CICERO ZANETTI DE LIMA

# IMPACTS OF LOW CARBON AGRICULTURE IN BRAZIL: A CGE APPLICATION

Thesis submitted to the *Universidade Federal de Viçosa*, Graduate Program of Applied Economics in partial fulfillment of the requirements for the degree of *Doctor Scientiae*.

VIÇOSA
MINAS GERAIS - BRAZIL
2017

**Ficha catalográfica preparada pela Biblioteca Central da Universidade Federal de Viçosa - Câmpus Viçosa**

T
L732i
2017

Lima, Cícero Zanetti de, 1985-
Impacts of low carbon agriculture in Brazil : a CGE application / Cícero Zanetti de Lima. – Viçosa, MG, 2017.
xiv, 113f. : il. (algumas color.) ; 29 cm.

Inclui apêndices.
Orientador: Erly Cardoso Teixeira.
Tese (doutorado) - Universidade Federal de Viçosa.
Referências bibliográficas: f.103-113.

1. Mercado de emissão de carbono. 2. Solo - Uso - Planejamento. 3. Agricultura. 4. Política ambiental.
I. Universidade Federal de Viçosa. Departamento de Economia Rural. Programa de Pós-graduação em Economia Aplicada.
II. Título.

CDD 22 ed. 363.7

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Submitted to the *Universidade Federal de Viçosa*, Department of Agricultural Economics in partial fulfillment of the requirements for the degree of *Doctor Scientiae* in Applied Economics.

APPROVED: August 22th, 2017.

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(Advisor)

*To my parents, Paulo and Catarina,*
*and my brother and sister, Juliano and Janaína.*

# Biography

I am CICERO ZANETTI DE LIMA, son of Catarina Serli Zanetti de Lima and Paulo Zóia de Lima, was born in Pelotas, Rio Grande do Sul, Brazil, in February 8th, 1985.

I began my undergraduate studies at *Universidade Federal do Rio Grande* in March 2003, and received my Bachelor in Economics in December, 2007.

I began the Markets and Organizations Graduate Program in April 2009 as master's student at *Universidade Federal de Pelotas*, and submitted my dissertation titled *Uma avaliação da capacidade de pagamento de financiamentos em projetos de fruticultura no PRONAF em Pelotas-RS* in November 7th, 2011.

In March 2013 I began the Applied Economics Graduate Program as PhD student at *Universidade Federal de Viçosa*, and submitted my thesis titled Impacts of Low Carbon Agriculture in Brazil: a CGE application in August 22th, 2017.

I spent a year as visiting researcher at São Paulo School of Economics, *Fundação Getúlio Vargas* (2015), and as visiting PhD student at Massachusetts Institute of Technology, Joint Program on the Science and Policy of Global Change (2016) during my period in the Graduate Program.

# Acknowledgments

Thank you Lord for my life and for this moment.

*"I can do all this through him Who gives me strength"* Phil 4:13.

I would like to thank my father, Paulo, and my mother, Catarina, for their unconditional love, support, and attention. Thank you very much for everything! Also, my sister, Janaína, and my brother, Juliano, as well as my brother-in-law, Mateus, all of them have supported me throughout this process and whose constant encouragement and appreciation remind me why I continue to study the economics and now the environmental impacts of our choices, and my nephew Gabriel who made me smile and very happy during the final stretch.

I owe much of my knowledge on CGE modeling and climate policies to Prof. Angelo Costa Gurgel, whose excellent course and patient advising over the last three years have opened up this exciting field to me, and given me a host of engaging long-term inquiries. He is also the nicest and most approachable world expert in any agricultural issue with whom I have had the privilege of working.

My choice to attend UFV was largely shaped by Prof. Erly Teixeira, who has been more generous with his time than any aspiring scholar could hope for in an advisor. Always helpful and wisely I am indebted to his first insights into CGE analysis, agricultural policies and international economics. A special thank for my friend Gabrielito Menezes always enthusiastic who encouraged me to attend UFV, our conversations were very enlightening and full of opportunities. All of my friends and colleagues in the Applied Economics Graduate Program had a hand in bringing this work to completion. I hope to return everyone with much work and dedication.

Talita's unconditional love, her attention and companionship during this period were essential to help me to go further. The days and distance that separated us for so long time become perseverance and love. My special thank you to you Talitinha!

I would like to thank the *Universidade Federal de Viçosa* for all infrastructure and support. Also the CAPES and the CNPq for providing financial support during the development of this research in Brazil. I owe a special debt to the *Fundação de Amparo à Pesquisa do Estado de Minas Gerais* (FAPEMIG) for provide financial support during the development of this research in the United States at the Massachusetts Institute of Technology.

Of course, the period at the Joint Program on the Science and Policy of Global Change - MIT was a great moment in this trajectory. I have benefited immensely from the entire research group, workshops, meetings, and every single conversation about climate and agricultural policies, politics, Brazil, cultures, languages, and sports.

Finally, I want to thank my housemates in Minas Gerais, Conrado, Rafael, and Luiz. Share a place with you was inspiring and a lot of fun, animals, and biking! Thank you *magrões*! Also Brie, Maya, Felicia, Steven, and Julien whom I shared an apartment in United States. You are part of one of the best years in my life.

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# Abstract

LIMA, Cicero Zanetti de, D.Sc., Universidade Federal de Viçosa, August, 2017. **Impacts of Low Carbon Agriculture in Brazil: a CGE application.** Advisor: Erly Cardoso Teixeira.

