastures in the initial period converted into crops in the final period. Thus, summing up the figures in the column (Total) generate the total of each category in the initial period, while summing up the figures in the lines we have the total in the final period.

Table 1 - Transition matrices for land use change, in million hectares (Mha)

Region 1	Crop	Pasture	PlantForest	Unused	**Total**
Crop	6.4	0.1	0.1	0.1	**6.7**
Pasture	0.4	6.6	0	0.1	**7.1**
PlantForest	0	0.1	0.3	0	**0.4**
Unused	0	0.1	0	10.6	**10.7**
Total	**6.7**	**6.9**	**0.4**	**10.8**	**24.8**
Region 2	Crop	Pasture	PlantForest	Unused	**Total**
Crop	8.7	0.2	0	0.1	**9**
Pasture	1	20.6	0	0.1	**21.8**
PlantForest	0	0.1	0	0	**0.1**
Unused	0	0.9	0.1	58.4	**59.4**
Total	**9.7**	**21.8**	**0.1**	**58.7**	**90.3**

Source: Adapted from Ferreira Filho and Horridge (2014)

In Table 1, we have an example of land allocation in two regions. In the first region, 6.4 Mha remain used as Crop over the time, while 0.4 Mha of Pasture were converted into crops. Thus, in the final period there are 6.7 Mha and 6.9 Mha of crops and pastures, respectively.

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 in Equation 1.

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

where (the r subscript denotes region):

$S_{pqr} =$ share of land type p that becomes type q in the region “r”

$\mu_{pq} =$ a slack variable, adjusting 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, with initial value 1.

Sensibility parameter α was set at 0.28 in order to give a normal, close to observed, representation. Therefore, if land rents of 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.

Thus, through transition matrices Ferreira Filho and Horridge (2014) advance in represent land-use change in Brazil, which permitted them to study the impact of specific policies on different regions. Furthermore, their developments capture the recent dynamics of land in the country, like agricultural expansion, deforestation, the substitution of traditional crops, among others.

However, the link between land-use change and its GHG emissions was not done. As a result, important issues for the study of the climate change and its economic impacts, like land heterogeneity, which convers different weather, types of soils, and, consequently, carbon content, were not incorporated in the model. Thus, the integration between land-use change and GHG emissions continues to be a promising area of study, especially the Brazilian case.

2.5 Final remarks

This essay analyzed the state of the art of the integration between land-use change and forests and GHG emissions into a CGE model framework. Following Peterson and Van der Werf (2009), two approaches were considered, the first of which is represented by individual models such as the GTAP-AEZ and FARM models, while the second considers integrated systems such as the EPPA and IMAGE-LEITAP models. In the Brazilian context, the contributions of Santos (2013) and Ferreira Filho and Horridge (2012, 2014) through the TERM-BR model were evaluated. Although, they didn't have integrated land-use change and GHG emissions, their models and result approach them to the group of individual models.

Nonetheless, all contributions considered here, regardless of their approach, face similar challenges. The first one is the interdisciplinary nature of the topic, which requires the harmonization of distinct databases and the use of concepts still under development. The second one is related to the heterogeneity of different land areas, whose implications range from productivity differentials to distinct GHG emission patterns. Thus, all of these issues must be circumvented through economic modeling.

In individual models such as the GTAP-AEZ and TERM-BR, land heterogeneity may be incorporated using AEZs, which allow them to capture emission and land differential. In the integrated model, this problem is usually smaller, as it uses data generated in other components of their system, which facilitate the integration and exchange of information between sub-models.

Therefore, integrated systems are now seen as promising for studying climate-related issues, as the lack of data on the terrestrial dynamics used in economic studies can be appropriately addressed by other system components. Moreover, integration can meet computing demands (data processing), as several sub-models can be applied separately, avoiding the simplification of assumptions used in large models.

Nevertheless, it is noteworthy that individual models can take advantage of observed data, which provide insights into problems under analysis based on the simple observation of reality. In addition, the TERM-BR is an example of an individual model that has made much progress in representing the GHG emissions of the economy and different land uses in Brazil, as well as in promoting database harmonization, generating important results about land dynamics in Brazil.

Finally, the modeling challenge of both approaches is to detail the terrestrial system accurately and capture economic implications. They also face the challenge of representing a phenomenon as complex as GHG removals and of assigning values to unused land, which requires more time.

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3 HALTING DEFORESTATION IN THE BRAZILIAN AMAZON REGION: ECONOMIC IMPACTS AND GREENHOUSE GAS EMISSIONS

Abstract

This essay analyzes the economic impacts of freezing deforestation in the Brazilian Amazon, through the use of a computable general equilibrium (CGE) model extended for handling land use changes and its GHG emissions. The main results show that deforestation control focused on the Amazon Biome can effectively reduce domestic GHG emissions, although some leakage may occur as a result of the displacement of deforestation to other regions and biomes. Such movement has another major implication, namely, that of enhancing regional inequalities. Therefore, the asymmetries between the southeast and mid-west regions were intensified, especially in the latter, where negative impacts on the regional GDP, consumption levels, employment, and other macroeconomic variables were quite pronounced, as expected. Finally, a promising approach to be evaluated in future research was identified, that of productivity gains in agriculture, as alternative for deforestation control.

Keywords: Deforestation; Greenhouse gases; CGE model

3.1 Introduction

Global agriculture faces the challenge of meeting an increasing demand for food resulting from fast urbanization rates, population growth, and rising incomes, especially in the developing world.

New arable land areas are being made available to meet the demand for agricultural products. As a result, over the past 50 years 67 million hectares (Mha) of arable land were set apart for agriculture, as a result of opposite trends, an increase of 107 Mha in developing countries and a decrease of 40 Mha in developed countries (FAO, 2013).

Brazil follows the trend for developing countries, as the supply of land for agriculture increased. Between the agricultural censuses carried out in 1995/96 and in 2006, cropland areas grew by 19.4%, from 50 Mha to just over 60 Mha, while pastureland areas grew by only 1.79%, from 100 Mha to almost 101 Mha (IBGE, 2014a).

Regionally, the expansion of Brazilian agriculture has been concentrated in the mid-west and north regions, where land is still available. However, most of these regions are covered by savannas and forests. Thus, agricultural expansion has incorporated new land and, consequently, led to the deforestation of a vast area of native vegetation, especially in the Amazon and Cerrado Biomes, which stretch over more than half of the Brazilian territory.

Recent estimates show that, in 1980, around 300,000 km² of native vegetation were deforested in the Amazon, accounting for 6 percent of this biome. In the 1980s and 1990s, a further 280,000 km² of forests were occupied to give way to other activities. The situation got worse in the early 2000s, when the (cumulated) deforested area rose to 670,000 km² - a deforestation peak in the Amazon region (BRASIL, 2013).

An important underlying issue must be considered in connection with the conversion of forests into other uses, namely, the issue of GHG emissions. In Brazil, they grew sharply in the Amazon region due to its high carbon content as compared to other biomes. In 2010, for example, 52.2 percent of all GHG emissions associated with land use change and forests were generated in the Amazon Biome (BRASIL, 2013).

Furthermore, 77 percent of all domestic CO2 emissions in 2005, i.e.; 1,637,905 gigagrams of CO2 came from land-use change and forests. Thus, the Brazilian government assumed the commitment to reduce the domestic GHG emissions by creating a national plan on climate change – *Plano Nacional sobre Mudança do Clima*. Such plan lists actions designed to reduce GHG emissions, highlighting the role of deforestation control to achieve this goal, as land-use changes account for the greatest part of all domestic emissions (BRASIL, 2013).

However, a policy that could reduce the domestic supply of new land should be evaluated in detail by, for example, considering its effects on land allocation, GHG emissions, and on the domestic economy. For this reason, this essay analyzes the economic impacts of zero deforestation in the Amazon Biome, i.e. of halting new land supply.

This policy is justified by the international efforts to halt deforestation around the world, as established by the New York Declaration on Forests, issued in the United Nations Climate Summit 2014[4]. Furthermore, an extreme policy deals with a very restricted scenario, considering the high costs and limitations involved for the agents, which may facilitate the design and implementation of intermediate policy scenarios.

Silva (2010), Diniz (2012), Ferreira Filho and Horridge (2012), and Cabral (2013) made progress in analyzing the curbing of deforestation and its impacts on land allocation, food security, prices, the farming sector, and the economy as a whole. In this essay, we take a step further in that analysis by linking land-use change to its GHG emissions in a regional CGE model disaggregated by biomes, which captures land and emission heterogeneity across the country.

Finally, this essay is divided into five sections, besides this introduction. The first

[4] In September, the United Nations promoted the UN Climate Summit 2014, a forum to discuss alternatives to reduce GHG emissions and mitigate the effects of the climate change. Policies to eliminate the deforestation was one of issues addressed in this meeting.

section sets out the main features of the deforestation under way in the Brazilian Amazon region. The second and the third sections are devoted, respectively, to presenting the methodology and the scenarios considered. The fourth section discusses results, and the last one presents the final remarks.

3.2 Deforestation in Brazil

Productivity, economic growth and increasing population growth rates, although the latter nowadays decreasing, are some of the elements leading to intense changes in land use and forests. In Brazil, deforestation is one of the consequences of this process, triggered by the substitution of large areas of native vegetation for roads, cities, crop fields, pasture and or simply by their use as a source of raw materials, such as timber.

However, after years of increasing and almost continuous deforestation (1997-2004), the pace of forest clearing slowed down in the mid-2000s, particularly in the Amazon region. Since then, deforestation rates in almost all states in that region have been lower than before 2004, as shown in Figure 6.

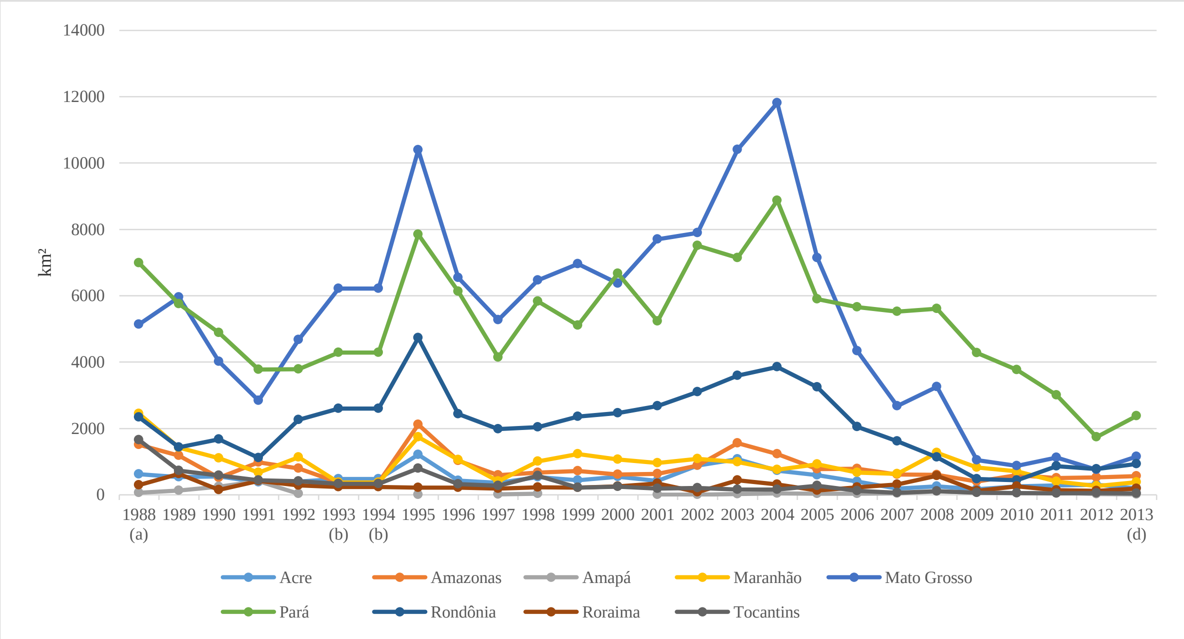

Figure 6 - Annual deforestation rates in the Legal Amazon region between 1988 and 2013, in km²/year
Source: Instituto Nacional de Pesquisas Espaciais (INPE, 2014). Prepared by the author
(a) Average between 1977-1988
(b) Average between 1993-1994
(c) Estimated rate.

Deforestation in the Legal Amazon region between 1988 and 2013 resulted in the clearing of 402.615 km², especially in the states of Mato Grosso (137.251 km²), Pará (136.127 km²), Rondônia (54.772 km²), and Maranhão (23.917 km²). Notwithstanding, the reduction observed in deforestation rates in these states was also pronounced and, as a result, Mato Grosso dropped from the first to the second position in the ranking of deforesters, second to the state of Pará (INPE, 2014).

Contrasting with these high deforestation rates, the Amazon and Pantanal regions were classified as the most preserved Brazilian biomes, especially as compared to the Atlantic Forest, which in 2010 had lost 88.4% of its original vegetation. In the remaining biomes the situation was similar, such as, for example, in the Caatinga, Pampa, and Cerrado regions, which lost 44.6%, 54.2%, and 49.1% of their native vegetation, respectively. In the Cerrado Biome, the most deforested area is to be found in the states of São Paulo and Mato Grosso do Sul, with percentages of 90.2% and 76.1%, respectively, while the lowest percentage of deforestation was recorded in the state of Rondônia, only 3.1% (IBGE, 2012).

Thus, the efforts being made to reduce deforestation in the Legal Amazon[5] region are concentrated in the states of Maranhão (MA), Pará (PA), Mato Grosso (MT), and Rondônia (RO), which form a strip of land known as the "Deforestation Arch," as shown in Figure 7. This area concentrates some of the municipalities with the highest rates of deforestation, such as Açailândia and Santa Luzia in the state of Maranhão and Vila Rica in the state of Mato Grosso, which in 2010 deforested 90.47%, 91.34%, and 61.83% of their natural vegetation areas, respectively (INPE, 2010).

[5] Legal Amazon is a region that comprises nine Brazilian states, namely, Acre, Amazonas, Roraima, Rondônia, Pará, Amapá, Tocantins, and part of Mato Grosso and Maranhão. It covers 59% of the national territory, and despite- the name, has three different biomes, all the Amazon, 37% of the Cerrado biome, and 40% of the Pantanal biome (INSTITUTO SOCIOAMBIENTAL, 2009).

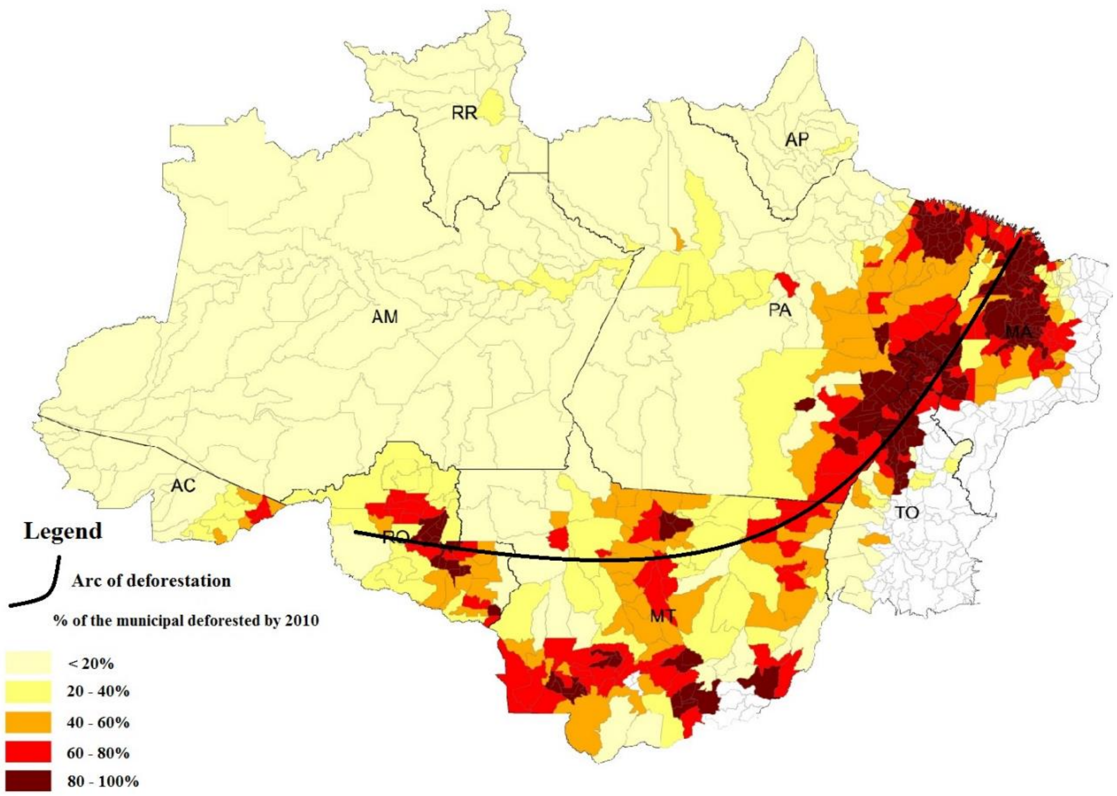

Figure 7 - Share of deforested areas in the Legal Amazon region by municipality in 2010
Source: Adapted from Instituto de Pesquisa Ambiental da Amazônia (IPAM, 2013)

Identifying the *locus* of deforestation can support the design of actions to curb it, as was done through the post-2004 policies that triggered a slowdown in forest clearings. Among other actions carried out, the following ones deserve special mention: creation of monitoring systems[6], repression of logging and land grabbing, credit constraints imposed on offenders of environmental laws, and establishment of a list of priority municipalities for deforestation control purposes[7] (BRASIL, 2013).

The actions to reduce the deforestation in the Brazilian Amazon region are listed in the *Plano de Ação para a Prevenção e Controle do Desmatamento na Amazônia Legal* - PPCDAm (Action Plan for Prevention and Control of Deforestation in the Brazilian Legal Amazon Region)[8]. This plan was launched in 2004 by the federal government and was structured around three thematic axes: territorial and property organization, environmental monitoring and control, and actions to boost sustainable productive activities.

[6] *Sistema de Detecção do Desmatamento em Tempo Real* (DETER) is a system designed to detect and monitor deforestation in real time and it was created by the National Institute for Space Research in 2004.
[7] It is worthwhile stressing that all measures adopted by the Brazilian government benefited from a drop in the prices of agricultural commodities and from the 2008 financial crisis, which slowed down international trade.
[8] For more details, see Brasil (2013).

Figure 8 shows that the policies adopted so far were efficient in reducing deforestation rates from an average of about 1,996 thousand hectares in 1995-2006 to 476 thousand hectares in 2012, the lowest rate in the time series. However, according to Assunção, Gandur e Rocha (2012) the 2000s deforestation slowdown in the Legal Amazon is explained by a mix of commodity prices and conservation policies, especially, from 2004 to 2007, while from 2008 onwards conservation policies were more significant. Besides, the target settled by the National Policy on Climate Change is to reduce the annual deforestation rate by 80% by 2020 in relation to the average rate observed in 1995-2006 (BRASIL, 2013).

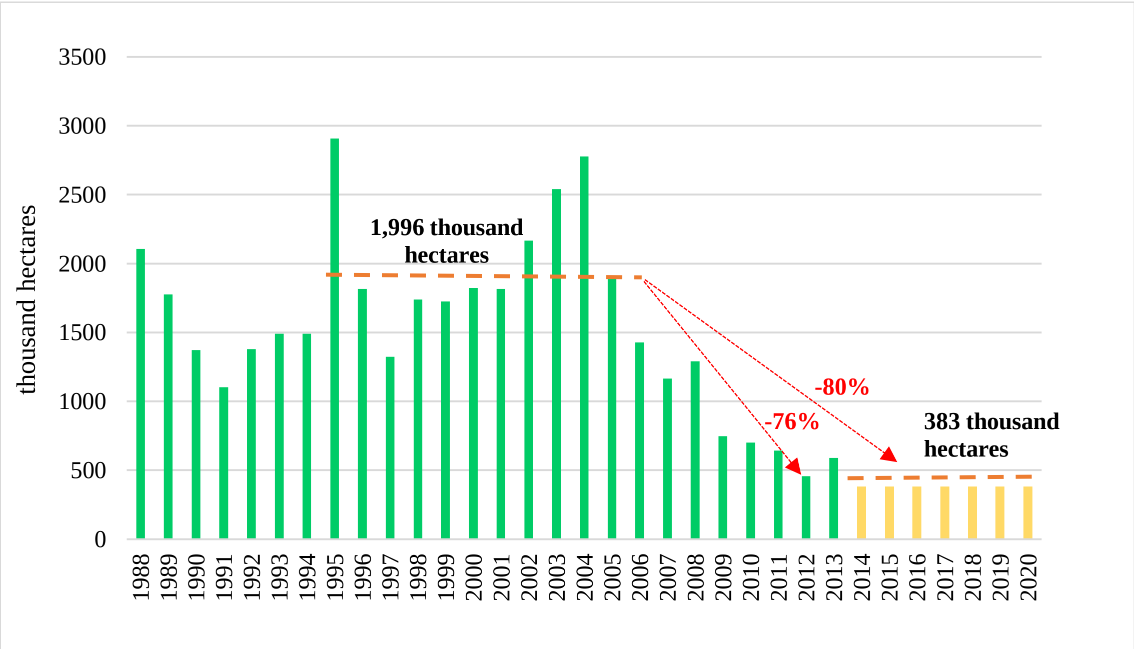

Figure 8 - Brazil's target to reduce deforestation rates in the Legal Amazon region by 2020: observed (green) and target (yellow) rates, in thousand hectares
Source: INPE (2014). Prepared by the author

It is worth noticing that despite the gains achieved in terms of avoiding the clearing of new areas, which in 2012 led to a reduction of 76% in the deforestation rate in the Amazon region, the annual target rate was not achieved. On the contrary, the rate rose to 28.9% in 2012-2013. For this reason, all the actions described before should be followed strictly to prevent the beginning of a new cycle of rising deforestation, since it is a dynamic phenomenon and, therefore, one that is difficult to control.

3.3 Methodology

This essay uses TERM-BR, an inter-regional, multi-period, general equilibrium model of Brazil, tailored for climatic analysis. As a bottom-up model, it may be thought as several CGE models, linked by trade and labor movements between regions. In other words, national results are driven by regional results, which allow modeling multiple regions within a single country.

TERM-BR is a typical CGE model, whereby each industry minimizes production costs to a specific output level by optimizing labor, capital, and material inputs. Production levels are chosen to meet the demand from their users, namely, several domestic industries, households, the government, and other countries.

The model captures supply and demand for commodities, as well as the movement of such goods from producers to consumers, considering several transportation modalities. In addition, TERM-BR evaluates demand and supply shocks and their effects on prices and quantities in a specific region, following its bottom-up structure, while its capacity to respond to exogenous shocks depends on three basic elements:

- The database (regional input-output tables);
- Behavioral parameters (how agents minimizes their costs) and;
- Closure (which variables will be exogenous or endogenous in the model).

TERM-BR is a multi-period, as noted before, and has a recursive-dynamic structure[9], which consists of: (i) a stock-flow relation between investment and capital stock, which assumes a one year gestation lag; (ii) a positive relation between investment and the rate of profit; and (iii) a relation between wage growth and regional employment, i.e. long-run labor market adjustment occurs as a combination of inter-regional labor migration and changes in regional real-wage differentials, as stated by Horridge (2012).

The model's dynamics allows the construction of a base forecast (baseline) for the future of the economy. The policy scenarios in turn, differ from the base only via shocks on policy variables. Thus, the deviations between base and policy scenarios can be interpreted as the effect of the policy change.

TERM-BR handles a large number of regions and sectors. However, in this essay the model has 15 regions, 36 commodities and industries, 10 labor grades, and two margins (trade

[9] More details in Appendix B.

and transportation). Finally, the model is solved using the GEMPACK system (HARRISON; PEARSON, 1996).

3.3.1 The TERM-BR data structure

The database of the model consists of flow matrices organized by commodity, industry, and region. The dimensions of the matrices are indicated by indices (s, c, m, i, o, d, r, p, f, u), as shown in Table 2.

Table 2 - Main sets of the TERM-BR model disaggregated.

Index	Set	Description	Size
s	SRC	Source (dom., imp.)	2
c	COM	Commodities	110
m	MAR	Margins (transport and trade)	2
i	IND	Industries	110
o	OCC	Skills	10
d	DST	Regions of use (destination)	15
r	ORG	Region of origin	15
p	PRD	Regions of margin production	15
f	FINDEM	Final demanders (HOU, INV, GOV, EXP)	4
u	USER	Users = IND + FINDEM	114

Source: Horridge (2012)

Figure 9 shows the schematic representation of the model's input-output database. It represents the model's core in bold and flow values (rectangles) as follows:

i. Basic values = output prices (for domestic goods) or CIF prices (for imported goods);
ii. Delivered values = basic values + margins;
iii. Purchasers' values = basic values + margins + tax = Delivered + Tax

The matrices on the left-hand side of Figure 9 are similar (for each region) to a standard single-region, input-output database. For example, the USE matrix at the top shows the delivered price of demand for every good (c in COM), whether domestic or imported (s in SRC) in every region of destination (DST) for each user (USER), considering each industry (IND) and individual demanders (households, investment, government and exports). The matrices can usually be represented as follows:

- USE ("rice", "imp", "HOU", "Bahia"): imported rice used by households in Bahia state;
- USE ("beef", "dom", "EXP", "São Paulo"): beef produced domestically but exported through a port in São Paulo state.

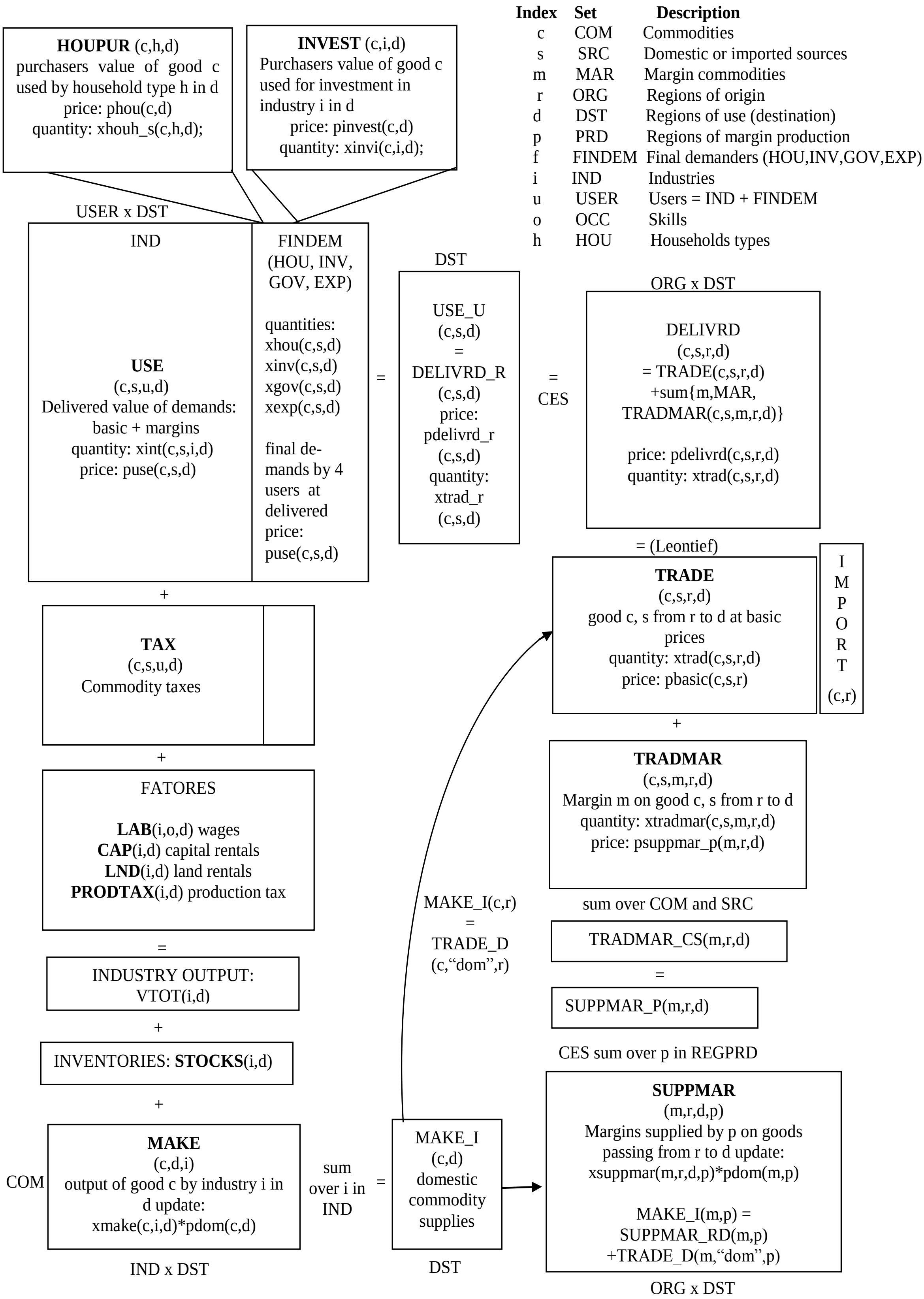

Figure 9 - The TERM flow database
Source: Horridge (2012)

The values of the USE matrix are at delivered prices and do not consider regional information on the origin of the goods. The TAX matrix, in turn, which represents tax revenues, contains an element that matches every element of the USE matrix. Such matrices, together with those of primary factor costs and production taxes, add production costs (or production value) for each regional industry.

The MAKE matrix, at the bottom of Figure 9, shows the production cost of each industry in each region. Moreover, a subtotal of the MAKE matrix, MAKE_I, represents the total production of each good (c in COM) in each "d" region. It is worth mentioning that, in principle, every industry is capable of producing several goods.

The regional sourcing mechanism is represented on the right side of Figure 9 TRADE is the key matrix that shows the interregional trade value by origin (r in ORG) and destination (d in DST) for each good (c in COM), whether domestic or imported (s in SRC). The diagonal of that matrix (r = d) shows the use value for goods of domestic origin. Imported goods (s = "imp") in turn, are represented by the origin subscript "r" (in ORG), which denotes the entrance port.

The TRADMAR matrix shows, for each cell of the TRADE matrix, the margin value of each good (m in MAR) which is required to facilitate that flow. Adding the TRADE and TRADMAR matrices, the DELIVRD matrix is generated, which represents the delivered value (basic prices + margins) of all intra and interregional flows of goods. It should be mentioned that there is no information in the TRADMAR matrix about where the margins are produced (the r subscript is related to the basic underlying flow).

It is the SUPPMAR matrix that shows where margins are produced (p in PRD). This matrix doesn't have a specific subscript for goods c (COM) and s (SRC), indicating that the same proportion of m is produced in that region for all margins on the goods used to transport any other good from region r to region d.

TERM-BR assumes that all users of a specific good (c, s) in a given region (d) have the same origin mix. Actually, for each good (c, s) and region of use (d) there is as a broker that decides, for every user in d, where the supply will come from. Furthermore, the equilibrium conditions of the model's database establish that the sum over users of USE, USE_U will be equivalent to the sum of regional origins of the DELIVRD matrix, i.e. DELIVRD_R.

Finally, the equilibrium between supply and demand for domestic goods remains, which is represented by the line connecting MAKE_I to the TRADE and SUPPMAR matrices. Goods with no margins, the domestic part of the TRADE matrix, will be added (over de in DST) to the matched element of the good supply matrix, MAKE_I.

3.3.2 The TERM-BR equation system

The equations of the TERM model are also similar to those of other CGE models. Producers choose a cost-minimizing combination of intermediate and primary factor inputs, subject to production functions, which are structured by a series of CES “nesting” assumptions.

Figure 10 shows TERM-BR’s production structure for a representative industry and region. At the top level, inputs of a goods composite and a primary factor composite are demanded in proportion to output (Leontief assumption). The primary factor aggregate is a CES composite of capital, land, and a labor aggregate – the latter being itself a CES composite of different labor types. The composite goods are a CES combination of imported and domestic goods, according to Armington assumption, which establishes that goods from different sources are considered imperfect substitutes.

Again, total demands of each region are a CES combination of goods from different regions. The final demand is represented by government, households, firms, rest of the world, and has similar nesting assumptions. Land supply showed in Figure 10 will be detailed further.

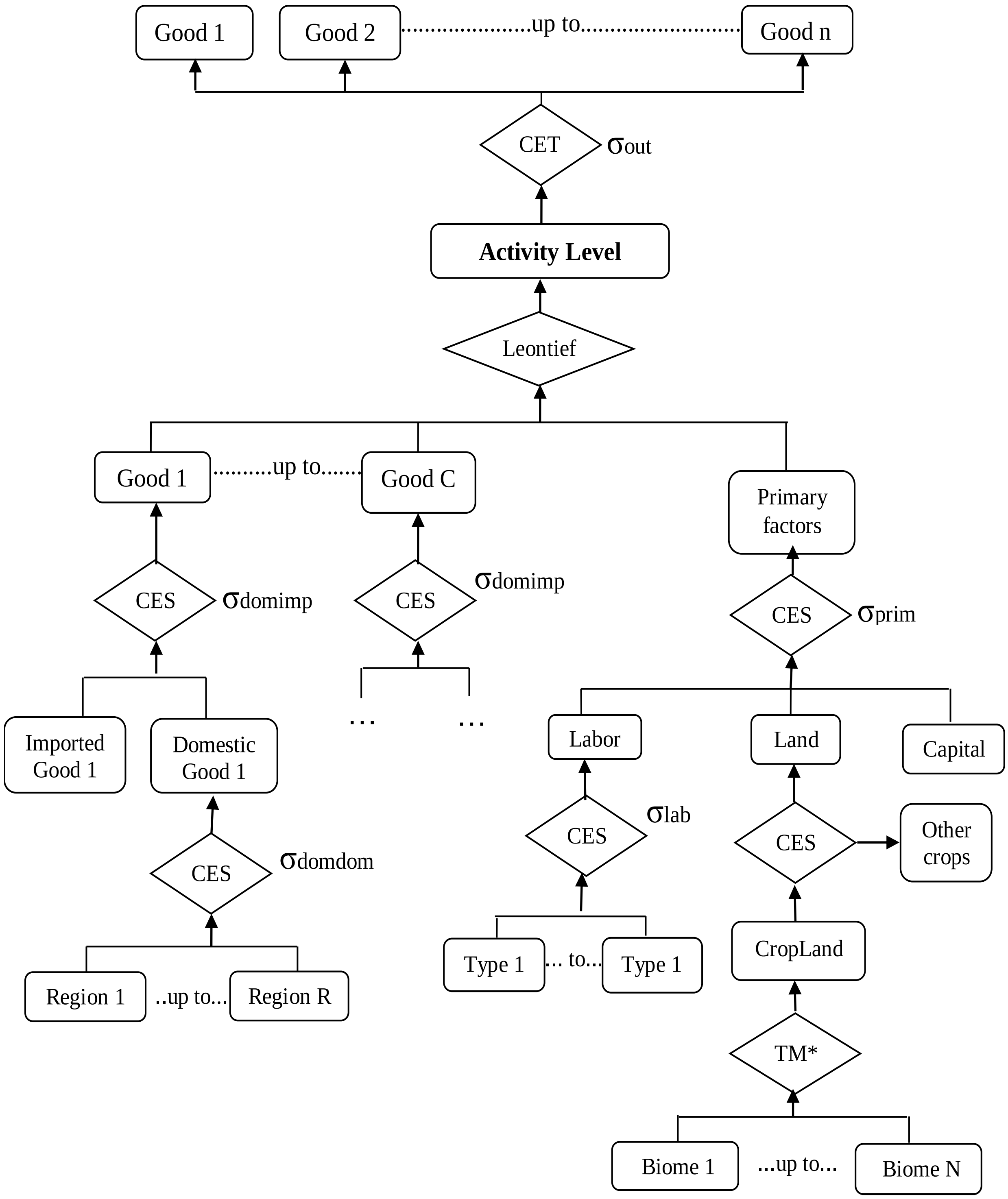

Figure 10 - TERM-BR production nesting structure
Source: Adapted from Horridge (2012)
* Transition Matrix (TM)

3.3.4 TERM-BR sourcing mechanisms

Figure 11 describes several nests representing all substitution possibilities permitted by the model. The dashed rectangles, on the left-hand side, show (in lowercase) the value of the flows associated with each level of the nested system. In addition, in the same dashed rectangles the lowercase represents price variables (p…) and quantity (q…) associated with each flow. The dimensions of those variables are indicated by subscripts c, s, m, r, and d, as shown in Table 2.