Brazil is considered one of the major players in World agriculture. Besides the economic relevance of agriculture and livestock productions in Brazil, the country has an active role in the international discussion about climate change. The agriculture, forestry and other land use (AFOLU) sector is the main source of greenhouse gas (GHG) emissions. It is a peculiar pattern among developing countries. At COP-15 2009, Brazil made a voluntary commitment to reduce emissions by 37% until 2025 and by 43% until 2030 compared to 2005 levels. The agricultural and livestock sectors are responsible to contribute with 22.5% of this total. The Brazilian Government released in the same year the Low Carbon Agriculture Plan (ABC Plan) as part of National Policy for Climate Change (PNMC) to achieve the GHG emissions reduction in the AFOLU sector. The ABC Plan has several actions, e.g., recover 15 million hectares (Mha) of degraded pasture, and increase by 4 Mha the integrated systems (crop-livestock integration and/or crop-livestock-forestry integration). The objective of this thesis is to evaluate the economic impacts and the land-use changes resulting from these actions present in the ABC Plan, such as pasture recovery (PR) and integrated systems (IS). I have built a new computable general equilibrium model (CGE) (BREA version 1.0) with detailed representation of six regions in Brazil representing the economic relevance and agricultural frontier. The regions are: South, Southeast, North (Amazon biome), Center-West (without Amazon biome), Northeast, and Northeast Cerrado (Maranhão, Tocantins, Piauí, and Bahia States) which is considered the new agricultural frontier in Brazil. The model represents several land uses, agricultural sectors, and it is the first CGE model to explicitly represent these technologies. Under different simulated scenarios, the outcomes indicate that the higher supply of recovered areas with high productivity pastures, combined with the integrated systems, promotes the land sparing effect. There is a reduction in the pressure to clear natural and forest areas made by livestock sector. Also, there is a decrease in the cropland use and an increase in the area of planted forest. However, regional results show that regions in the agricultural frontier respond differently to the ABC Plan. In the Center-West and North regions the pasture area increases more than recovered areas. At the same time, the cropland area is converted to high quality pasture. In the South and Southeast regions the pasture area increases less than the recovered areas. It means that part of this area is converted in cropland, forest or secondary vegetation. At macroeconomic level, there are welfare gains in all regions, except in the Northeast and Northeast Cerrado regions. Also, regional GDP changes indicate significant losses in these regions. Modern compensation mechanisms should be develop to avoid these losses increasing the production capacity and the technology absorption in these regions. Considering the economic costs of PR and IS the model projects R$ 39 billion (2009 values). This value is significantly lower compared to those projected in the original text of the ABC Plan (around R$ 37 billion for PR and R$ 57 billion for IS). The actual adoption level of resources present in the ABC Program is also lower compared to the value projected by the model. By the end of 2015/2016 crop-year the volume of credit taken by farmers reached R$ 13.8 billion, including all actions present in the ABC Plan and not only PR and IS. It suggests that if the adoption of the ABC credit continue in a low rate the goals of the ABC Plan will not be met.

# Resumo

LIMA, Cicero Zanetti de, D.Sc., Universidade Federal de Viçosa, agosto de 2017. **Impactos da Agricultura de baixo carbono no Brasil: uma aplicação de EGC.** Orientador: Erly Cardoso Teixeira.

Além da relevância econômica, o setor agrícola fez com que o Brasil assumisse um papel ativo na discussão internacional das mudanças climáticas. O setor de agricultura, floresta e outros usos da terra (AFOLU) é a principal fonte de emissão de gases de efeito estufa no país, padrão peculiar entre os países em desenvolvimento. Durante a Conferência das Nações Unidas sobre as Mudanças Climáticas de 2009 (COP-15) o país assumiu o compromisso voluntário de reduzir suas emissões em 37% até 2025 e em 43% até 2030 em relação aos níveis de 2005. O setor agropecuário é responsável por contribuir com 22,5% do compromisso voluntário. Afim de atingir essa meta, foi criado em 2009 o Plano Setorial de Mitigação e de Adaptação às Mudanças Climáticas para a Consolidação de uma Economia de Baixa Emissão de Carbono na Agricultura (Plano ABC). O Plano ABC faz parte da Política Nacional de Mudanças Climáticas (PNMC). Entre as diversas ações do Plano ABC, estão a recuperação de 15 milhões de hectares (Mha) de pastagens degradadas e aumentar em 4 Mha as áreas de integração lavoura-pecuária (iLP) e/ou lavoura-pecuária-floresta (iLPF). O objetivo da tese é avaliar os impactos econômicos e de mudança no uso da terra decorrentes dessas duas ações presentes no Plano ABC. Para tal, foi construído um modelo de equilíbrio geral computável (EGC) (BREA versão 1.0) com representação detalhada de seis grandes regiões brasileiras divididas por relevância econômica e fronteira agrícola: Sul, Sudeste, Norte (bioma Amazônia), Centro-Oeste (sem o bioma Amazônia), Nordeste, e Nordeste Cerrado (Estados do Maranhão, Tocantins, Piauí e Bahia) que é considerada a nova fronteira agrícola brasileira. O modelo representa diversos usos da terra com desagregação setorial agropecuária, e é o primeiro modelo de EGC a explicitamente representar a implementação das tecnologias do Plano ABC. Sob diferentes cenários simulados, os resultados indicam que a maior oferta de pastagens recuperadas e com alta produtividade, somadas às tecnologias iLP e iLPF, promovem o efeito poupador de terra como resultado agregado. Há redução na pressão que a atividade de pecuária promove sobre as áreas naturais e florestas. Ao mesmo tempo, há queda das áreas destinadas às atividades de grãos, principalmente soja e milho, e aumento da área de florestas plantadas. Entretanto, os resultados regionais mostram que as regiões de fronteira agrícola respondem diferentemente às ações do Plano ABC. Nas regiões Centro-Oeste e Norte as pastagens crescem mais do que as áreas recuperadas, sendo que parte das áreas de culturas são convertidas para pasto de boa qualidade. Nas regiões Sudeste e Sul essas pastagens aumentam menos do que a área de pastagens recuperadas, o que significa que parte das pastagens boas são convertidas em áreas de culturas ou em florestas e áreas de vegetação secundária. Em termos macroeconômicos, percebe-se ganhos de bem-estar para as regiões brasileiras, com exceção das regiões do Nordeste e Nordeste Cerrado. Ademais, a variação do PIB regional indica queda expressiva nessas regiões. Esses resultados sugerem que o Plano ABC aumenta as disparidades regionais no Brasil evidenciando que o desenho de políticas públicas precisa levar em conta tais diferenças. A pesquisa sugere mecanismos modernos de compensação de perdas reestruturando as cadeias de valor regionais, para que no longo prazo aumente a capacidade de produção e absorção de tecnologias. Em termos de custo econômico, o modelo indica que para o atingimento das metas do Plano ABC referentes a recuperação de pastagens e sistemas integrados seriam necessários cerca de R$ 39 bilhões (valores nominais de 2009), valor inferior aos valores projetados no lançamento do Plano ABC (cerca de R$ 37 bilhões para recupeção de pastagens e R$ 57 bilhões para iLP e iLPF). O atual nível de adoção de recursos do Programa ABC é bem inferior ao montante necessário projetado no presente estudo. Até o final do ano safra 2015/2016 os desembolsos haviam alcançado quase R$ 13,8 bilhões, incluindo os gastos não apenas com recuperação de pastagens e iLPF, mas também com as demais linhas do programa, como o plantio direto e o tratamento de dejetos de animais. Essa constatação sugere que, a continuar o ritmo atual observado de adoção do crédito do Programa ABC, as metas do Plano ABC no âmbito da Política Nacional de Mudança do Clima não serão atingidas.