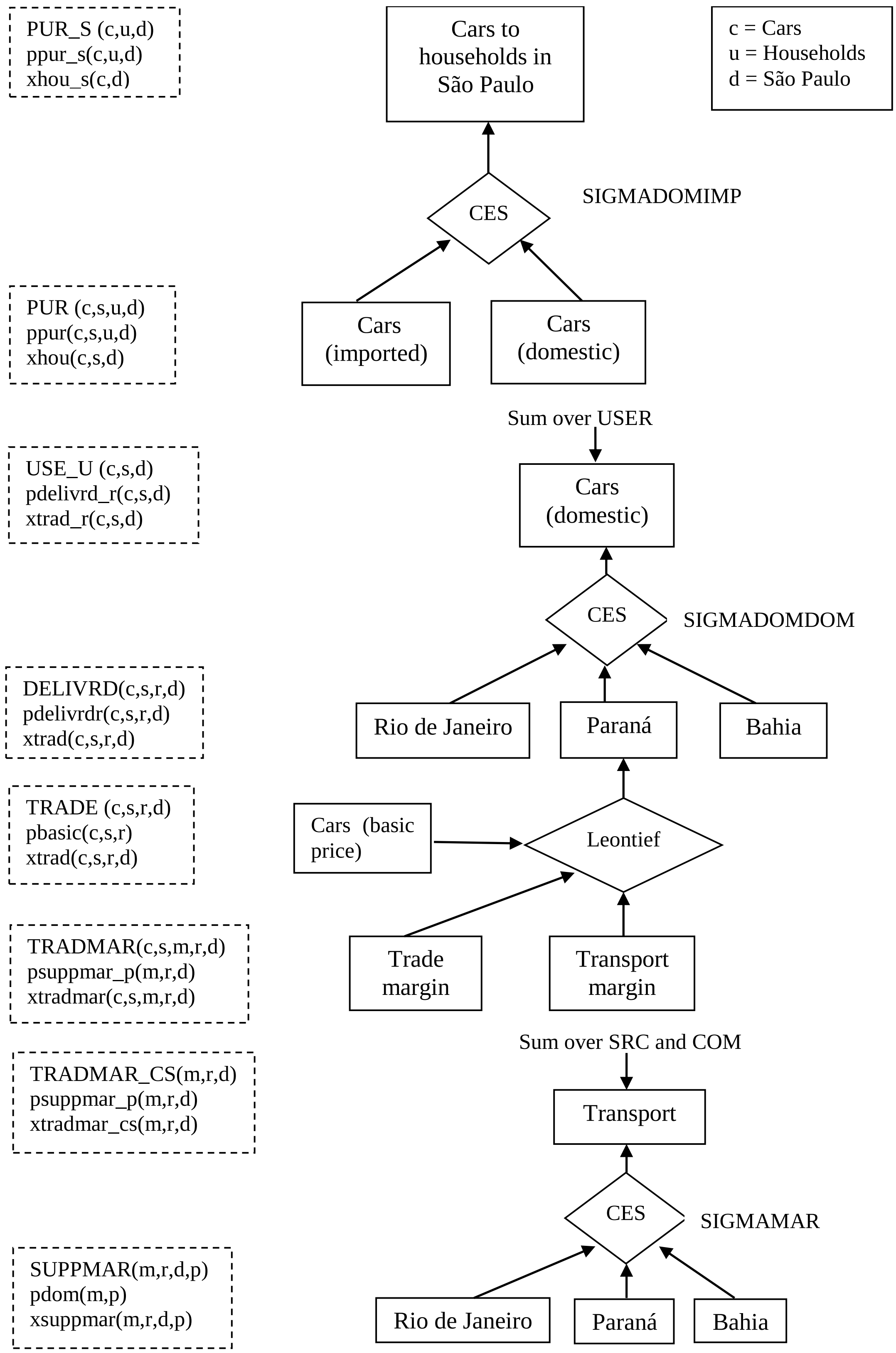

Figure 11- TERM-BR sourcing mechanisms
Source: Adaptaded from Horridge (2012)

At the first level, at the top of the structure, households choose between imported or domestic cars, which is a choice described by a CES specification, with an Armington elasticity that governs the substitution between domestic and imported cars. At this level of the demand structure, flows can be obtained through the PUR_S (c, u, d), which is expressed in terms of purchaser prices. Its values are obtained adding the PUR matrix over (s), which in turn results from the sum between the USE and TAX matrices.

Domestic cars are in turn a composite of the output from the region of origin, in this case Rio de Janeiro, Paraná, and Bahia. Such production is governed by a CES function, which allows the substitution of goods with high relative costs (basic value + margins) for goods (cars) from the region of origin, but with a lower relative cost. Therefore, variations in basic values or margins change the share of the region of origin (supplier) in the market under consideration.

At the third level, cars demanded by Paraná state are an aggregation of the output at basic prices (TRADE matrix) and margins (TRADMAR matrix). Therefore, the Leontief function combines those elements, so that the transportation cost has a higher weight for remote regions (FACHINELLO, 2008).

The last level of the structure shows that trade margins are produced in the region of origin, while transportation margins can be produced in both origin and destination regions. As a result, possibilities of substituting margins is represented by a CES function, which allows for changes in margins according to the region under consideration.

3.3.5 Land-use change and GHG emissions module

Land-use changes and forests are treated endogenously through a transition matrix approach, which was calibrated with data from the Brazilian Agricultural Censuses carried out in 1995/96 and 2006. The transition matrix shows the land use dynamic in a specific region (r) at two points in time – initial (i) and final (f). In Table 3, there are four land use categories: crop (cr), pasture (pt), plantforest (pt), and unused land (un). The latter 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 works as a proxy for evaluating deforestation.

Table 3 - 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 in 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) converted into crops (cr) in the final period (f). Moreover, summing over the column (total) shows the total for each category in the initial period, whilst summing over lines $(TOTAL_i)$ shows the total in the final period. The transition matrix can be expressed in share form, as in Ferreira Filho and Horridge (2012, 2014). This was done employing 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:

$S_{pqr} =$ share of land type p that becomes type q in region "r";

$\mu_{pq} =$ a slack variable, adjusting to ensure that $\sum_q S_{pqr} = 1$;

$L_{pqr} =$ a constant of calibration = initial value of S_{pqr};

$P_{qr}^{\alpha} =$ 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 parameter of sensibility "α" was set at 0.28 in order to approach a normal representation. Therefore, if land rents of crop areas increase, the rate of conversion of pastures into crops will also increase. Furthermore, for representing the rate of conversion of the "Unused" category into other uses, a fictitious rent was employed that is based on a regional CPI (FERREIRA FILHO; HORRIDGE, 2014).

In this version of TERM-BR, land-use changes and forests, as well as their GHG emissions, are based on observed data. Such representation also employs transition matrices, but calibrated with satellite imagery provided by the Brazilian National Institute for Space Research.

The new transition matrices also made progress, as compared to the former version, in incorporating a new dimension in the TERM-BR model, that of the Brazilian biomes, namely, the Amazon (rainforest), Cerrado (savannah), Atlantic Forest (tropical forest), Pantanal (wetlands), Caatinga (semi-arid), and Pampa (grasslands) regions, as show in Figure 12.

Figure 12 - Brazilian biomes
Source: Adapted from IBGE (2014b)

The biomes capture the heterogeneity associated with different types of soil, weather and carbon content, resembling the idea of the AEZs developed by the GTAP[10]. Besides, those differentials of soil, vegetation and weather are represented accurately by biomes, as compared to the counterpart structures widely used for studying physical aspects related to land-use changes.

[10] More details in Lee (2004).

In the new production structure of TERM-BR, land supply are driven by transition matrices, which are summed over biomes, to determine in each state and year the total area of each land use category, namely, Crop, Pasture, PlantForest, and Unused. Then, the resulting total area is allocated among crops, livestock activities according to the CET-like rule:

$$A_{jr} = \lambda_r . K_{jr} . R_{jr}^{0.5} \qquad (2)$$

where A_{jr} is the area of crop land in region r used for industry j, and $R_{jr}^{0.5}$ is the unit of land rent earned by industry j. K_{jr} is a constant of calibration, while a slack variable λ_r adjusts so that:

$\sum_j A_{jr} = A_r =$ pre-determined area of cropland.

Such strategy is also used to distribute Pasture areas between Beef and Diary uses, while Forestry has only one use. Besides, the model considers a land use category, called Unused, which represents all areas not used in agriculture, like native forests, urban areas, grasslands, reservoirs, lakes and roads. Thus, changes in Unused are considered as a proxy for deforestation.

Finally, the resulting model captures differentials of GHG emissions associated with the same land use category, but in distinct biomes. For example, the conversion of unused areas into pastures, which releases more carbon dioxide in the Amazon than in the Cerrado biome.

3.3.5.1 Data strategy

The new version of the TERM-BR model with a module based on new information about land use and emissions was developed in two steps. First, it was built from transition matrices by Brazilian biome and state. At this stage, it used satellite images, as noted before, which were disaggregated into polygons, biomes, municipalities, and GHG emissions for the whole country[11].

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[12]. However, initially the Brazilian states were explicitly represented to meet the CGE model demands and research concerns related to the implementation of regional policies.

[11] For more details see Brasil (2010).
[12] The initial transition matrix is shown in Table 20, in the Appendix A.

At the second stage, the transition matrices built by state and biome were aggregated again under the set CAT, which considers 15 land use categories (Non-managed forests, Managed forests, Secondary forests, Forests with selective timber extraction, Reforestation, Non-managed fields, Managed fields, Field with secondary vegetation, Planted pastures, Crops, Urban areas, Rivers and lakes, Reservoirs, Other uses, and Non classified areas). These 15 land use categories were aggregated into 4 broader categories (Crop, Pasture, Plantforest and Unused) under a new set, the ALNDTYPE set.

The number of land use categories of the former model remains, but as noted before a new dimension biome 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 as 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 13 shows the procedure 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.

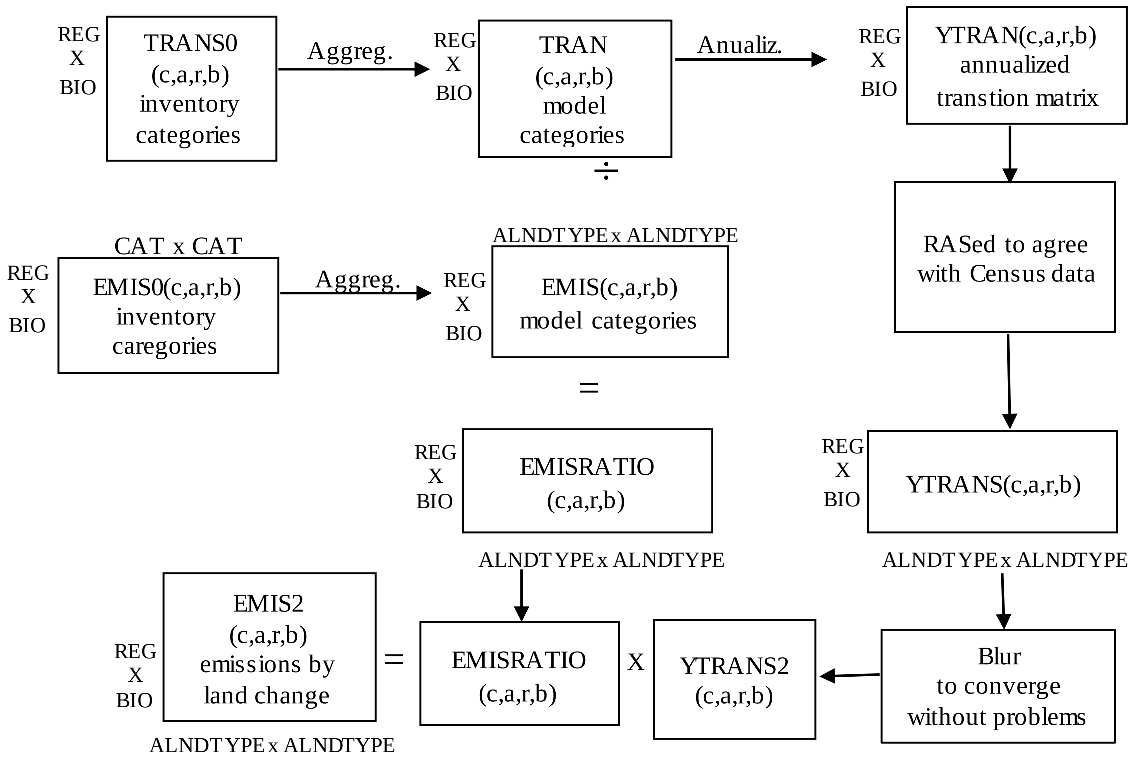

Figure 13 - Treatment of data on land-use change and emissions
Source: Prepared by the author

The RAS[13] 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. 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.

At the end of the stages described above, 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 4 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

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[13] For more details about RAS method, see United Nations (1999).

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 4 - 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**
1 Crop	118799	146693	23509	4481	0.0	1383	**294866**
2 Pasture	891264	165451	27913	91285	1.0	11829	**1187743**
3 PlantForest	1337	2076	-25	289	0.0	0.0	**3678**
4 UNUSED	-173462	-14652	-4770	2427	-122	-366	**-190945**
Total	**837939**	**299569**	**46627**	**98481**	**-121**	**12847**	**1295342**

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

This essay evaluates the economic impacts of halting deforestation in the Amazon Biome and its consequences in terms of GHG emissions in Brazil in the 2005-2035 period. This policy goes beyond the targets of the PPCDAm, which established reducing deforestation in the Legal Amazon region by 80% by 2020, in relation to the average recorded in 1996-2005, as noted before. Such policy, although extreme, is feasible, since the clearing of new areas has been successfully curbed in Brazil over the past few years. Furthermore, it matches the goals of the New York Declaration on Forests, agreed in the United Nations Climate Summit 2014.

In summary, the simulations have the following structure:

- **Baseline:** 2005 is the starting point, and year of the most recent Brazilian Input-Output table. However, model's database was updated up to 2012, with observed data (historical simulation) to capture macroeconomic changes during 2005-2012. For 2013-2035, base simulation assumes moderate economic growth, around 3% per year, and follows population growth rates from the IBGE. For land allocation, after the historical period, the model was calibrated according to the rate of deforestation observed for 2009-2013 by the PRODES monitoring project. Besides, land-augmenting technical change was set to 1 per year. Thus, the transition matrix will lead the land allocation, considering the recent rates of deforestation.

- **Policy:** simulations follow the previous scenario up to 2014. For 2015-2035, a zero percent variation was imposed on the "Unused" category (which represents native vegetation areas) in the agricultural frontier of the Amazon Biome. Therefore, a scenario was considered wherein the supply of new land in that biome is suspended, with crops, pastures, and reforestation activities continuing to grow across the country.

3.4.1 Model closure

The main features of the model's closure 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 from IBGE.
- Capital accumulates between periods following the dynamic investment rule. Furthermore, the capital stock is updated based on the new capital price, i.e. the start-of-period price.
- Regional consumption is linked to regional wage income and to national household consumption. Moreover, regional real government spending demand follows regional real household demand.
- The national GDP price index is chosen as the fixed *numeraire* price. Other prices should thus be interpreted as relative to the GDP price index.
- The national balance of trade is a percentage of real GDP. Thus, in the long run that account is close to zero.
- The regions of the model were divided into two groups: Land-constrained (LndUsed, where agricultural land is consolidated) and Frontier (region where there is land available for expanding agriculture), as shown in Figure 14. Thus, the regions where deforestation is growing will be easily identified, so that specific policies can be applied to just those regions.

Figure 14- Frontier (green) and Land-constrained (yellow) regions of the model
Source: Prepared by the author

3.5 Results

The policy of zero deforestation in the Amazon Biome means imposing a constraint on the land supply for the Brazilian economy. Hence, major macroeconomic variables such as consumption, investment, and government spending follow the performance of GDP, which decreased in relation to the baseline, as shown in Figure 15.