# Chapter 1

# Introduction

Brazil is considered one of the major players in World agriculture. The Brazilian Agribusiness sector has grown in real terms around 2.1% per year between 1994-2015 and is responsible for 21.5% of Brazil's GDP (CEPEA, 2016). The Agribusiness GDP was US$ 374 billion in 2015. The agro-processing industry accounts for 27% of it, the input and supply industry contributes with 12% inputs, service sectors 31%, and primary agriculture and livestock production with 30%. For the same year, the Agribusiness exports were US$ 88.2 billion and its trade balance was four times greater than Brazilian trade balance.

The crop and vegetables production grew from 76.6 Mt to 209 Mt between 1998-2016. In the same period the planted area grew from 35 Mha to 58.4 Mha. The production growth rate has been 2.6 times greater than the area expansion, representing a strong productivity gain. The increase in yields was responsible for 94% of the growth in the period 1975-2011 (GASQUES *et al.*, 2013). In the period from 1990 to 2014 the livestock production grew 460% in the poultry sector, 225% in the case of pork, and 101% for beef. It was related to a productivity gain of 3.62% per year between 1975-1996, and 6.64% between 1996-2006 (MARTHA *et al.*, 2012).

These outcomes can be attributed to the generation and adoption of technologies due to investments in agricultural research, as well as to changes in macroeconomic and sectoral policies over the 90's (GASQUES *et al.*, 2008; TEIXEIRA *et al.*, 2013). Such policies promoted greater openness for the Brazilian economy, deregulated several agricultural products markets and reduced the government intervention on food prices and agribusiness primary products (OECD, 2005; CHADDAD; JANK, 2006). The current agricultural policy model is based on public and private instruments for financing the production without price distortions, e.g., the interest rate equalization policy. These instruments have contributed for the agribusiness growth in recent years (GASQUES *et al.*, 2008; PINTO, 2015).

Together with this remarkable performance new challenges arise for the Brazilian agribusiness, the forestry sector, and other land use activities. Several environmental pressures pose limits to the expansion of agriculture: climate change, preservation of ecosystems and biodiversity, and the new national institutional framework related to land use changes and climate – the National Plan for Climate Change (PNMC) and the New Forest Code (NCF).

Also, deforestation was the main source of greenhouse gas (GHG) emissions until 2005 in Brazil (MCTI, 2016). The deforestation rate at the Amazon dropped to low values due to command and control actions conducted by the Brazilian government, including law enforcement, creation of protected areas, interventions in soy and beef supply chains, restrictions on access to credit, as well as a reduction on the demand for new deforestation (NEPSTAD *et al.*, 2014). Furthermore, the pressure of society for public policies which preserve the stock of forest and other natural ecosystems acts to preserve the country's biodiversity (PERES *et al.*, 2010).

Unfortunately, the NCF regarding land use change and land cover is still surrounded by uncertainties, such as legal reserve areas that should be recovered and the total deficit in permanent preservation areas. The demand for recovered areas likewise respect for the new legislation generate pressure for a production expansion through productivity gains (SPAROVEK *et al.*, 2011).

The PNMC establishes several sectoral plans for mitigation and adaptation to climate change, aiming to consolidate a low carbon economy in various sectors. According to the Ministry of Environment, plans for prevention and control of deforestation in the Legal Amazon (PPCDAM) and Cerrado (PPCerrado), energy (PDE), transformation industry (Industry Plan), urban mobility and transportation (PSTM), and health are part of the National Plan for Climate Change.

Moreover, Brazil has an active involvement in the international discussion about climate change. The country has committed to reduce GHG emissions by 37% below 2005 levels in 2025, and 43% in 2030. In 2015 the agriculture, forestry and other land use (AFOLU) "sector" emitted 67% (1,310 Mt CO2eq) of total GHG emissions in Brazil. Land use change and livestock ranching are the main sources of emissions in the AFOLU sector. In global terms the AFOLU sector is responsible for under a quarter of global anthropogenic GHG emissions (SMITH *et al.*, 2014).

On the other hand, the global food demand is expected to grow between 70% and 100% by 2050, which will require an increase in global agriculture production (WORLD BANK, 2008; GODFRAY *et al.*, 2010). Brazil is capable to increase the supply of agricultural products due to its expertise in tropical and subtropical production, as well as natural conditions, climate, and weather (ALEXANDRATOS *et al.*, 2012). However, the expected growth in production of food, fiber, and bioenergy needs to come mostly from productivity gains, since the restrictions on the expansion of cultivated area in Brazil, as in the World, are increasing (TILMAN *et al.*, 2011). In particular, the current land use legislation in the country (NCF) requires that farmers retire some areas to protect rivers, watersheds and fragile land, as also as keep legal natural reserves in their private land.

In 2010 the Brazilian Government released the Low Carbon Agriculture Plan (ABC Plan) (MAPA, 2012) as part of the voluntary climate policy commitments set in the COP of Copenhagen, to be implemented until 2020. The ABC Plan aims to mitigate GHG emissions in agriculture, improve efficiency in the use of natural resources and increase the resilience of productive systems and rural communities, as well as enable the sector to adapt to climate change.

The actions present in the ABC plan seek to train technicians and farmers, technology transfer, environmental and land regularization, technical assistance and rural extension, research, development and innovation, availability of inputs, seeds and forest seedings production and subsidized rural credit (ABC Program).

The ABC Plan targets strategic investments in sustainable technologies to recover 15 Mha of degraded pasture, increase the use of production systems combining crop, livestock and/or forestry production in the same area in 4 Mha, expand no-tillage use and foster other low carbon technologies. Besides the ABC Plan, the Brazilian NDC in the Paris Agreement targets the recovery of additional 15 Mha of degraded pasture and the expansion of combined crop-livestock-forestry system in additional 5 Mha, from 2020 to 2030. It also sets the need for an increase of 12 Mha of forest for multiple uses in private areas.

The ABC Plan (MAPA, 2012) foresees an intensive use in agriculture of the recovery of currently degraded pasture; promotion of crop-livestock integration; increase in the use of Direct Planting System (SPD) and Biological Fixation of Nitrogen (FBN); expansion of planted forest area; use of animal waste treatment to generate biogas and organic compounds; encouragement for studies and adoption of adaptation techniques for plants, productive systems, and rural communities to the new atmospheric warming scenario; and support to efforts for reducing deforestation as a result of the advancement of livestock and other factors.

Such technologies for emissions mitigation are derived from their own capacity to directly reduce GHG emissions, that is, as a consequence of the productive process itself, and not as intensifying technologies which reduce the pressure on area expansion.

Therefore, the environmental issue imposed by climate change brings two uncertainties for the future of agricultural production. Foremost, there is the risk of losses due to the intensification of extreme phenomena, such as droughts and floods, and the difficulty of adapting seeds and cultivars resistant to the changes in the climate characteristics of the current crop regions. On the other hand, the promotion of agricultural technologies capable of reducing emissions, such as those recommended in the ABC Plan, can be an important ally to encourage productivity gains. This is because the technologies emphasized by the ABC Plan induce, for the most part, land sparing and emissions mitigation.

Carbon Dioxide (CO2), methane (CH4) and nitrous oxide (N2O) are the main GHG responsible for global warming. According to the (IPCC, 2014b) report, the projection of the average elevation of Earth's temperature for the next 100 years is between 1.4C and 5.8C with the CO2 atmospheric concentration at 394 ppm in 2010, against 280 ppm in the year 1750, well above the natural range.

From all the economic activities, the agriculture is, naturally, the most dependent on climate and, consequently, the most sensitive to its changes. In addition to the possibility of being negatively affected, agriculture and livestock are activities that generate GHG emissions into the atmosphere, mainly of carbon compounds (CO2 and CH4) [1] and nitrogen (N2O). Therefore, they can contribute to greenhouse effect and to global warming while being affected[2] by these phenomena.

As stated by (ASSAD *et al.*, 2008), the temperature raise in Brazil may lead to a decrease in suitable areas for grains cultivation. With the exception of sugarcane and cassava, all crops would suffer a fall in the low-risk area and, consequently, in the production value, which could generate losses in grain harvests of R$ 7.4 billion by 2020 - number that could rise to R$ 14 billion in 2070.

Moreover, it is necessary to take into account the role, yet not well defined, that agriculture and livestock have for bioenergy production, influencing the energy efficiency policies mentioned above, which aim to reduce emissions. Even with uncertainties regarding the future of these policies, both nationally and internationally, the last decade experienced a considerable growth in ethanol biofuel production, partially influenced by market forces.

In face of the aspects highlighted so far, it is clear that the future of Brazilian agriculture and livestock will be influenced by the following issues: production rise, through productivity increase and technology, preserving the existing environmental assets, restoring degraded areas and, simultaneously, avoiding GHG emissions derived from land use change, forests, and agriculture. The "challenge" of the future

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[1] Although the occurrence of CO2 emissions from agricultural activities is scientifically proven, the Inventory of Anthropogenic Emissions and GHG sink removal, according to the current guidelines of UNFCCC, does not account for CO2 as an emission from the agricultural sector, but only CH4 and N2O, since these, when unidentified, are attributed to other sectoral scopes, such as land use change or energy.

[2] Increase in CO2 concentration; increased air and soil temperature; increased droughts and torrential rains (rainfall extremes)

of Brazilian agriculture is defined and it will be shaped by the conditions of the national and international markets for food and energy, macroeconomic, sectoral, and environmental public policies, as well as problems with global impact such as climate change.

Given these insights, I define the research objective as assessing the economic impacts of the ABC Plan's actions on the Brazilian economy, specially the agricultural sector. What will be the effects of the sectoral plan for the economic growth in terms of welfare and aggregate production? What will be the impacts on sectoral production and their effects on other sectors and their trade flows? What will be the new pattern of land use and competition and regional production given the large volume of degraded areas that will be recovered?

This thesis innovates in evaluating an agro-environmental policy that has not yet been quantitatively assessed in Brazil. Specifically, it also innovates by proposing the construction of a new Computable General Equilibrium (CGE) model. It will represent the agricultural markets and segments of the main Brazilian agro-industrial chains, taking into account regional differences, competition for land use by different crops and activities, environmental aspects related to greenhouse gas emissions, and the evolution dynamics of the Brazilian economy, inserted in the global context.

The main hypothesis of this research is based on the technologies present in the ABC Plan for mitigating GHG emissions promoted by ABC Program[3] are capable to reduce emissions, increasing agricultural and livestock productions, as well as productivity, efficiency, and cost reduction.

The general objective of this thesis is to assess the economic impacts of the ABC Plan on the Brazilian agriculture, considering several aspects as productivity, technology, crops, land-use and forests.

Specifically, I intend to:

i Evaluate the economic impacts of the ABC Plan in terms of GDP changes, welfare, sectoral production and trade flows;

ii Evaluate the new land-use pattern in Brazil by recovering 15 Mha of degraded pasture and increasing the integrated systems in 4 Mha;

iii Evaluate the economics impacts of choose the priority areas defined by degraded level of pasture as strategy to apply the investments present in the ABC Program;

iv Evaluate the policy costs of pasture recovery and integrated systems technolo-

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[3] Rural credit to investments that contribute to the reduction of environmental impacts caused by agricultural activities. The ABC Program has subsidized interest rates between 8-8.5% per year according to the 2016/2017 crop-year.

gies present in the ABC Plan.

## 1.1 Thesis structure

Chapter 2 presents a discussion between mitigation and adaptation options, and the ABC Plan description. Chapter 3 focuses on the general equilibrium model for land-use change applied in this research, as well as the technological representation, land supply function, as well as the low carbon technologies. The results and discussion are presented in Chapter 4. Finally, the Chapter 5 presents the conclusions of this research.

# Chapter 2

# Theoretical brackground

## 2.1 Mitigation versus Adaptation

This section discuss a literature review on the state-of-the-art among synergies and trade-offs of mitigation and adaptation measures in a global level and its parallel with the ABC Plan. This review is qualitative and does not aim to exhaust the whole discussion of the subject in question. Next, I present the studies in Brazil that try, to a certain extent, to assess mitigation and adaptation potentials, yet without modeling and evaluating their synergies and trade-offs.

### 2.1.1 AFOLU sector

Agriculture, Forestry and Other Land-Use (AFOLU) sector is responsible for about 25% of the anthropogenic GHG emissions, mainly due to deforestation of native areas and emissions from livestock activities and agricultural management (SMITH *et al.*, 2014). Land-use is determinant for the supply of goods and services on a planet in which a population between 9 and 10 billion people is estimated in 2050 (GODFRAY *et al.*, 2010).

The availability and competition for land among multiple demands, such as for food production, maintenance of water resources, timber production, energy, housing, infrastructure, biodiversity and environment, become key issues for planning and assessing global and regional policies aimed at the AFOLU sector. According to Smith *et al.* (2013), the major challenges of the sector are: to produce food and agricultural inputs for a growing global population, and ease the environmental impacts of this process with GHG mitigation measures and adaptation to the impacts that can not be avoided.

Such issues and challenges posed to the AFOLU sector have given rise to a great discussion about the synergies and trade-offs, benefits, adverse effects and barriers of measures for GHG mitigation and adaptation to climate change. Internationally this discussion drives climate, environmental, economic and social policies. Reports of the Intergovernmental Panel on Climate Change[1] (IPCC, 2001; IPCC, 2007; IPCC, 2014a) are the main sources of information and updates on the state-of-the art of these policies application and of the scientific knowledge generated in several areas addressing the issue of climate change.