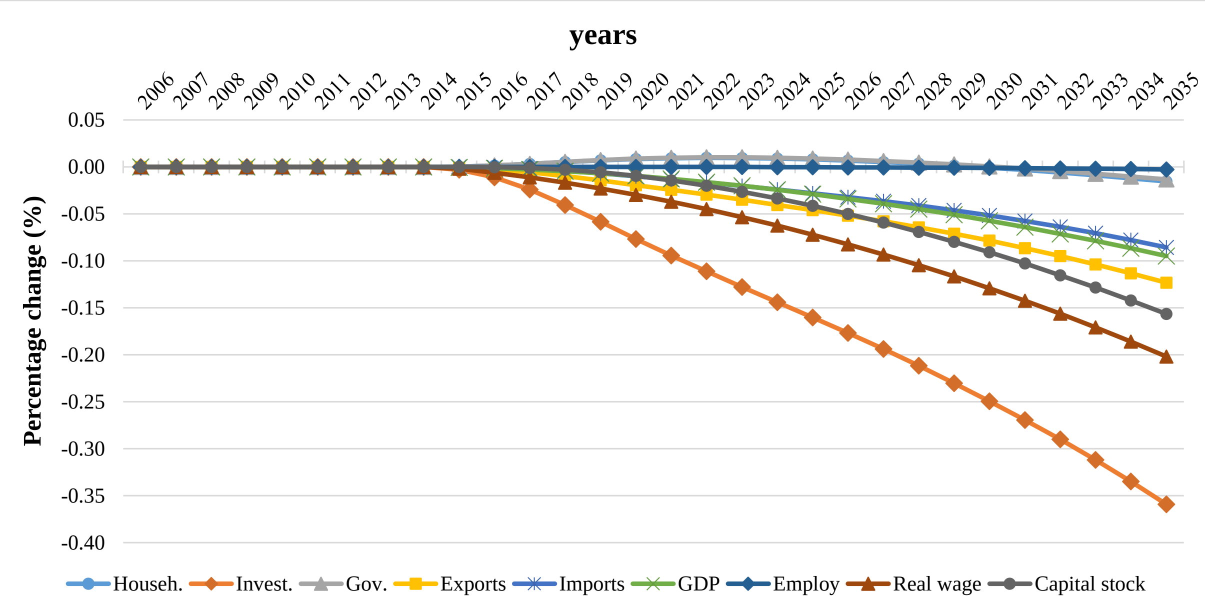

Figure 15- Annual growth rates of major macro variables in real values in 2005-2035 (cumulative % growth)
Source: Model results

In 2005-2035, GDP decreased by -0.09% in relation to the reference scenario, while consumption, investment, and capital stock grew by -0.02%, -0.36%, and -0.16%, respectively, over the same period. The shock applied imposed a land restriction, as noted before, which increased production costs and reduced the rate of return and investment. The impact on capital stock was in turn sluggish, since this variable is somewhat rigid in the short run, but over time it incorporates the effects of reductions in investment.

Furthermore, it is worth mentioning that despite a worse macroeconomic scenario, the negative impact of zero deforestation in the Amazon Biome on GDP, consumption, and investment levels was relatively modest, which is a major result of this policy.

In regional terms, the effects of the policy, as expected, enhanced inequalities between Brazil's mid-west and north regions due to the high costs imposed on the latter, which is located within the Amazon Biome, as shown in Figure 16.

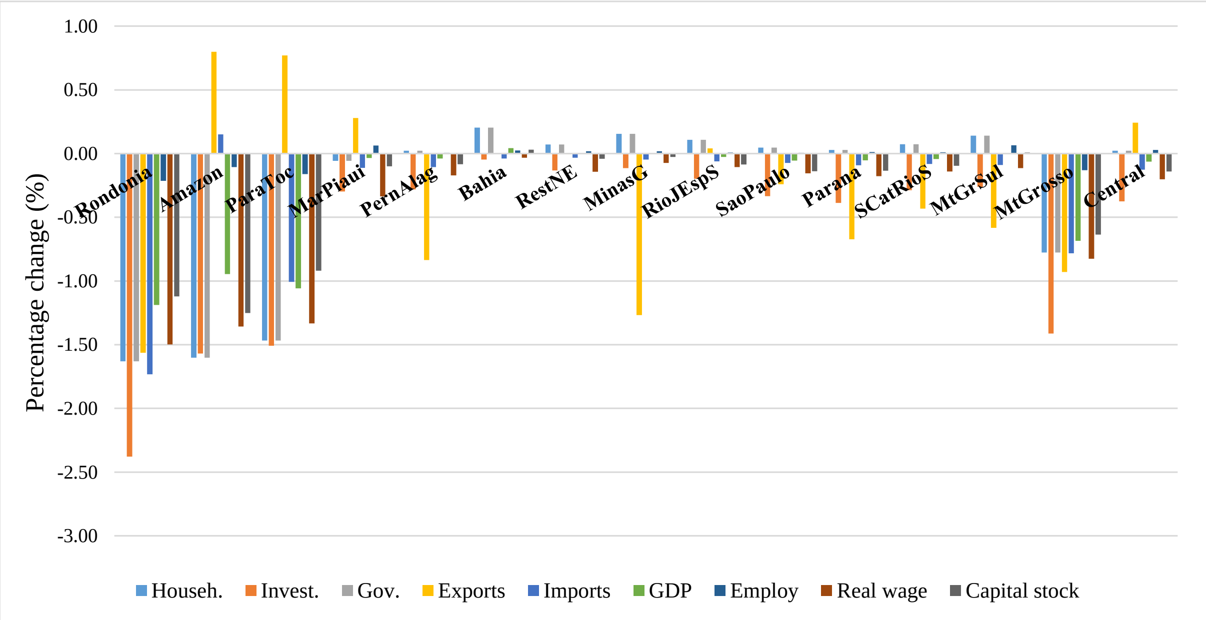

Figure 16 - Policy deviations: growth rates of the main macro variables by region in real values cumulated in 2035 (percentage change)
Source: Model results

In Rondônia, ParaToc (Pará and Tocantins), and MtGrosso (Mato Grosso) states, regional GDP dropped by -1.19%, -1.06%, and -0.68%, respectively, over the 2005-2035 period. In other regions, such as in RestNE (rest of the Northeast), MinasG (Minas Gerais), and Paraná, the impact on GDP was less pronounced, as expected. However, Bahia state was benefited from the policy, once it still has available lands for expand agriculture, especially in the Cerrado Biome.

Economic performance in terms of production also highlights the negative effects of the policy in the agricultural frontier in the Amazon Biome, as shown in Table 5. In Mato Grosso, for example, the cumulative production growth of soybean, maize, and beef cattle in 2005-2035 amounted to -1.68%, -1.79%, and -2.87%, respectively. Similarly, in Pará and Tocantins, the production of agricultural commodities decreased as a result of the constraints imposed on land supply.

Table 5 - Agricultural output, cumulative ordinary change in 2035 (deviations from the baseline).

agricxtot	Frontier-regions					
	Amazon	Rondonia	ParaToc	MarPiaui	Bahia	MtGrosso
Rice	-50.59	-9.42	-10.27	1.10	4.18	0.27
Maize	-17.40	-5.76	-5.35	-0.14	0.46	-1.79
Wheat	-40.16	-10.06	-9.18	-2.48	-0.16	-2.49
Sugar cane	-3.57	-0.96	0.58	-0.27	-0.52	0.00
Soybean	-25.48	-2.90	-4.37	-1.45	-0.09	-1.68
Other agric	-9.23	0.34	-0.54	-0.22	-0.07	-0.70
Cassava	-13.78	0.93	-0.23	1.21	1.24	0.05
Tobacco	-16.23	-1.85	-3.77	-1.19	0.04	-1.10
Cotton	-15.76	-0.37	-1.40	-0.33	0.29	-0.66
Citrus fruits	-15.79	1.09	-1.52	-0.27	-0.02	-1.23
Coffee	-15.00	-1.30	-1.86	-1.09	-0.42	-1.36
Forestry	-21.88	-1.43	-8.57	-1.49	1.76	-1.45
Beef cattle	-39.62	-5.95	-11.92	1.74	3.02	-2.87
Milk cattle	-39.64	-5.61	-11.72	-0.49	-0.04	-3.64

Source: Model results.

In the states of Bahia, MarPiaui (Maranhão and Piauí) and Mato Grosso, production decreased less due to the characteristics of those frontier regions. Bahia, for example, is not located in the Amazon Biome and therefore it is not directly affected by the impacts of deforestation control, meaning that agriculture can expand into Cerrado areas. In the latter two regions, the drop in production was balanced by production growth in land located in other biomes, especially in the Cerrado Biome.

In the rest of the country, in general, there was a reduction in traditional crops, such as in coffee, wheat, and sugar cane crops, at the same time that rice, cotton, and beef cattle production grew in other regions, as shown in Table 6.

Table 6 - Agricultural output, cumulative ordinary change in 2035 (deviations from the baseline).

Agricxtot	Land-constrained regions								
	Central	Pern Alag	RestNE	MtGr Sul	MinasG	RioJ EspS	Sao Paulo	Parana	SCat RioS
Rice	3.49	3.66	3.69	2.99	3.58	2.95	4.05	3.97	1.71
Maize	-0.38	-0.11	-0.07	0.01	-0.13	-0.51	-0.17	-0.15	-0.30
Wheat	-0.62	-0.18	-0.54	-0.81	-0.32	-0.60	0.29	0.12	-1.52
Sugar cane	-0.19	-0.45	-0.27	-0.48	-0.24	-0.45	-0.27	-0.40	-0.60
Soybean	-0.33	-0.13	-0.32	-0.54	-0.08	-0.58	0.16	-0.07	-0.91
Other agric	0.02	-0.09	-0.14	-0.05	-0.04	-0.44	0.12	0.03	-0.36
Cassava	2.19	0.48	0.60	2.35	1.50	0.73	1.56	1.17	0.91
Tobacco	0.28	-0.04	-0.07	0.09	0.09	-0.16	0.66	0.52	-0.20
Cotton	0.65	0.20	0.12	0.40	0.38	0.09	0.86	0.80	0.17
Citrus fruits	0.03	-0.14	-0.16	-0.28	-0.18	-0.57	-0.09	0.02	-0.89
Coffee	-0.34	-0.41	-0.49	-0.57	-0.43	-0.64	-0.03	-0.09	-0.89
Forestry	1.11	2.50	2.31	1.68	1.03	1.25	1.35	0.69	0.56
Beef cattle	2.12	2.02	1.94	2.27	3.00	4.73	4.36	4.67	4.47
Milk cattle	0.03	0.79	0.85	0.73	0.75	0.29	0.09	-0.22	0.07

Source: Model results.

Therefore, it is worth highlighting the performance of the forestry sector, as well as the boost in agriculture in São Paulo and Paraná. These states were benefited from constraints imposed on the agricultural frontier and stepped up their production, except in their citrus and sugar cane crops. The former was substituted by other cultures, while the latter are being displaced to the mid-west region (Central, Mato Grosso do Sul, and Mato Grosso), particularly to Cerrado areas.

The constraints imposed on land supply, as well as the resulting production drop in some of the most important Brazilian crops, adversely affected the prices paid by households, as shown in Figure 17. More specifically, low-income households (POF1-POF5) were forced to pay higher prices, while prices decreased for most medium- and high-income households (POF6-POF10)[14]. In other words, the policy tends to worsen income distribution. Nonetheless, the magnitude of these price variations was small, since the policy shock was only applied to the Amazon Biome.

[14] 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

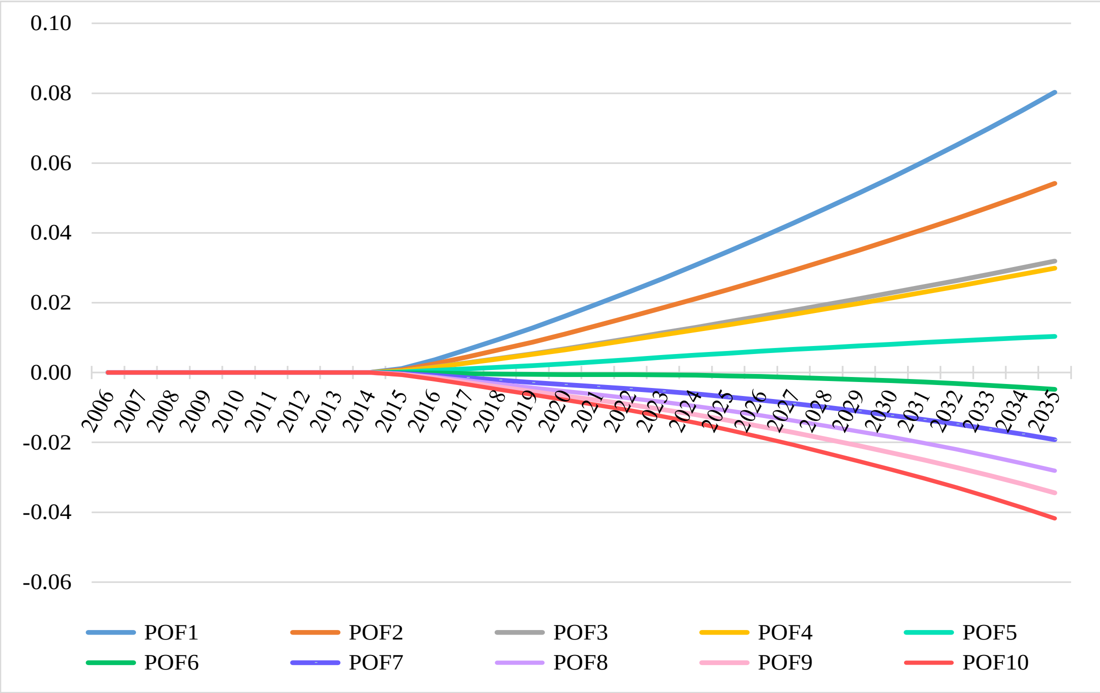

Figure 17 - National CPI by household income, policy deviations, cumulated values in 2005-2035 (in percentage change).
Source: Model results.

Thus, halting land supply in the Amazon Biome tends to shift agricultural production to other Brazilian biomes, as well as deforestation. This process would be important in the Cerrado, Caatinga, and Pantanal biomes, where areas of native vegetation (Unused) may decrease, respectively, by -0.19 Mha, -0.05 Mha, and -0.02 Mha, accumulated in 2035, as shown in Figure 18.

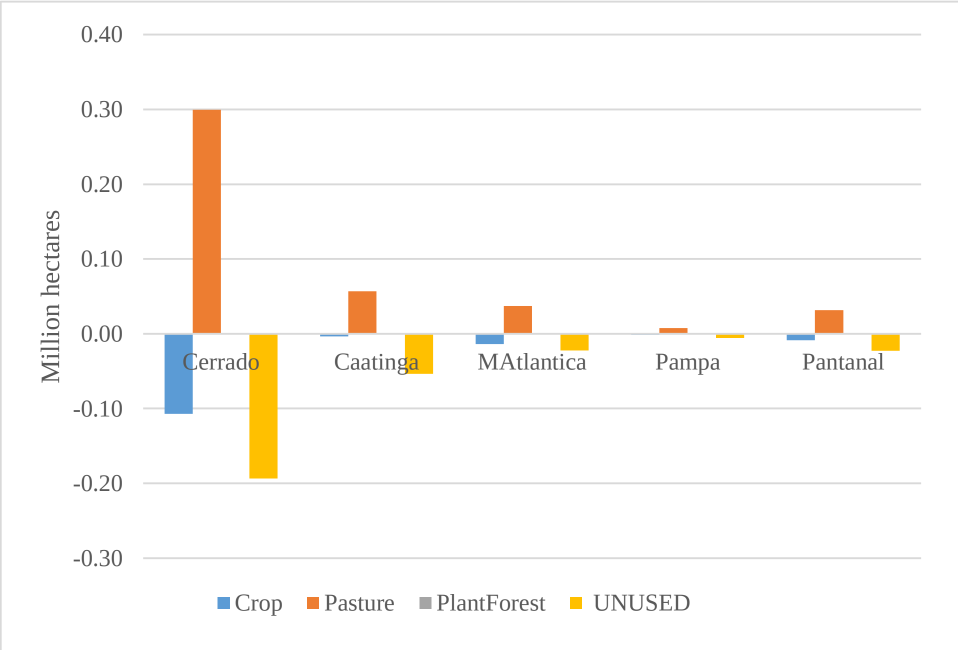

Figure 18 - Policy deviations of land-use change, by Brazilian biomes, cumulated values in 2035 (ordinary change).
Source: Model results.

Deforestation can also be noticed by observing the growth of pasturelands, the predominant land use category in Brazil after clearing of forests. In the Amazon region (Frontier), the slowdown observed in the growth of crops, pastures, and forestry, by assumption, results of freezing land supply.

The role of livestock, as the main agent of deforestation, is highlighted by the simultaneous reduction in pasturelands and the increase in "Unused" areas, as shown in Figure 19. Therefore, the constraints to convert areas of native vegetation into other uses in the Amazon region would cause a reduction in areas occupied by crops, pastures, and forestry by -1.57 million of hectares (Mha), -12.06 Mha, and -0.14 Mha, respectively, cumulatively in 2005-2035. When aggregated, these results correspond to the total "Unused" area preserved by the policy.