The synergy among both strategies, mitigation and adaptation, had already been pointed out in the (IPCC, 2001) report, but this was more focused on the impact of climate change when mitigation or adaptation efforts were applied or not (SMITH *et al.*, 2001). The report stated:

> *"[...] climatic changes today still are relatively small, thus there is little need for adaptation, although there is considerable need for mitigation to avoid more severe future damages. By this logic, it is more prudent to invest the bulk of the resources for climate policy in mitigation, rather than adaptation."*

On the other hand, the (IPCC, 2007) report seemed to be more concerned with the interest of stakeholders and policy makers in the intrinsic relationship between the two strategies. Recognizing the need to exploit trade-offs and synergies among them, the authors devote and entire chapter of the report (18) to this discussion in a global level.

Recently, the advancement of this discussion, according to chapter 11 of the (IPCC, 2014a), presents mitigation opportunities both on the supply side of products and services, and on the demand side for the AFOLU sector. On the supply side, land-use change, sustainable agricultural and livestock management can reduce GHG emissions, increase soil carbon storage and through carbon sequestration and biomass, and emissions from energy production can be reduce with the replacement of fossil fuels by biomass biofuels. On the demand side, the emissions can be mitigated by the reduction of food loss and waste throughout the production chain and final consumers, dietary changes (substitution of animal protein for vegetable protein), and changes in the use of timber production.

As stated by Smith *et al.* (2001), in reality, there are many obstacles for implementing mitigation measures in agricultural systems. Those can be structural, institutional, financial, and of development and diffusion of new technologies (Figure 2.1). Overstepping this obstacles will only be possible with the dedication and efforts of all agents directly and indirectly connected to the AFOLU sector.

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[1] The Intergovernmental Panel on Climate Change is an United Nations body established by the United Nations Environment Program (Unep) and by the Word Meteorological Organization (WMO), being composed of scientific delegations from governments to promote regular assessments on climate change.

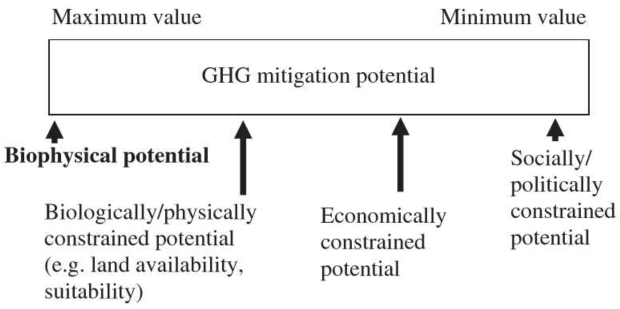

Figure 2.1: Impacts of different constraints on reducing GHG mitigation potential from its theoretical biophysical maximum to the lower achievable potential
Source: Smith e Olesen (2010) *apud* Smith *et al.* 2007.

The mitigation potential of the AFOLU sector is estimated in 7.18-10.60 Gt CO2eq year$^{-1}$ in 2030 with carbon prices until 100 USD/tCO2eq. Thus, the AFOLU sector has a large cost-effective potential for GHG mitigation (IPCC, 2014a). In order to achieve this potential it is necessary to consider land use competition, specially in the cases where it is mutually exclusive, e.g., food production and bioenergy production. On the other hand, synergies of land use should be enhanced, such as integrated production systems or multi-functional systems which extract various services from the land.

The major challenge of the AFOLU sector is to increase production, reduce emissions and adapt to a warmer and more variable climate. Especially in developing countries, it is necessary to increase agricultural production, reduce GHG emissions and adapt to climate change (MERTZ *et al.*, 2009). The goal of mitigation strategies is to increase soil carbon storage and/or reduce CH4 and N2O emissions, the main greenhouse gases. The link with adaptation strategies occurs due the increase of organic matter in the soil, which can also increase productivity and make agricultural production more stable, thus improving the soils adaptation capacity to climate change. This link is known as a win-win-win option (PAN *et al.*, 2009).

On the other side, as suggested by Smith e Olesen (2010), many adaptation strategies to climate change affect mitigation options: measures that reduce soil degradation; measures that reduce the leaching of nitrogen and phosphorus; soil moisture conservation measures; increased diversification of crop rotation; modification of "microclimates" for reducing extreme temperatures in crops; and land-use change that involves abandoned and/or degraded areas. The authors stress that such adaptation measures, if properly applied, reduce GHG emissions through a more efficient use of nitrogen and an increased soil carbon storage.

Furthermore, some mitigation strategies may have negative effects on adaptation strategies, such as secondary crops that reduce nutrients and carbon addition to the soil and increase water consumption. The use of crop waste can act as insulator in the transfer of heat from the soil or the use of these waste to produce bioenergy, reducing the soil carbon stock.

### 2.1.2 Sinergies and barriers

Consistent with Margulis e Dubeux (2010), GHG mitigation measures are seen as a proactive response of policies aimed at climate change, while adaptation measures are reactive. Hence, the first is related to the cost benefit of reducing emissions and reaches all agents involved in the policy, while the second strategy links the costs and benefits which directly affect the individuals of the places where the policies are implemented. Adaptive efforts can be seen as direct prevention of environmental impacts, while mitigation measures can be considered an indirect prevention (VERHEYEN, 2005).

In this sense, several studies aim to identify the potential synergies, trade-offs and barriers in the implementation of GHG mitigation policies in the AFOLU sector. Institutional, socioeconomic, environmental and technological aspects are approached (SMITH *et al.*, 2007; ROSENZWEIG; TUBIELLO, 2007; SMITH; OLESEN, 2010; BUSTAMANTE *et al.*, 2014).

Concerning the institutional aspects, Bustamante *et al.* (2014) highlights possible positive and negative points, affirming that those depend on factors such as: institutional regulation of land tenure and property rights, and the level of compliance of these institutions. In the absence of these, the mitigation potential of the sector can be compromised. In the Brazilian case, the institutional aspects are extremely important for the execution of sectoral GHG mitigation plans, as foreseen by the ABC Plan. In particular, the new agricultural frontier in the North and Northeast Cerrado of the country is still vulnerable to the issues of land tenure and property rights, thereby compromising any public policies implementation for access to low carbon technologies (STRASSBURG *et al.*, 2014; LARSON *et al.*, 2013).

Socioeconomic aspects, such as food security and health, also are extremely relevant to the implementation of carbon mitigation policies. Bustamante *et al.* (2014) posit a series of studies that deal with the subject, such as Smith *et al.* (2013) and Valin *et al.* (2013), which address it in the context of developing countries.

Mitigation measures, by and large, result from improvements in land use and management. The potential synergies highlighted by Smith *et al.* (2013) concerning food security are: increase in food and fiber production, improvement in water resources quality, biodiversity conservation, adoption of sustainable agricultural practices, restoration of degraded pasture and increase of economic activity. On the other hand, the trade-offs can emerge due food competition and availability, degradation of water resources, impacts in biodiversity and restrictions in land-use change.

The authors emphasize that:

> *"Getting a balance between mitigation options and other societal goals – including food security and preservation of ecosystem services – requires understanding the dynamics of land governance. It is necessary to assess the role of different social actors under different land management options as well as the potential impacts of various incentives mechanisms, financing schemes, technology access and land tenure agreements.".*

Connections between mitigation measures of the AFOLU sector and demand for agricultural production and food security can be represented by Figure 2.2.

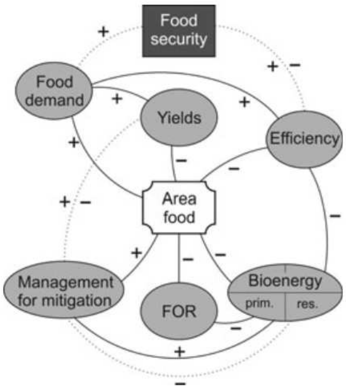

Figure 2.2: Interrelationships between different bundles of GHG mitigation options (grey shaded boxes) and food security.
Source: Smith *et al.* (2013).
Note: mitigation options are related to food demand. (+) or (-) indicate the relationship direction. (+) indicates that an increase in one factor implies an increase in the following. Dotted lines represent ambiguous or weak interrelationships.

Considering an increase in food demand, for instance, an increase in the consumption of vegetal protein implies an increase in the demand for agricultural area, that is to say, there is a positive effect; nevertheless, Smith *et al.* (2013) points out that this is not a sufficient condition to ensure food security. The demand for agricultural area is negatively affected by productivity and efficiency gains, since both, combined or not, reduce the demand for land, that is, the so-called land-saving effect takes place. However, efficiency can have a double effect on food security. In one side, a positive effect, because it increases food production; on the other side, a negative effect when there is an intensification in a production with a high degree of GHG emissions. Furthermore, increases in productivity are linked to a higher demand for food and, consequently, greater food security given the greater supply.

At the bottom of the figure, an increase in food production area reduces the mitigation potential of Forestry Systems and Bioenergy. This highlights the competition for land use, both for agricultural, forestry or bioenergy production, and for GHG mitigation options. Thus, mitigation activities, for example, that increase the carbon concentration in the soil, can increase the productivity of agricultural production, therefore with positive effect. Conversely, if such mitigation activities reduce productivity, there may be a shifting effect in the production for other regions or agricultural activities.

It is also clear that mitigation options compete for land, for instance, with bioenergy production, since the increased use of agricultural waste reduces the capacity of producing bioenergy through biomass. The same is true for forestry systems and bioenergy. Therefore, mitigation options for the AFOLU sector are extremely interdependent, specially regarding food security issues. The authors conclude that this interdependency relationships, when direct, as in the case of comparing mitigation options in reforestation systems or biofuels production, are directly quantified. The indirect relationships, require systematic approaches and are less trivial to be quantified.

### 2.1.3 Brazilian case

In the Brazilian case, climate change is approached in the National Plan for Climate Change which instituted the Climate Change National Policy. This policy institutionalized mitigation goals and the strengthening of sinks, the understanding between economic growth and climate protection (OBERMAIER; ROSA, 2013). The policy is based on adaptation measures and in the execution of integrated sectoral plans for mitigation and adaptation.

The ABC Plan (MAPA, 2012) aims to promote the mitigation of GHG emissions, improving efficiency in the use of natural resources. To this end, the ABC Plan was structured in seven programs, the first six referring to mitigation technologies and the last to climate change adaptation technologies. The programs are: pasture recovery (PR); integrated systems (IS), such as cropland-livestock or crop-livestock-forestry integration, and agroforestry systems (SAFs); direct planting system (SPD); biological fixation of nitrogen (FBN); planted Forests; treatment of animal waste; and, adaptation to climate change.

Notwithstanding, the ABC Plan does not state that synergies are expected between the mitigation and adaptation technologies present in the actions and programs of the plan, even more so when it comes to food security - as discussed above. Concerning technologies for PR, IS, SAFs, and SPD, technologies directly or indirectly applied in the livestock sector, it is expected an intensification process of production per area and, consequently, "saving" land, and such measures are also considered to be adaptive. This process was highlighted by Gouvello (2010): "Increasing [...] intensification of livestock-raising can play an essential role in reducing the need for land [...], while releasing the land required for expansion for other activities".

Therefore, few studies in Brazil seek to identify synergies and trade-offs between mitigation and adaptation strategies. There is still a shortage of tools in the country which are capable of identifying the aggregate gains in each process. In the sectoral context, for instance, for agricultural sectors, it is still difficult to identify in each technology gains resulting from mitigation and/or adaptation. What can be found are sets of agronomic research results; environmental, econometric and general equilibrium model parameters, the latter being strictly economic results. In Brazil, there is still a lack of Research in the level of Integrated Assessment Modeling, as suggested by IPCC (2014a).

From the agronomic point of view, the technologies previously mentioned as IS, allow reducing the incidence of weeds, diseases and pests with the introduction of pastures in grain production systems (COSTA; RAVA, 2003; AIDAR *et al.*, 2003; VILELA *et al.*, 1999). Positive impacts on the chemical, physical and biological quality of the soil reflect, in particular, the increase in organic matter (SOUSA *et al.*, 1999; SALTON, 2005). Consequently there is, for example, an increase in soil nutrients storage capacity and a greater efficiency in the use of this nutrients and response potential of post-pasture crops to fertilization.

The interaction of several factors, such as adaptation and carbon sequestration, are difficult to separate and are responsible for productivity increases of the crops and the animal system in the crop-livestock integration. There is a breakdown of biotic cycles (pests, diseases), in addition to improvements in physical, chemical, and biological properties of the soil, contributing to increase the productivity of the whole system (VILELA *et al.*, 1999; COSTA; RAVA, 2003).

Júnior e Vilela (2007) affirms that productivity gains of grains and meat in these mixed systems are explained by positive interactions. In addition, productivity gains have the effect of land-saving, potentially reducing the pressure for opening new vegetation areas in Cerrado and Amazon Biomes and minimizing the competition for land.

Cohn *et al.* (2014) emphasize that policies for cattle breeding intensification in Brazil are cost-effective in limiting deforestation and mitigating GHG emissions. Villoria *et al.* (2014) indicate through empirical evidence a weak positive relation between regional technological progress and deforestation. However, the authors highlight that in global-level models, technological advances tend to be land savers. The decomposition of these results is important, since in regions of low productivity and abundant land are more prone to land-use expansions.