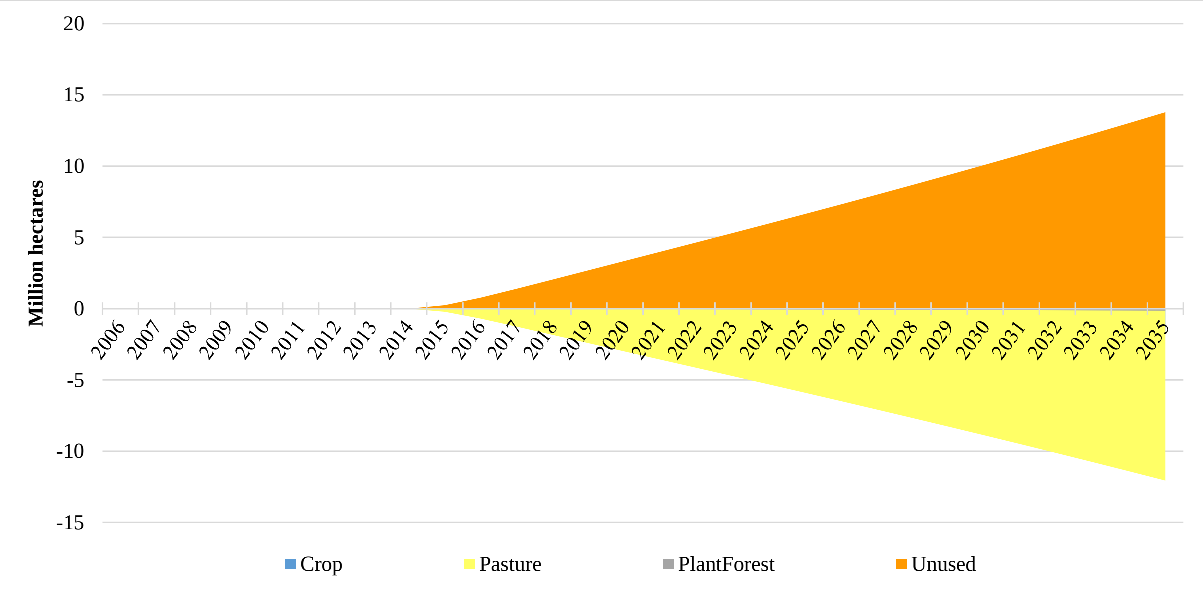

Figure 19 - Policy deviations: land areas, cumulative ordinary change during 2005-2035 (Million hectares)
Source: Model results

Furthermore, land conversion into pastures constitutes the main source of GHG emissions among all land use categories in Brazil, as noted before. Such emissions have been higher in the Amazon Biome, because of its greater concentration of carbon above and below the soil. These emissions are followed by those from the Cerrado Biome, released from agriculture, which grew throughout this region over the last decades (Table 7).

Table 7 - Emissions by Brazilian biome, policy deviation cumulated in 2035 (Net gigagrams of CO_2eq.)

delucemit_d	Amazon	Cerrado	Caatinga	Atlantic Forest	Pampa	Pantanal	**Total**
Crop	-28,239.53	243.12	6.26	-35.25	-0.04	-12.25	-28,037.69
Pasture	-247,205.91	2,423.83	256.60	422.91	-0.01	224.06	-243,878.51
PlantForest	-98.38	-0.92	-0.77	3.53	0.04	0.00	-96.50
UNUSED	10,719.04	-455.10	1.85	-77.91	-0.45	-28.18	10,159.25
Total	-264,824.77	2,210.92	263.94	313.29	-0.47	183.63	-261,853.46

Source: Model results

Table 7 shows how specific policies for the Amazon Biome is important, since in the simulation, even after a net reduction of 264,824.77 gigagrams of carbon dioxide equivalent (Gg. of CO_2eq.) cumulated in 2035, as a result from the policy. The Cerrado region, in turn, after its net emissions rose by 2,210.92 Gg. of CO_2eq. (cumulated value in 2035), accounts for 17.6% of all domestic emissions or for 97,258.91 Gg. of CO_2 eq. in 2035.

The emissions shift from the Amazon to other biomes is an expected result of halting deforestation in the former. The policy shifts emissions from the Amazon to the Cerrado Biome as a result of agricultural activities movement from the former to the latter, in response to the land constraints imposed on the Amazon Biome. Among the factors explaining those shifts, the major one is the nearness between these biomes, which facilitates the spillover of productive activities between them.

Figure 20 shows the effectiveness of a zero deforestation policy in the Amazon Biome in reducing domestic GHG emissions, especially those from the conversion of land into crops and pasture. Emissions from such converted land would amount to 2,454 Gg. of CO_2eq. and 14,671 Gg. of CO_2eq. cumulatively in the 2005-2035 period, respectively. However, the balance was negative, in terms of emissions, which means removal of GHG emissions by saved unused areas.

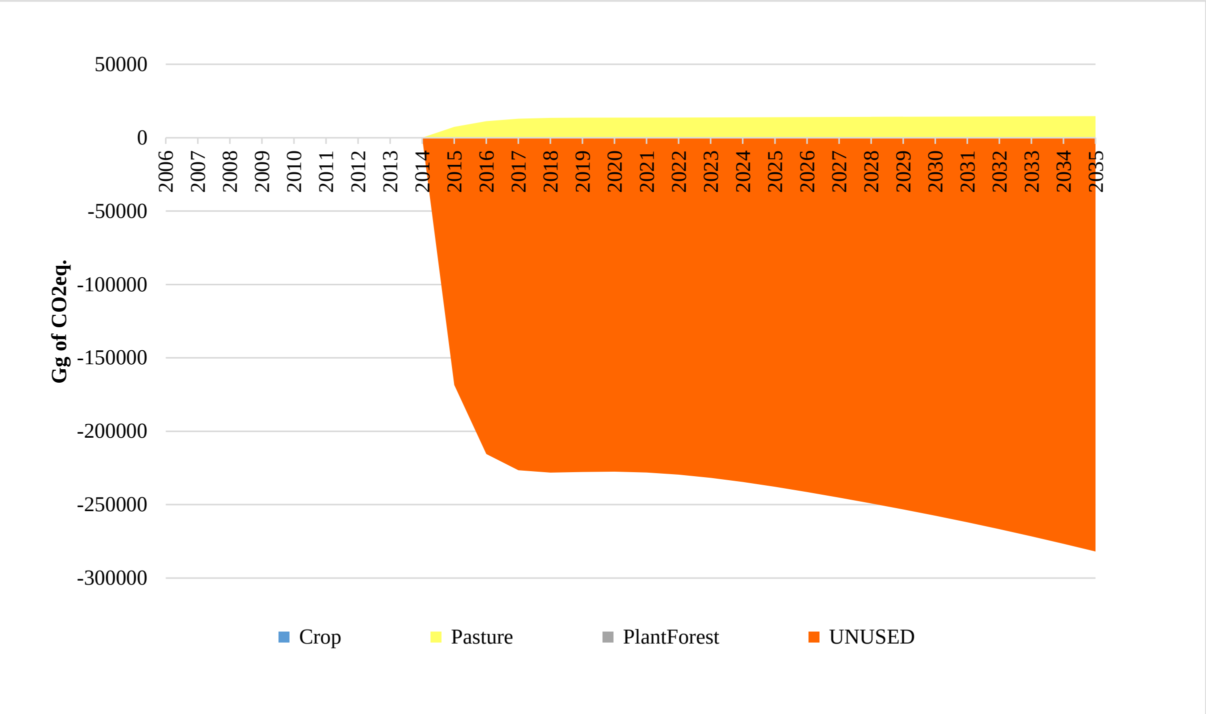

Figure 20 - Policy deviations of emissions from land use categories in the Amazon Biome, during 2005-2035 (net gigagrams of CO_2e. - cumulative)
Source: Model results

Figure 21 shows in turn the evolution of GHG emissions in the Cerrado Biome. In the 2005-2035 period, the amount emitted is a result of land conversion into crops and pastures, which can increase by 243 Gg. of CO_2 eq. and 2,424 Gg. of CO_2 eq., respectively, while unused removed 455 Gg. of CO_2 eq. in the same period. This growth indicates the shifting of livestock toward Cerrado areas, as a result of the constraints imposed on the Amazon Biome, as noted before. However, it is worth noticing that the growth in cattle farming observed in the Cerrado region occurred at the expense of crops and unused areas/emissions.

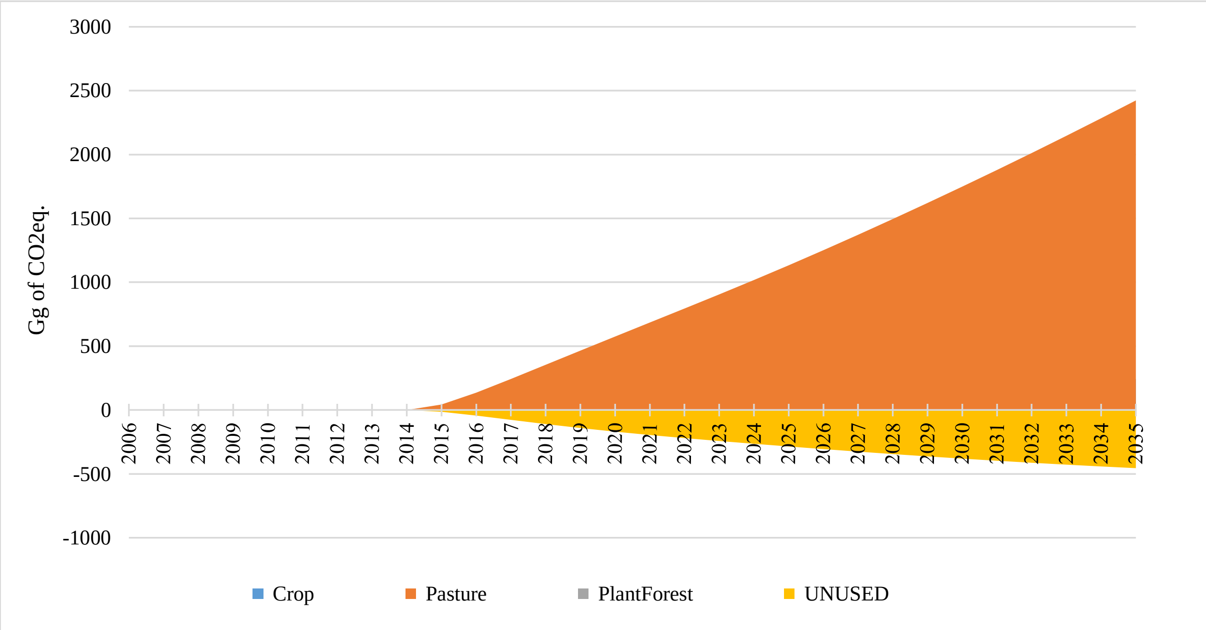

Figure 21 - Emissions from land use categories in the Cerrado Biome, policy deviations during 2005-2035 (net gigagrams of CO_2eq. - cumulative)
Source: Model results

The growth in emissions in the Cerrado region did not undermine gains in terms of GHG reductions achieved in the Amazon Biome. However, the other Brazilian biomes must be contemplated by the same policies as an alternative to controlling possible leaks of emissions and the spillover of deforestation agents such as livestock.

Table 8 shows the effectiveness of the policy to curb domestic GHG emissions. The amount of gases related to land-use change (LUC) released from Brazil was reduced by almost half, from 1,329,081 Gg. of CO_2 eq. to 299,232 Gg. of CO_2 eq. in 2035, the last year under consideration. In other words, the share of LUC emissions would drop from 62.7% in 2005 to 14.6 % in 2035.

Table 8 - Total emissions and their shares, by source in the initial and final periods.

EMIT	2005		2035	
	Gg. CO2 eq.	Share	Gg. CO2 eq.	Share
Mining	113,665	0.054	254,194	0.124
Gasoline	32,705	0.015	66,809	0.033
Gasohol	9,449	0.004	20,728	0.010
Combustible oil	139,591	0.066	323,359	0.158
Petrochemicals	15,364	0.007	37,211	0.018
Activity	479,533	0.226	1,050,320	0.512
LUC	1,329,081	0.627	299,232	0.146
TOTAL	2,119,387	1.000	2,051,852	1.000

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

When the main target is reduce GHG emissions, the deforestation in other Brazilian biomes should not be neglected, especially emissions from cattle farming. Notwithstanding the effectiveness of zero deforestation in the Amazon in reducing domestic emissions, these gains would be amplified by, for example, including the Cerrado Biome, which was affected by the policy's spillover effect.

In addition, reduction in emissions from land-use change were partially offset by those from fuels and other activities. The increase in the latter is due to the reallocation of factors in the economy, which adapted itself to the constraints. Besides, non-land intensive sectors may increase their production and, consequently, GHG emissions, such as the fuel, mining, and transportation industries, among others.

Finally, the balance of freezing deforestation in the Amazon Biome, albeit positive in respect of deforestation and emission reduction, failed to produce positive results for the economy. Besides, the zero deforestation policy designed for the Amazon region alone was not capable of fully halting deforestation and its GHG emissions and neither of protecting the economy from its adverse consequences. Alternative policies should therefore be considered in connection with, for example, productivity gains in agriculture, which can generate a land saving effect combining environmental preservation and production, with positive implications for food security and the economy as a whole.

3.6 Final remarks

This study analyzed the economic consequences of zero deforestation in the Amazon Biome in Brazil. Albeit this is an extreme case, the Brazilian government has ambitious targets to reduce deforestation and has made progress in achieving them. The step forward taken through an extreme case in this essay provides important insights into the dynamic of deforestation and, consequently, of its GHG emissions, which were displaced to other Brazilian regions and biomes, which

Deforestation control in the Amazon Biome can effectively reduce domestic GHG emissions; however, leaks of deforestation and emissions to other regions and biomes can compromise the gains achieved. Such leaks or movements have another important implication, namely, that of increasing regional inequalities. The policy applied intensified asymmetries between Brazilian regions, especially between the mid-west and all the other regions, since in the former the negative impacts on the regional GDP, consumption levels, and employment, among other variables, were more pronounced, as expected.

The gains of halting deforestation in the Amazon Biome would be amplified by, for example, including the Cerrado Biome, which was affected by the policy's spillover effect triggered by available lands close to the former (border) region. The increase of fuels and activities emissions also would offset policy gains, in terms of emissions. Such increases, would be caused by factors reallocation in the economy, which adapted itself to the constraints. Besides, non-land intensive sectors would increase their production and, consequently, GHG emissions, such as the fuel, mining, and transportation industries, among others.

In addition, this essay draws attention to the importance of specific policies for the different Brazilian regions, as the costs and benefits of these policies vary considerably and, as a result, they can impose more constraints on less developed regions and on important sectors such as agriculture, but with no effects on deforestation and GHG emissions.

The specialized literature considered productivity gains in agriculture as an important alternative for reducing the demand for new land for farming and, consequently, for reducing deforestation. However, the consequences of productivity gains in agriculture for the Brazilian economy, land allocation, and GHG emissions are still not accurately known and, therefore, constitute an important field for future research.

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3 CLIMATE CHANGE MITIGATION THROUGH AGRICULTURE AND LIVESTOCK INTENSIFICATION IN BRAZIL: THE BORLAUG HYPOTHESIS

Abstract

This essay analyzes the economic impacts of productivity gains in agriculture to reduce deforestation and, consequently, GHG emissions in Brazil, as proposed by Borlaug Hypothesis. For this purpose, it was used a Computable General Equilibrium (CGE) model, tailored to include a module of land-use change and GHG emissions. Three policies were implemented, through shocks applied to livestock, agriculture, and both sectors aggregately. The results show that productivity gains can "save" land and thus avoid deforestation, as indicated by Borlaug Hypothesis. In addition, the policies promote a reduction in GHG emissions, especially in the Amazon and Cerrado biomes, with no adverse effects on the economy. 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 for the Brazilian case, 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.

4.1 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 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 Brazilian agriculture growth. Conversely, productivity increases in agriculture would allow production to grow without clearing new areas – the Borlaug effect (BORLAUG, 2002).

This essay analyzes the economic impacts of productivity gains in the Brazilian agriculture. Policy effects on land allocation and GHG emissions were also evaluated, using a CGE model tailored for the Brazilian economy with a land-use module that captures heterogeneity in different land types and emissions in Brazil.

This work contributes to the existing literature in two main ways. First, it distinguishes the biome dimension in dealing with land use modeling. This is crucial for emissions analysis, due to the different rate of emissions associated to different biomes. Second, the model associates emissions to an endogenous module of deforestation, according to different biomes. This is done through a transition matrix between land uses obtained from satellite imagery, by biome and region, and which is linked to a corresponding emission matrices.

This essay is organized in four sections, besides this introduction. The first section evaluates the evolution of agricultural productivity in Brazil. The second describes the methodology and the empiric strategy of this work. In the third section the results are discussed. Finally, final remarks are presented.

4.2 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 essay, is reinforced.

4.3 Methodology

This essay uses a computable general equilibrium model of Brazil, the TERM-BR, to analyze the importance of productivity increases for 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.

The model in this essay includes 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[15]: (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.

4.3.1 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 22 shows the 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.

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[15] More details in Appendix B.

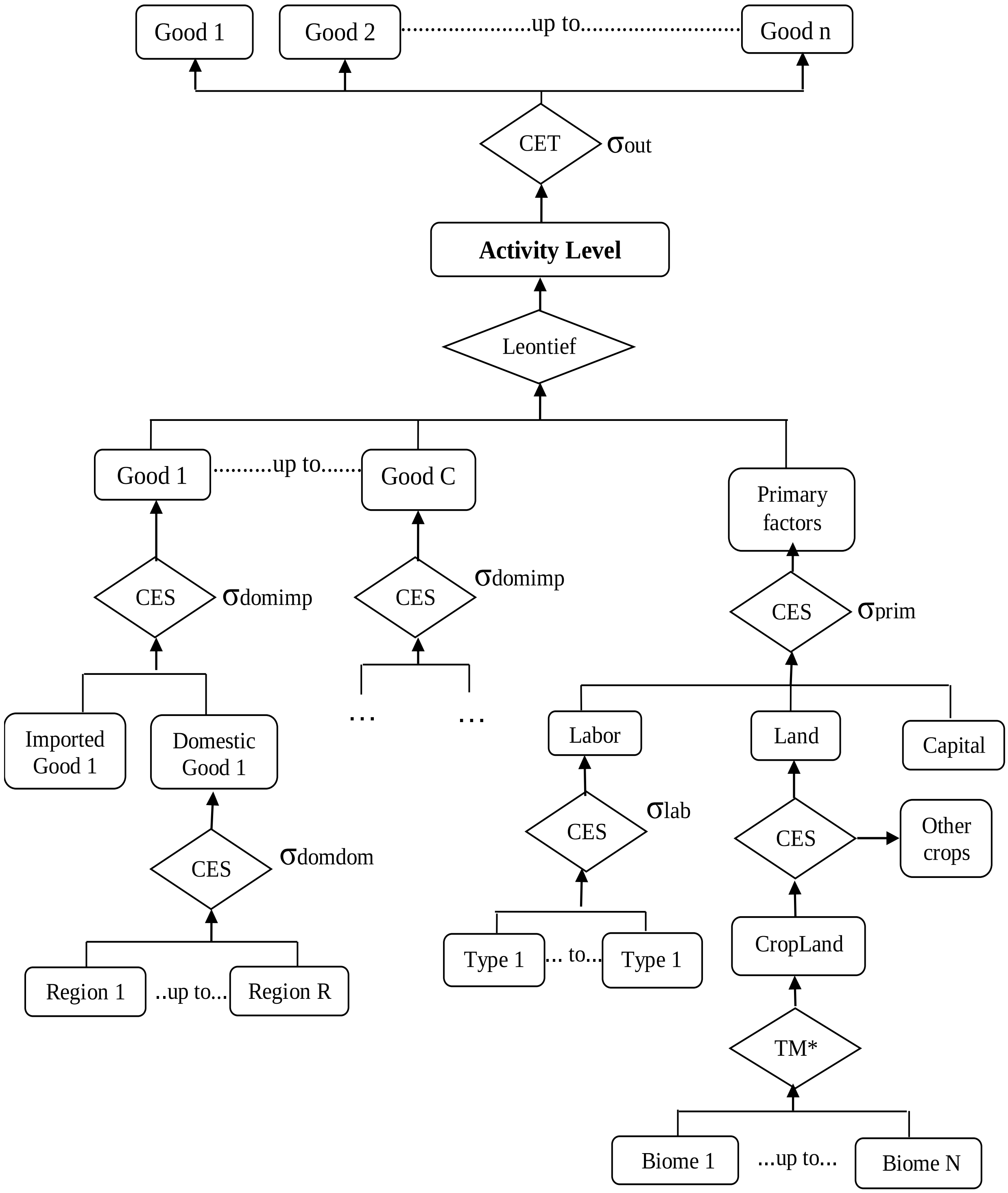

Figure 22 - TERM-BR nesting production structure
Source: Adapted from Horridge (2012)
* Transition Matrix (TM)

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.

4.3.2 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. 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 23 shows consumption possibilities for households, considering the maximization of the Klein-Rubin utility function.

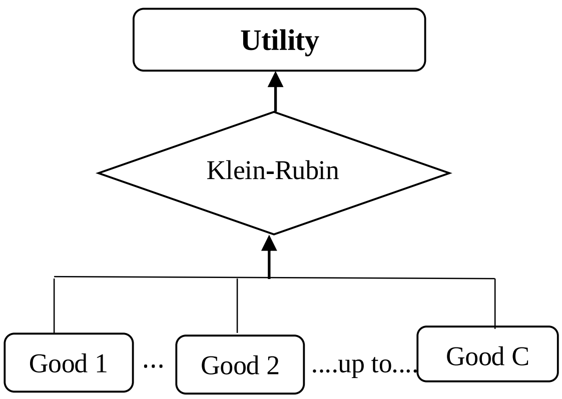

Figure 23 - Household demand structure in the TERM-BR model
Source: Santos (2006)

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.

Once the factors that drive the demand decisions of households are defined, the sourcing and flows that meet their demand and substitution possibilities in the model must be presented, as shown in Figure 24. This figure shows a generic example, considering only one commodity (cars), one user (households), in a single region (São Paulo), but other commodities, regions, and users may be represented in the same structure.

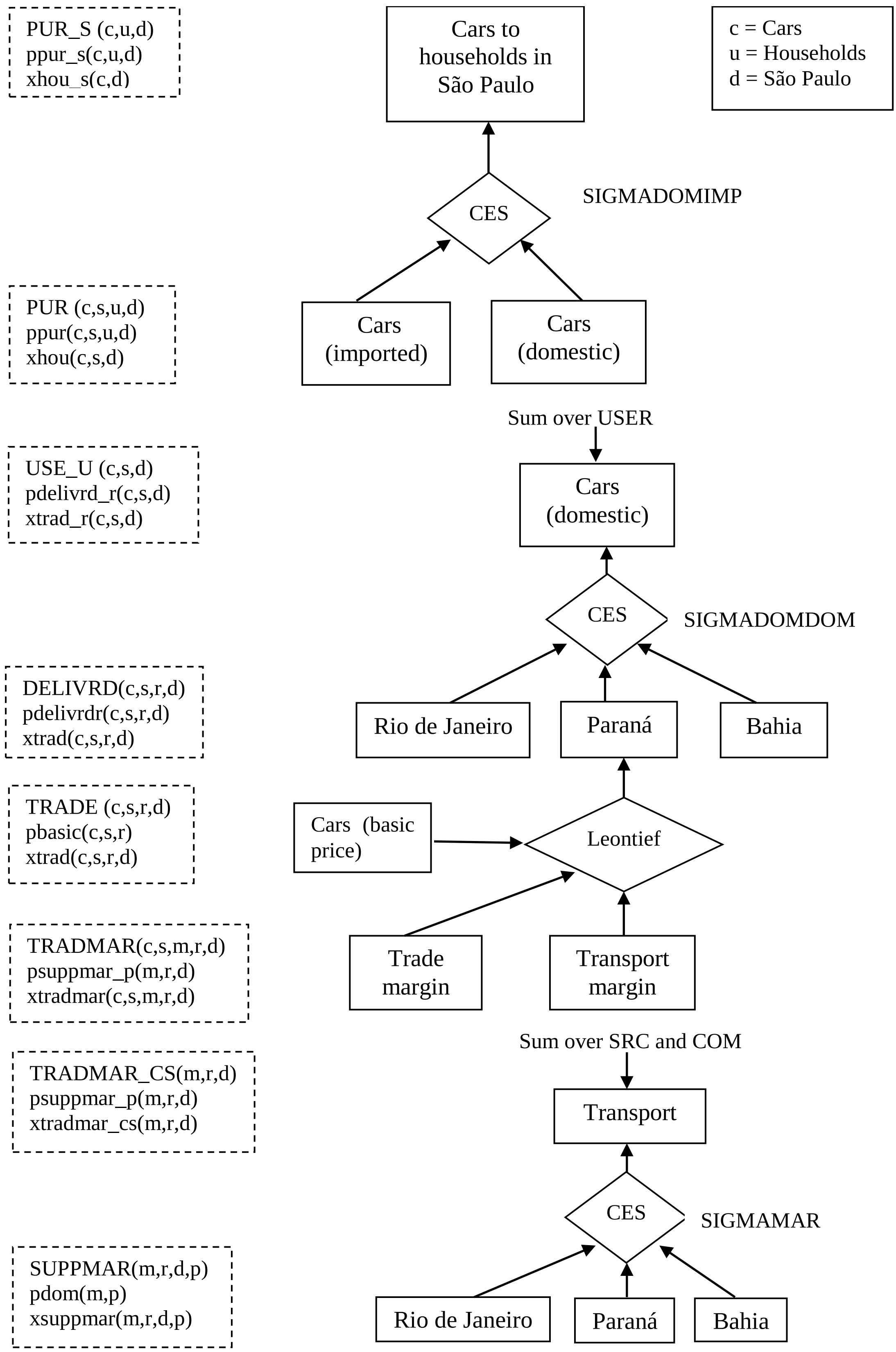

Figure 24 - The TERM-BR sourcing mechanism.
Source: Adapted from Horridge (2012).

The several nests representing all substitution possibilities that the model allows for are displayed. The dashed rectangles on the left-hand side show (in lowercase) the value of the flows associated with each level of the nested system. Still in the same dashed rectangles, the words in lowercase letters represent price (p…) and quantity (q…) variables associated with each flow. The dimensions of these variables are indicated by subscripts c (commodities), s (origin), m (margin), r (region of origin), and d (region of destination).

At the first level (on top of the structure) households choose between imported or domestic cars, which choice is described by a CES specification and an Armington elasticity that governs the substitution between domestic and imported cars. At this level of the demand structure, flows may be obtained through the PUR_S (c, u, d) matrix, which is expressed in terms of consumer prices. Its values are obtained by adding the PUR matrix in (s), which in turn results from adding the USE and TAX matrices.

Domestic cars are in turn a composite of the output from the region of origin, in this case the states of Rio de Janeiro, Paraná, and Bahia. Besides, production is led by a CES function, which allows for goods with high relative costs (basic value + margins) to be substituted for goods (cars) from the region of origin but with a lower relative cost. Therefore, variations in basic prices or margins change the share of the region of origin (supplier) in the market under consideration.

At the third level, cars in demand in Paraná state are an aggregation of the output at basic prices (TRADE matrix) and margins (TRADMAR matrix). So the Leontief function combines those elements in such a way that transportation costs will weigh more for more remote regions (FACHINELLO, 2008).

The last level of the structure shows that trade margins are produced in the region of origin, while transportation margins can be produced in both regions of origin and of destination. As a result, the relation that governs possibilities for substituting margins is represented by a CES function, which allows for margins to be changed according to the region under consideration.

4.3.3 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 a final (f) point. Table 9 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 9 - 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}

$P_{qr}^{\alpha} =$ 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 25.

Figure 25 - 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 developed by the

GTAP [16]. 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[17].

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[18].

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 (Non-managed forests, Managed forests, Secondary forests, Forests with selective timber extraction, Reforestation, Non-managed fields, Managed fields, Field with secondary vegetation, Planted pastures, Crops, Urban areas, Rivers and lakes, Reservoirs, Other uses, and Non classified areas). These 15 land use categories were aggregated into 4 broader categories (Crop, Pasture, Plantforest and Unused) under a new set, the ALNDTYPE.

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 as 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;

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[16] More details can be found in Lee (2004).
[17] For more details, see Brasil (2010).
[18] The initial transition matrix is shown by Table 20, in the Appendix A.

- 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 26 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.

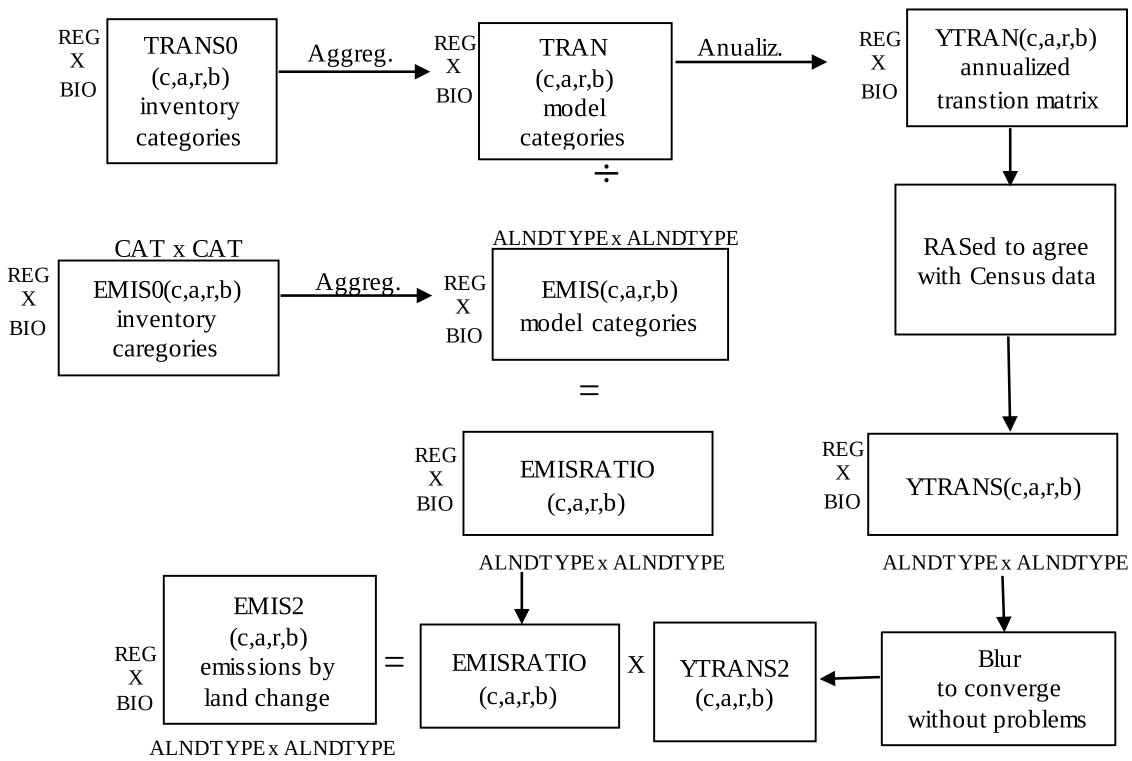

Figure 26 - Treatment of data on land-use change and emissions.
Source: Prepared by the author.

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 27 shows the new land supply and demand structure in the model with the new dimension, biome, incorporated into it.

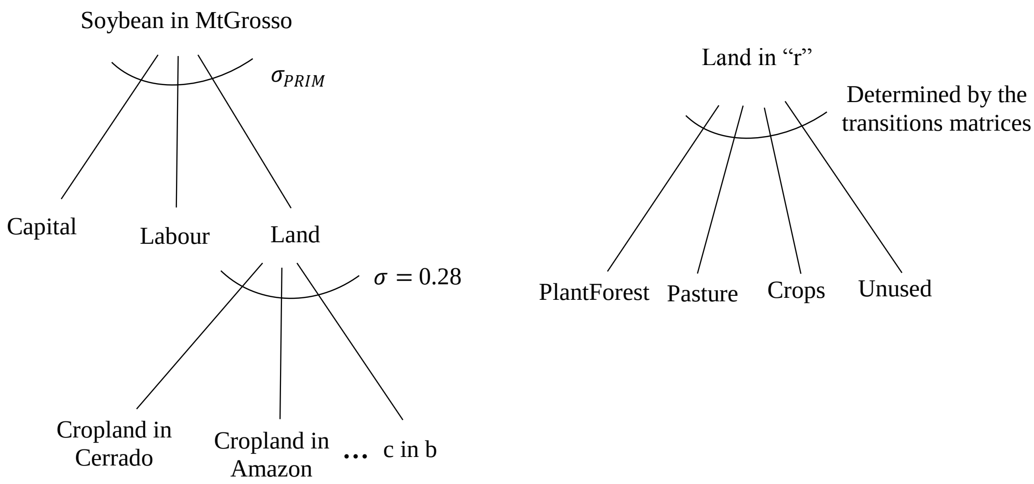

Figure 27 - Land supply (right-hand side) and demand (left-hand side) of the TERM-BR model.
Source: Prepared by the author.

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 10 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 10 - 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.

4.4 Scenarios

The shocks implemented in this essay 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.

4.4.1 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 28. Regions where deforestation is on the rise can be separated and specific policies applied to them.

Figure 28 - Frontier (green) and Land-constrained (yellow) regions of the model.
Source: Prepared by the author.

4.4.2 Baseline

The simulations started in 2005, the year of the most recent Brazilian input-output table. The TERM-BR equation system generates an initial solution that creates a picture of the

Brazilian economy in the first year. After that, a historical simulation updates the database with observed figures of the national economy until the present.

The availability of economic data determines the extension of the historical simulation, which in this paper ends in 2012. However, a forecast simulation continues to move the economy to future periods through the equation systems. So the historical and forecast simulations make up the base scenario that is used as reference for policy simulations.

In this study, the main macroeconomic variables were updated with observed data until 2012, as noted before. For the ensuing periods, 2013-2035, a moderate growth rate of 2.84% on average was assumed for the Brazilian economy. The other economic variables follow the same pattern of moderate growth such as consumption (2.79%), investment (2.83%), and government spending (2.79 %), as shown in Table 11.

Table 11 - Model results, base scenario. Macro variables (real values): cumulated growth in 2005-2035 and final annual growth rates

natselmacro	Real Hou	Real Inv	Real Gov	Exp Vol	Imp Vol	Real GDP	Employ	Real wage	Cap Stock
Cumulative % growth	115	118	85	152	23	135	43	35	98
Terminal growth rate %	2.79	2.83	2.79	2.99	2.73	2.84	1.14	1.64	2.81

Source: Model results

In the base scenario, land allocation follows the growth trends of crops, pastures, and forestry, whose expansion occurred simultaneously with a reduction in areas of native vegetation represented by the “Unused” category, as shown in Figure 29. The evolution of land allocation highlights the deforestation process under way in Brazil, characterized by the conversion of forests, grasslands, and other areas of native vegetation into pastures and crops, despite the recent reduction in deforestation rates observed in the country, especially in the post-2005 period.