On the other hand, a series of studies in Brazil developed estimations which anticipate the effects of climate change by structuring the scenarios to be analyzed (ASSAD *et al.*, 2008). They consider the interactions among the environmental parameters and essentially attempt to predict percentage losses (or gains) in agricultural productivity, as well as land-use changes in different regions of the country.

There are still few studies in the national literature which investigate how different scenarios of climate change specifically affect agriculture, in its various forms, such as productivity, land use, deforestation, energy; and that considers the synergy between mitigation and adaptation. As an example, Assad *et al.* (2008) consider only the first-order impact of a reduction in the agricultural productivity, not taking into account the interaction among the agricultural sector and the rest of the economy.

From a socioeconomic point of view, some adaptation and vulnerability research can be highlighted, such as Gurgel (2011), FERREIRA FILHO (2013) and FERREIRA FILHO e Horridge (2014) that consider the sectoral policy for stimulating biofuels production. Diniz (2012), Carvalho *et al.* (2016), approach command and control policies in the Amazon and the Forest Code. Also, FERREIRA FILHO e Moraes (2015) study which are the regional economic impacts of the scenarios suggested by Assad *et al.* (2008).

Concerning research focused on mitigation in Brazil, FERREIRA FILHO e Rocha (2008), Feijó e Júnior (2009), Silva e Gurgel (2012) and Gurgel e Paltsev (2014) attempt to identify the associated costs of reducing GHG emissions. Nardy e Gurgel (2013) approachs land-use change, while Lima e Gurgel (2012) and Daubermann *et al.* (2011) approach sectoral mitigation policies.

In a complementary way, it is important to highlight studies on health and migration dimensions, such as Barbieri *et al.* (2010) that advance in the calculation of vulnerability indicators of population in the Brazilian territory. Using the input-output approach, Guilhoto *et al.* (2002) simulates environmental impacts derived from the economic growth trajectory of the Brazilian economy. Hilgemberg (2004), Carvalho e Perobelli (2009) identify the most sensitive sectors to emissions restricting policies and assess its impacts for sectoral intermediate consumption and the pollution load in exporting sectors. This type of modeling, although very useful, has limitations in the specification of agents behavior and in the representation of markets for primary production factors and their constraints.

All in all, the studies that approach mitigation and adaptation technologies in the Brazilian case are not well connected. As previously mentioned, IPCC (2014a) indicates integrated assessment models of these technologies which consider socioeconomic and climatic variables, sectoral dynamics, energy use and land-use and competition. Especially in the case of agriculture, the decomposition of mitigation and adaptation gains is very important, since the agricultural sector is at the center of the debate on emissions mitigation at the same time that is directly affected by climate change. Additionally, investments in technologies for GHG mitigation and climate change adaptation for Brazil, specially for the agricultural sector and for reduction in the deforestation pressure, in one side must be accompanied by control policies, land regularization to reduce speculation around the land value and guarantee of property rights. On the other side, accompanied by adequate policies for rural credit subsidized to the sector, labor-force training in the agricultural frontiers as well as qualified technical monitoring.

## 2.2 Low carbon technologies: ABC Plan

The Low Carbon Agriculture Plan (ABC Plan) was created by the decree 7,390/2010. The ABC Plan aims to mitigate GHG emissions in agriculture, improve efficiency in the use natural resources and increase the resilience of productive systems and rural communities, as well as enable the sector to adapt to climate change.

The ABC Plan has different actions to achieve the goals defined in the decree. For each action has a specific program that presents the guidelines to make them viable. In the end, six programs have technologies to mitigate GHG emissions, and one program to adapt to climate change. The actions present in ABC Plan are:

1. recover 15 Mha of degraded pasture;
2. increase the adoption of crop-livestock-forestry systems in 4 Mha;
3. increase the no-till system in 8 Mha;
4. increase the Biological nitrogen fixation in 5.5 Mha, substituting the nitrogen fertilizers;
5. increase the planted forests in 3 Mha;
6. expand the treatment of animal waste in 4.4 $Mm^3$;
7. encourage the implementation of adaptation actions to climate change, specially to those with GHG mitigation potential.

These technologies stem from their ability to directly reduce GHG emissions, i.e., as a consequence of the production process itself, rather than as intensifying technologies that reduce the pressure on area expansion. A sustainable agricultural intensification can be achieved with the use of technologies for reducing negative externalities, promoting improved yields, while controlling GHG emissions, and conserving biodiversity and ecohydrological processes (GODFRAY *et al.*, 2010; MUELLER *et al.*, 2012).

Actions in the ABC Plan are a strategy focused on fostering agricultural development while reducing deforestation rate and GHG emissions (BULLER *et al.*, 2015). Although the reduction of deforestation rates retains the greatest potential for mitigating GHG emissions, a low-carbon agriculture can also reduce GHG emissions, facilitate the removal of carbon, increase livestock productivity, and reestablish large areas of grassland currently used inefficiently in the Brazilian biomes, e.g., Cerrado and Amazônia (AUSTIN *et al.*, 2013).

### 2.2.1 Recovery degraded pasture

Degraded pasture is defined as an evolutionary process of loss of vigor, productivity, and the natural recovery capacity of pastures to sustain production levels and the quality required by the animals. Also the harmful effects of pests, diseases and invasive species, culminating in the advanced degradation of natural resources due to inadequate management (ZIMMER *et al.*, 2012).

An important indicative feature for pasture degradation is the animal capacity over time. When the livestock farm is handle with organization, it is often observed that the capacity of support for the same supply of forage is diminished. If no management action is taken the quantity and quality of the forage will decrease. Therefore, there is reflection in the individual performance of the animals. At this stage it is possible that the lawn is no longer uniform, having uncovered areas, without forage and with exposed soil. Also can be noted an occurrences of pests and diseases. The cultivated pasture introduced begins to lose the natural recovery capacity by the competition with native species.

As the pasture productivity fall so does the support capacity in terms of animal units. The landholders have an incentive to clear new areas increasing the pressure to clear new natural areas as well as deforestation. The gradual decline of soil fertility indicates a primary factor of pasture degradation. There is a six-stage of soil degradation after clearing a new area for agriculture. The area could be suitable for crop production; unproductive for crops; suitable for livestock ranching; unproductive for livestock ranching; abandoned, degraded area; and clearing a new area (CORNEJO NORONHA *et al.*, 2010). However, the process of recovery degraded pasture could slow this pressure, increasing the pasture and beef productivity, sparing land, and settling area for crops and forestry, e.g., soybean, maize, or reforestation.