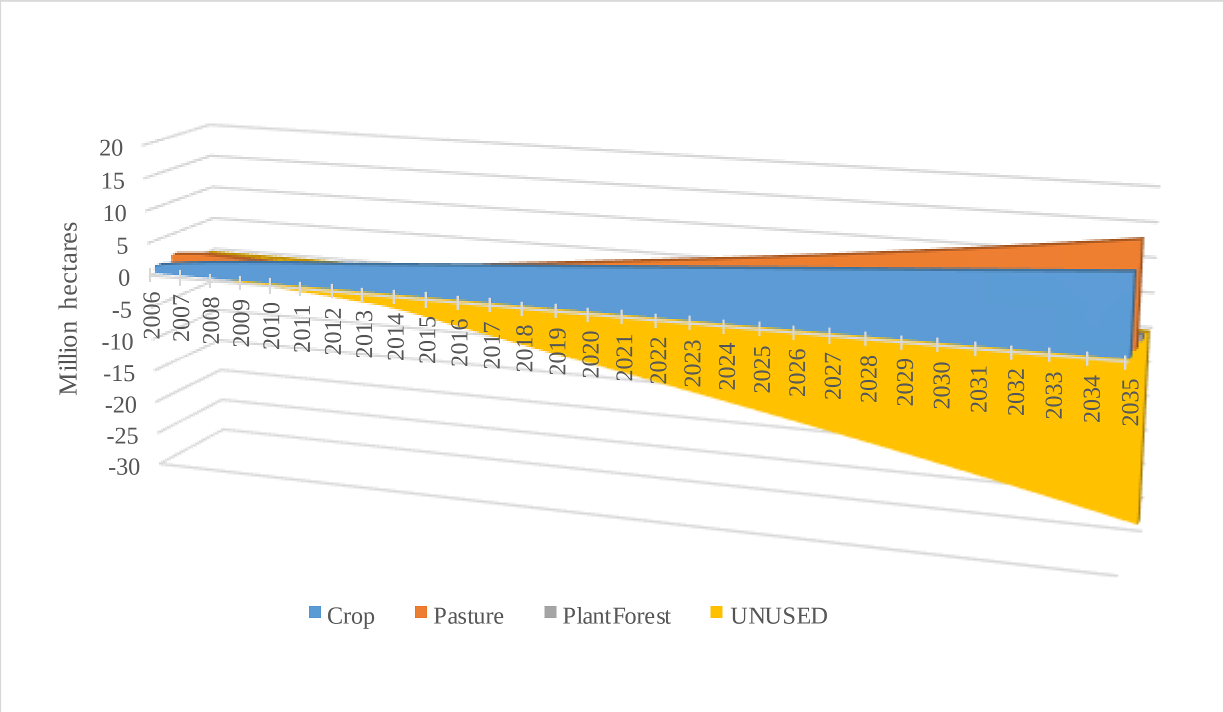

Figure 29 - Evolution of broad categories of land use in Brazil, cumulated in 2005-2035 (Million hectares in the baseline).
Source: Model results.

Table 12 shows the growth of the Brazilian agriculture in the baseline, especially in the frontier region. In such area, both livestock and crops are important activities, specially soybean, maize, cotton, and sugarcane crops. In the rest of Brazil, cattle farming became more intense, with decreasing area but a higher production. The lower variations in area and production outside the frontier due to the lower land supply and higher productivity of livestock, making it difficult for marginal gains to be obtained.

Table 12 - Agricultural output and land area variation, cumulative percent change 2005-2035 (base scenario).

Activity	Output				Land area variation	
	Frontier	LndUsed	Frontier (share)	LndUsed (share)	Frontier	LndUsed
Rice	140	51	0.05	0.029	-19	-53
Corn	194	122	0.069	0.069	85	23
Wheat	472	365	0.168	0.205	112	77
Sugarcane	271	139	0.096	0.078	185	64
Soybean	158	128	0.056	0.072	11	3
Other agric	130	96	0.046	0.054	39	-2
Cassava	177	80	0.063	0.045	39	-27
Tobacco	153	110	0.054	0.062	40	-7
Cotton	201	181	0.071	0.102	39	41
Citrus fruits	222	94	0.079	0.053	84	-22
Coffee	146	62	0.052	0.035	81	-30
Forestry	220	149	0.078	0.084	55	10
Meat cattle	166	98	0.059	0.055	30	-7
Milk cattle	165	107	0.059	0.06	30	-2
Unused			1.000	1.000	-6	-1

Source: Model results

In regional terms, livestock gained momentum in frontier states, mainly in ParaToc (Pará and Tocantins), MtGrosso (Mato Grosso), and MarPiaui (Maranhão and Piauí). The first two regions concentrate the dynamism of agriculture in the north, as the area occupied by crops also increased in that region, especially the areas occupied by sugarcane, maize, and other crops. In addition, areas of natural vegetation represented by the "Unused" category decreased, strongly suggesting deforestation, as shown in Table 13.

Table 13 - Land areas of the base scenario, cumulative ordinary change in 2005-2035 (million hectares)

del_AREASPLU	Frontier-regions					
	Amazon	Rondonia	ParaToc	MarPiaui	Bahia	MtGrosso
Rice	0.1	0.1	0.2	-0.2	0.0	-0.5
Corn	0.2	0.2	0.7	0.5	0.4	0.6
Wheat	0.0	0.0	0.0	0.0	0.0	0.0
Sugarcane	0.0	0.0	0.1	0.1	0.1	0.4
Soybean	0.1	0.1	0.6	0.2	0.0	-0.1
Other agric	0.2	0.1	0.4	0.2	0.3	0.0
Cassava	0.2	0.0	0.3	0.0	0.0	0.0
Tobacco	0.0	0.0	0.0	0.0	0.0	0.0
Cotton	0.0	0.0	0.0	0.0	0.1	0.2
Citrus fruits	0.0	0.0	0.1	0.0	0.0	0.0
Coffee	0.0	0.2	0.0	0.0	0.0	0.0
All crops	**0.8**	**0.8**	**2.4**	**0.8**	**0.9**	**0.5**
Forestry	**0.2**	**0.0**	**0.0**	**0.0**	**0.2**	**0.0**
Meat cattle	6.6	0.4	4.9	2.1	1.5	4.2
Milk cattle	0.5	0.1	0.3	0.2	0.1	0.3
All pasture	**7.1**	**0.5**	**5.2**	**2.3**	**1.6**	**4.5**
Unused	**-8.2**	**-1.2**	**-7.6**	**-3.1**	**-2.7**	**-5.0**

Source: Model results

Table 14 shows, in turn, the process of land allocation in traditional agricultural regions such as MtGrSul (Mato Grosso do Sul) and Central (Goiás and the Federal District), where the reduction in pasture areas may confirm the shift of cattle farming to the north and northeast regions.

Table 14 - Land areas of the base scenario, cumulative ordinary change in 2005-2035 (million hectares)

del_AREA SPLU	Land-constrained regions								
	Central	Pern Alag	Rest NE	MtGr Sul	MinasG	RioJ EspS	SaoPaulo	Parana	Scat RioS
Rice	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	-0.7
Corn	0.8	-0.1	0.2	0.4	0.3	0.0	-0.3	0.3	0.3
Wheat	0.1	0.0	0.0	0.3	0.0	0.0	0.0	0.7	1.1
Sugarcane	0.6	0.3	0.2	0.3	0.4	0.0	1.3	0.4	0.0
Soybean	2.0	0.0	0.0	1.1	-0.3	0.0	-0.4	-1.3	-0.7
Other agric	0.4	-0.2	0.0	0.1	-0.1	-0.1	-0.2	0.0	0.0
Cassava	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	-0.1	0.0
Tobacco	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cotton	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Citrus fruits	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	0.0	0.0
Coffee	0.0	0.0	0.0	0.0	-0.2	-0.3	-0.1	0.0	0.0
All crops	**4.1**	**0.0**	**0.3**	**2.3**	**0.1**	**-0.4**	**0.0**	**0.0**	**0.0**
Forestry	**0.0**	**0.0**	**0.0**	**0.1**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**
Meat cattle	-3.2	0.2	-0.1	-2.3	0.1	0.3	-0.1	-0.1	-0.1
Milk cattle	-0.6	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.0
All pasture	**-3.9**	**0.2**	**-0.1**	**-2.3**	**0.2**	**0.4**	**0.0**	**0.0**	**0.0**
Unused	**-0.3**	**-0.2**	**-0.2**	**0.0**	**-0.4**	**0.0**	**0.0**	**0.0**	**0.0**

Source: Model results

It is worth noting that cattle farming and crops have grown in areas of native vegetation, which explains the reduction observed in the “Unused” category in the agricultural frontier region, where land is still available for expanding such activities.

Figure 30 shows that emissions from biomes are on the decline, following the decreasing deforestation rates as in the Amazon Biome, especially in the post-2004 period.

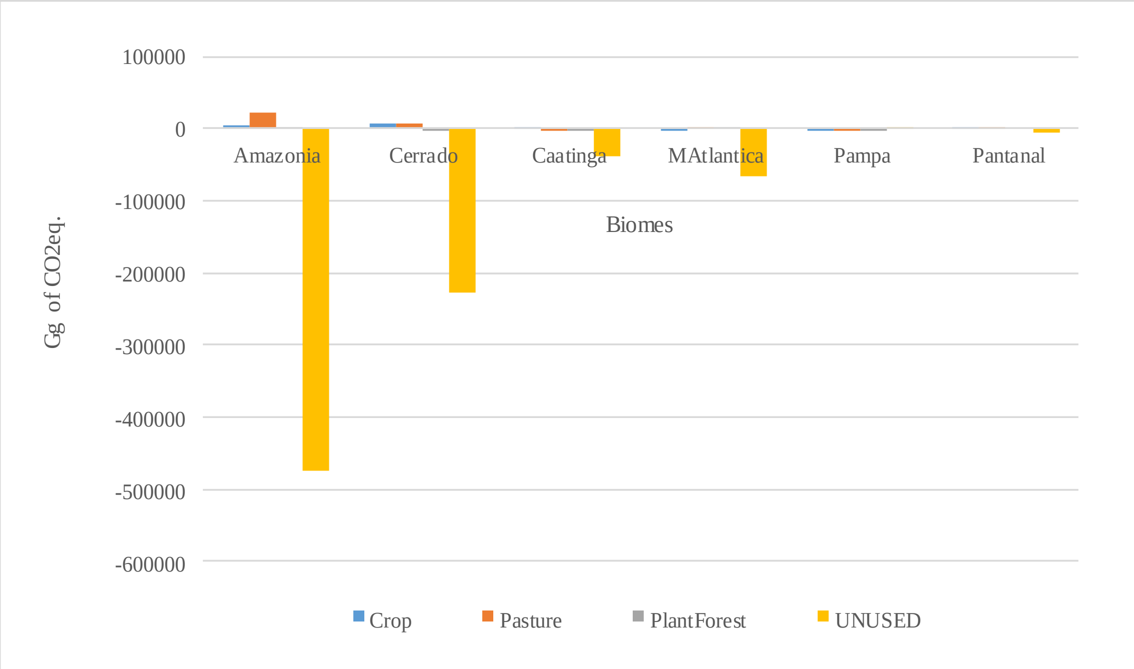

Figure 30 - Land use emissions by biome, gigagrams of CO_2 equivalents. Baseline, cumulated in 2035.
Source: Model data.

Figure 30 also highlights the importance of designing policies focused on the Amazon Biome, since it is the one with the greatest potential for reducing emissions from land-use change and forests.

4.5 Results

Table 15 shows the results of the main macroeconomic variables cumulated in 2005-2035. As expected, the increase in productivity in agriculture was positive for the Brazilian economy, as 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 15 - 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

Nonetheless, 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 16. 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 16 - 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 31. It presents the results of Policy 3, the broadest one, dividing the consumers into 10 income ranges[19] (POF1 to POF10).

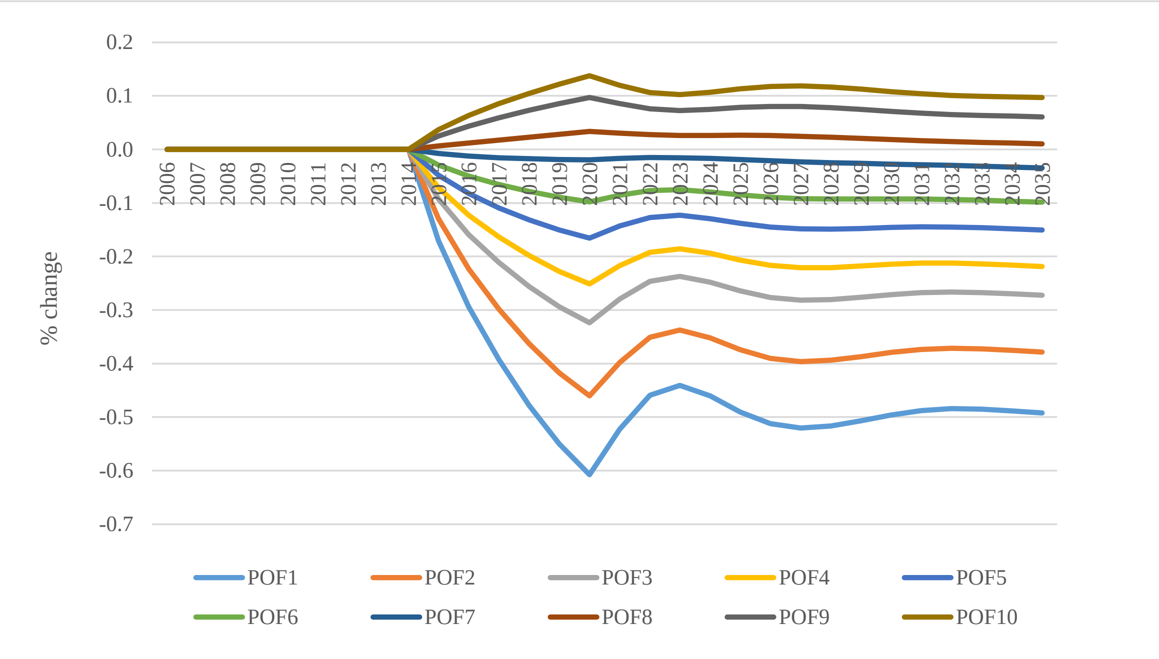

Figure 31 - Policy 3: consumer price index by household income, cumulative percentage change in 2005-2035 (deviations)
Source: Model results

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[20]. 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 17 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

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[19] 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

[20] Shown in Table 21, in the Appendix C.

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 17 - 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 18.

Table 18 - 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 32.

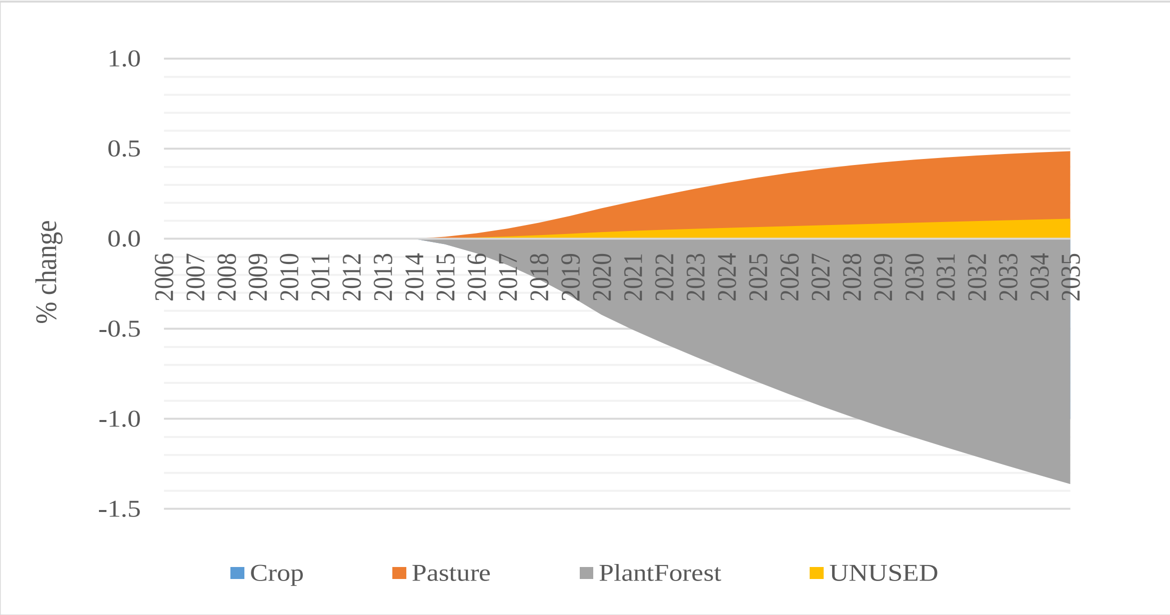

Figure 32 - Policy 3: land use variation in the Cerrado region as a result of a productivity shock, cumulative percent change in 2005-2035 (deviations).
Source: Model results.

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 33, 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.

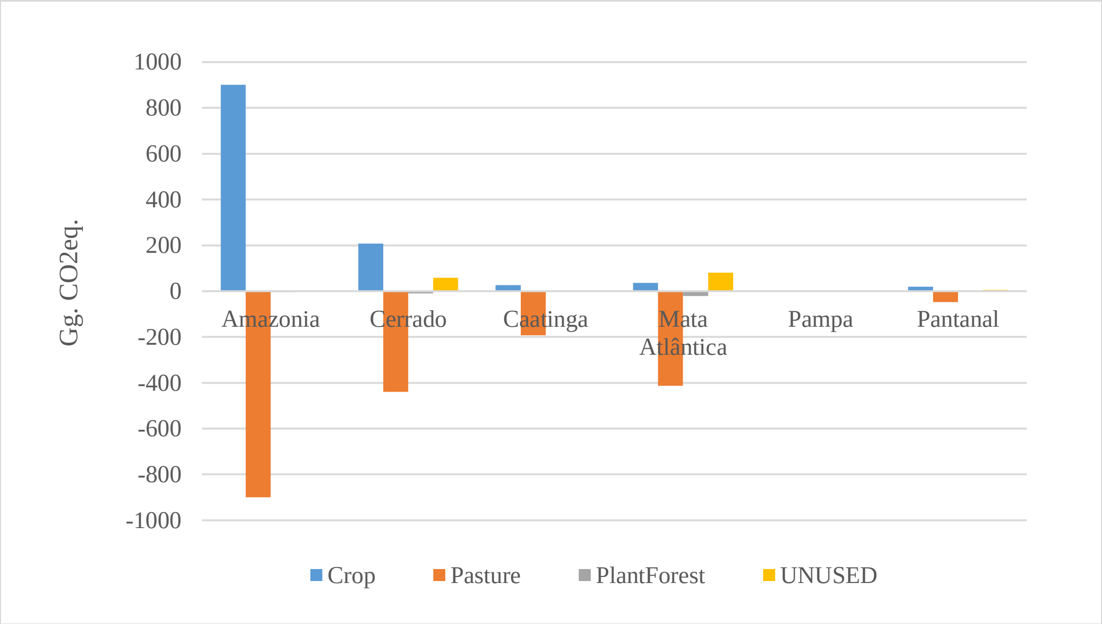

Figure 33 - Policy 1: land use emissions in Brazil by biome, in gigagrams of carbon dioxide equivalent cumulated in 2035 (deviations from the baseline).
Source: Model results.

Nonetheless, the Cerrado region 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 34.

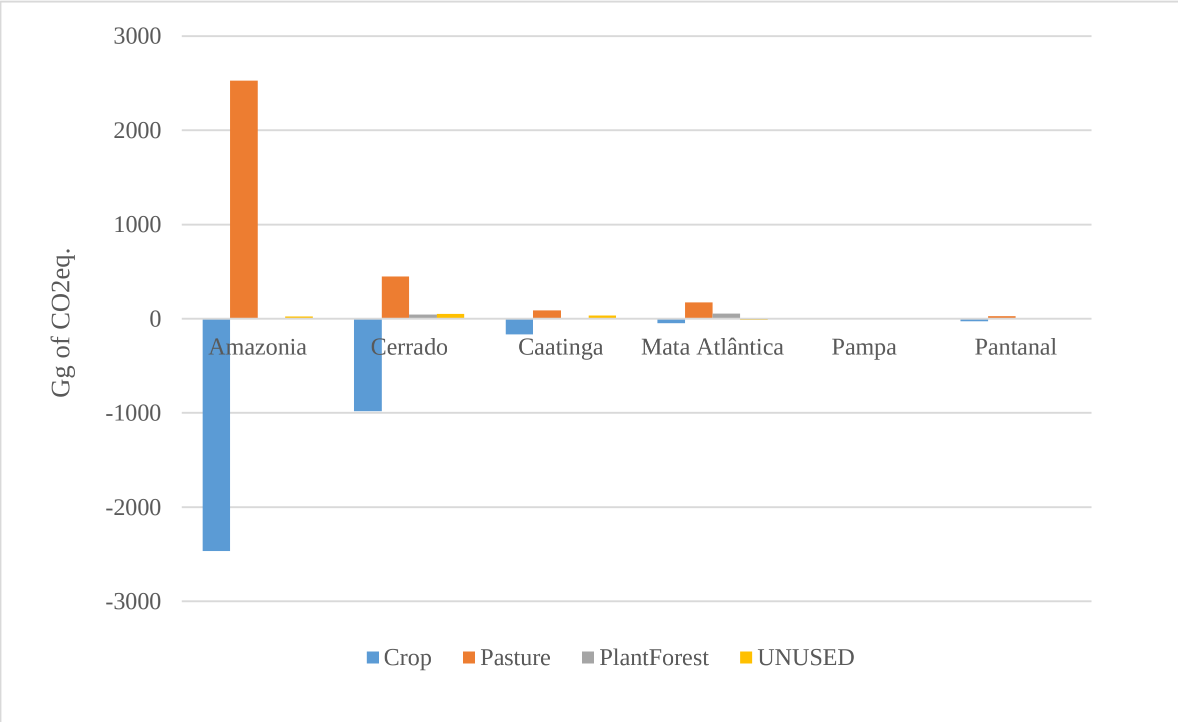

Figure 34 - Policy 2: land use emissions in Brazil by biome, in gigagrams of carbon dioxide equivalent, cumulated in 2035 (deviations from the baseline).
Source: Model results.

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 35.

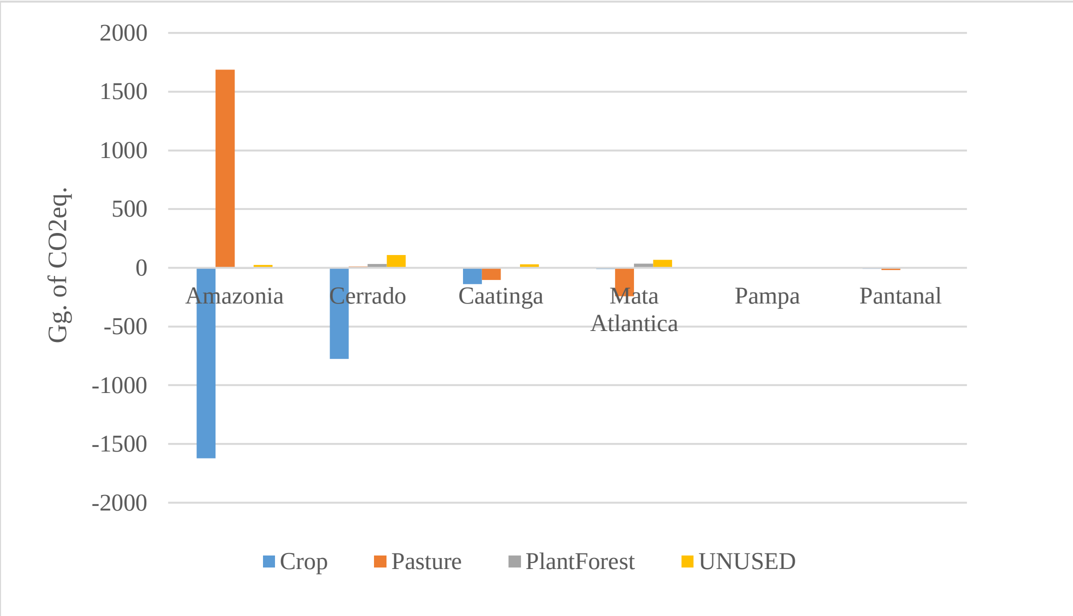

Figure 35 - Policy 3: emissions by biome, in gigagrams of carbon dioxide equivalent, cumulated in 2035 (deviations from the baseline).
Source: Model results.

Table 19 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 19 - 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.

4.6 Final remarks

This essay 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 essay 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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APPENDICES

APENDICES

APPENDIX A

Table 20 - Hypothetical broad transition matrix of land use change (in hectare)/(Gg of CO_2eq.)

Land use 1994	Land use categories in 2002															
	FNM	FM	FSec	Ref	CS	GNM	GM	GSec	Ap	Ac	S	A	Res	O	NO	**Total 1994**
FNM						..	..	..				..				
FM	..					..	..	..				..				
FSec	..	..			..	..	..	..				..				
Ref	..	..			..	..	..					..				
CS	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	
GNM	..	..	..		..							..				
GM	..	..	..		..	..						..				
GSec	..	..	..		..	..	..					..				
Ap	..	..			..	..	..					..				
Ac	..	..			..	..	..					..				
S	..	..	..	..	..	..	..	..	..	..		..	..	..		
A	..	..	..	..	..	..	..	..	..	..	..					
Res	..	..	..	..	..	..	..	..	..	..	..			..		
O	..	..	..	..	..	..	..									
NO	..	..														
Total 2002																

Source: Brasil (2010)

APPENDIX B

B.1 DYNAMIC COMPONENT

The TERM-BR, as other CGE models, assumes “myopic expectations” that were incorporated into the model dynamic through equations designed to handle capital growth and its return rate, as well as to relate investment to capital stock in annual simulations. Thus, its forecasting mechanism comprises the following elements:

i. A flow-stock relation between investment and capital, which assumes a one-year gestation lag;
ii. A positive relation between investment and the rate of profit;
iii. A relation between increases in wages and employment level.

Such elements allow applying the model to build a plausible base scenario for the next 10 years or more, as well as setting up another scenario, which differs from the former by the incidence of some policy, i.e. a shock applied to the base values, for example, a tax on carbon dioxide emissions.

The main objective of the policies must be one of producing feasible estimates of the difference between both scenarios, i.e. with and without the policy shock. Such difference may be interpreted as the effect of the policy change, which should not be very sensitive to the specificities of base simulations.

B.1.1 Capital accumulation and investment allocation in the TERM-BR model

Capital in each period grows as much as the investment rate in the first period, descanting less the depreciation rate, as shown by equations (1) and (2):

$$\Delta K = I_0 - DK_0, \text{ ou} \quad (1)$$

$$\Delta K\Pi_0 = I_0\Pi_0 - DK_0\Pi_0 \quad (2)$$

where:

I = investment;

K = capital stock;

D = depreciation rate;

Π = a unit price of new capital.

The subscript “0” denote the initial value (at the initial period). Thus, changing the investment in the beginning affects the capital growth rate, not in current period, but in the next one. It’s considered that investment has a “gestation” period of one year. Furthermore, in equation (2) both sides are multiplied by Π_0, so, I0 e K_0 are related to the values of the initial database: $I_0\Pi_0$ e $K_0\Pi_0$.

Turning into percentage change form:

$0.01[K\Pi_0].k = [I_0\Pi_0 - DK_0\Pi_0].delUnity$ (3)

In that representation, k is the percentage change in K ($kK/100=\Delta K$). O TABLO[21] does not allow to appear a constant term in a change equation, thus it is necessary to multiply the right hand side by an artificial variable DelUnity, which is always shocked by 1. It is worth highlights that only the first coefficient in (3), k, has to be updated during the computation.

A.1.2 Investment allocation mechanism

The investment mechanism has two components:

i. Investment/capital ratios are positively related to the expect rates of return;
ii. The expected rates of return converge to actual rates of return through a partial adjustment mechanism.

Investment and expected rates of return

Dropping the industries subscripts, we have:

P_k = unit rental price of capital;

Π = unit asset price of capital;

I = investment;

K = capital stock.

Defining:

$R = P_k/\Pi$ actual gross rate of return; (4)

[21] TABLO is a text editor tailored to GEMPACK use. It translates a TAB file into an executable program, or in other words, it translates an algebraic language of an economic model into the suitable language to carry out the simulation by GEMPACK software.

$G = I/K$ gross rate of capital growth next period; (5)

E expected gross rate of return for next period.

The assumption about that the growth rates of capital stock depend on expected rates of return, may be expressed as:

$G = F(E)$ onde $F_E > 0$ (6)

It is worth highlights thas both G and R (and by extension E) must be >0. In the case of R, this is guaranteed by other model equations – capital always yields a positive rent. For convenience, equation (6) is expressed in terms of gross instead of net rates of growth and return.

Therefore, it was assumed the hypothesis that each industry has a long-run and normal rate of return R_{normal} and, when E, the expected rate, is equal to R_{normal}, then, $G = G_{trend}$, where G_{trend} is a normal or secular gross growth rate. That is,

$G_{trend} = F(R_{normal})$ (7)

We choose a logistic curve for the function F:

$G = Q.G_{trend}M^{\alpha}/(Q\text{-}1+M^{\alpha})$ where (8)

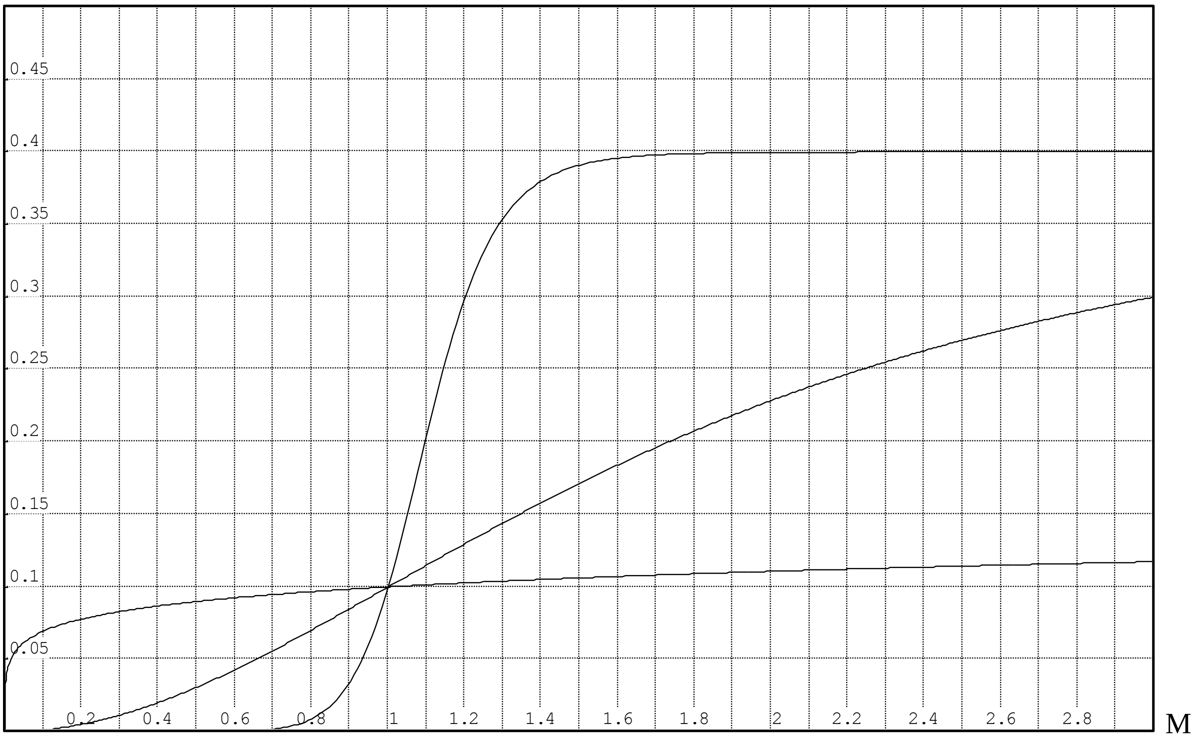
$M = E/R_{normal}$ (9)

if $M = 1$ then $G = G_{trend}$

if M is large than $G = QG_{trend} = G_{max}$ Typically Q might be equal to 4.

if M is 0 then $G = 0$

Graph below shows $G = Q.G_{trend}M^{\alpha}/(Q\text{-}1+M^{\alpha})$ {Q = 4; G = 0.1; α = 0.2, 2, 12}



Equation (8) was used to deduce the initial value of M and E, i.e., end and last period:

$M_0^{\alpha} = [G_0Q-G_0]/[Q.G_{trend} - G_0]$ (10)

and $E_0 = M_0.R_{normal}$

In percentage change form (8) becomes:

$g - g_{trend} = [1 - G/G_{max}]\alpha m$ (11)

A.1.3 Partial adjustment of expected to actual rates of return

The end-of-period expected rates of return of, E_1, are an average of the initial (star-of-period) expected rate, E_0, and the end-of-period actual rate of return, R_1. This implies that investors both conservative and myopic – only past and current rates of return affect the expected rate for the next period. So, we have:

$E_1 = (1-a)E_0 + aR_1 \quad 0 < a < 1$ (12)

$E_0 + \Delta E = (1-a)E_0 + a(R_0+\Delta R)$

$\Delta E = a(R_0-E_0+\Delta R)$ (13)

It is convenient express ΔE in terms of m, using $M = E/R_{normal}$:

$$m + r_{normal} = e = 100.\Delta E/E \quad (14)$$

$$\Delta E = 0.01E(m+r_{normal}) \quad (15)$$

Real wage adjustment equation

The model allows real wages adjust to employment levels as follows: if end-of-period exceeds some trend level by x %, then real wages will rise, during the period, γ.x %. Since employment is negatively related to real wages, such mechanism causes employment to adjust towards the trend level, which corresponds to NAIRU's employment level. Thus, we have:

$$\Delta W/W_0 = \gamma[(L_0/T_0)-1] + \gamma\Delta(L/T) \quad (8)$$

where:
L = acutal employment;
T = trend employment;
W = real wage.

Following Dixon and Rimmer (2002), TERM-BR as other CGE models may assume an intermediate position between the assumption of total real wages adjustment (no effect on employment) and fixed real wages (employment adjustment). Such intermediate position considers that real wages are sticky in the short run and flexible in the long run. This implies that in successive year, the gap between supply and demand will gradually return to forecast through a further decline in real wages. Such adjustment has its speed governed by γ.

APPENDIX C

Table 21 - Consumer Price Index by region, cumulative percentage change 2005-2035 (Policy 3 deviations)

phouhtot	POF1	POF2	POF3	POF4	POF5	POF6	POF7	POF8	POF9	POF10
1 Rondonia	-0.22	-0.16	-0.53	-0.32	-0.74	0.07	0.07	0.12	0.20	0.24
2 Amazon	-0.38	-0.37	-0.27	-0.23	-0.17	-0.08	-0.14	-0.02	0.03	0.02
3 ParaToc	-0.57	-0.41	-0.36	-0.28	-0.37	-0.15	-0.09	0.00	0.00	0.12
4 MarPiaui	-0.51	-0.40	-0.31	-0.17	-0.18	-0.09	0.00	0.07	0.10	0.19
5 PernAlag	-0.58	-0.45	-0.35	-0.20	-0.18	-0.03	-0.01	-0.01	0.09	0.13
6 Bahia	-0.61	-0.53	-0.40	-0.30	-0.26	-0.21	-0.12	-0.06	-0.03	0.02
7 RestNE	-0.62	-0.49	-0.36	-0.26	-0.18	-0.09	-0.03	0.00	0.07	0.11
8 MinasG	-0.43	-0.37	-0.36	-0.25	-0.24	-0.18	-0.12	-0.12	0.04	0.09
9 RioJEspS	-0.43	-0.42	-0.32	-0.27	-0.24	-0.21	-0.13	-0.10	-0.05	-0.01
10 SaoPaulo	-0.31	-0.24	-0.21	-0.23	-0.12	-0.09	-0.04	0.04	0.08	0.12
11 Parana	-0.16	-0.16	-0.12	-0.06	-0.02	0.04	0.10	0.15	0.18	0.26
12 SCatRioS	-0.24	-0.19	-0.15	-0.22	-0.07	-0.04	0.03	0.08	0.14	0.21
13 MtGrSul	-0.40	-0.31	-0.29	-0.24	-0.16	-0.12	-0.03	-0.02	0.05	0.10
14 MtGrosso	-0.31	-0.18	-0.16	-0.12	0.03	0.12	0.19	0.24	0.29	0.42
15 Central	-0.27	-0.24	-0.17	-0.18	-0.11	-0.08	-0.02	0.01	0.05	0.11

Source: Model results