Pasture recovery is among the Brazilian voluntary commitments assumed to reduce GHG emissions. Recovered pastures reduce CO2 emissions by at least 60% in a production system and increase the biomass production. The nutrient replacement in the pasture improves the quality of the animal diet, reducing the time of slaughter and the emission of methane gas (CH4) by the enteric fermentation (KURIHARA *et al.*, 1999). Also reducing the pressure to convert new natural areas into pasture. When compared to a degraded pasture recovered areas provide a higher carbon stock to the system since with the accumulation of organic matter in the soil provides lower CO2 losses to the atmosphere.

### 2.2.2 Integrated crop-livestock systems

Production systems are always being reformulated to increase production efficiency and protect the natural environment by intensification of agricultural yield. The expansion of soybean, the degradation of large areas due to livestock ranching, and low livestock productivity in Brazil play an important pressure to development of new agricultural practices to intensify the agriculture yield (SALTON *et al.*, 2014). Agricultural systems that integrate grain production and livestock ranching could be advantageous to both farmers and the environment. IS could make it possible to recover pasture productivity and increase crop stability at the same time (DE MORAES *et al.*, 2014; Sá *et al.*, 2017).

Integrated systems are planned systems involving temporal and spatial interactions on different scales with animal and crop exploitation within the same area, simultaneously or disjointedly and in rotation or succession. The adoption of integrated systems is beneficial by reducing pasture degradation. The benefits of IS include improved nutrient cycling, increased fertilizer efficiency, increased soil fertility due to the accumulation of organic matter, and better soil aggregation (DE MORAES *et al.*, 2014). Also, IS promote improvement in production processes, such as the machinery and labor, economic stability of factors, as well as risk reduction.

Due to its economic and ecological advantages, IS have been proposed as a strategy to contain agricultural expansion, the degradation of pastures, and the reduction of deforestation. Each type of IS bring its combination of benefits to agriculture. IS are considered to be key among sustainable technologies to overcome the problems arising from decades of using farming practices with high environmental impact. The IS have potential to mitigate GHG emissions, reduce the erosion and fertility losses, reduce the silting of watercourses and prevent soil and water pollution, among others. The IS can guarantee the sustainable intensification of agriculture, promoting increased production of foods, fibers and energy, associated with the promotion of ecosystem services (DE MORAES *et al.*, 2014).

### 2.2.3 ABC Program

The ABC Program is a special credit line to finance the ABC actions presented above, also the program incorporates other activities and actions. The Program has as beneficiaries farmers, and cooperatives which are able to transfer to their associates. The credit line aims to recover degraded pastures; implement and improve organic systems of agricultural production; implement and improve no-till systems; implement and improve crop-livestock, forest-livestock or crop-livestock-forestry integration and agroforestry systems; implement, maintain and improve the management of commercial forests, including those for industrial use or the production of charcoal.

Futhermore, adequate or regularize rural properties according to the environmental legislation, recover degraded areas and implement and improve sustainable forest management plans; treat waste and residues from animal production for the generation of energy; implement, improve and maintain palm oil forests, primarily in degraded productive areas; stimulate the use of biological nitrogen fixation.

The ABC program has a credit limit per beneficiary per crop year, independently of other credits granted and credit resources. The ABC Program's financing lines are the instrument used by the financial institutions to achieve the Brazilian goals for reducing emissions by making funding available for the actions of the ABC Plan. The limits reach R$ 2.2 million per farmer; R$ 3 million for commercial planted forest; and R$ 5 million for farmers with more than 15 fiscal modules[2].

Figure 2.3 shows the recent performance of the ABC Program. The range of the credit data available and contracted in the ABC program is from 2010/2011 crop-year to 2016/2017 crop-year (February). The available data are organized by crop-year and only after 2015 has the information concerns all the ABC credit categories, i.e, credit data for PR, IS, and so on. In the 2011/2012 crop-year the credit line for the ABC Program was R$ 3.15 billion, with interest rate of 5.5% per year, which 48% of the resources were used (R$ 1.5 billion). The value in the crop-year 2011/2012 represents an increase of 262% when compare to 2010/2011 crop-year. Almost all the funds for the program were transferred by BNDES to Banco do Brasil (R$ 1.2 billion), only around R$ 300 million to other public and private banks. In terms of projects, 5,038 projects were implemented, which 2,022 were in the Southeast, 870 in the Center-West, and 233 in the North.

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[2] Fiscal module is a unit of measure in hectares. The value is set by INCRA for each municipality, taking into account: (a) the predominant type of farm in the municipality (permanent crop, temporary crop, livestock or forestry); (B) income obtained in the predominant type of economic activity; (C) other existing economic activities in the municipality which, although not predominant, are expressive according to the income or area used; (D) the concept of "family farmer". The size of a tax module varies according to the municipality where the property is located. The fiscal module value in Brazil ranges from 5 to 110 hectares.

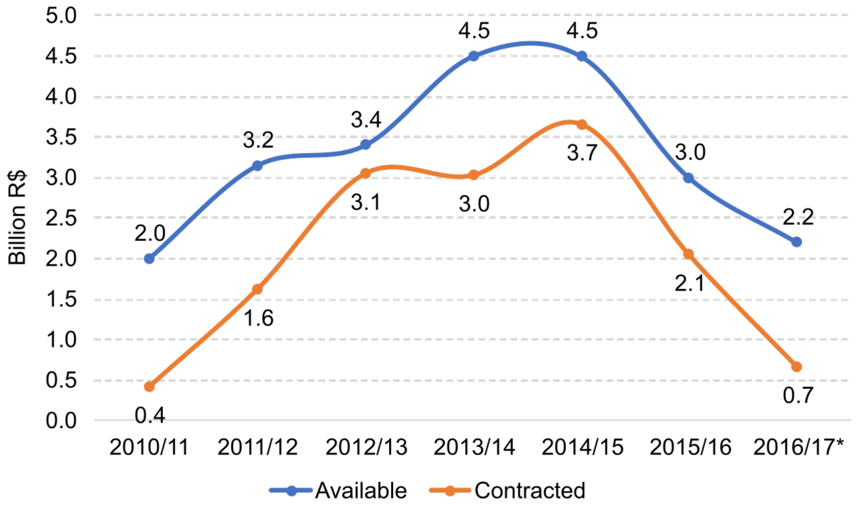

Figure 2.3: Total credit available and contracted in the ABC Program.
* Until February, 2017.
Source: (BACEN, 2017)

North and Northeast regions had the lowest number of financing contracts, although the plan has strong adherence to PPCDAm actions, as well as the Caatinga biome is one of the most environmentally vulnerable. Also, it would be expected the Central-West region, would be the region that sought the largest number of projects and had the largest funding application. However, the regions is the third in terms of contracts and application of resources.

Other central point to explain the growth until 2014/2015 was the rise in the interest rate associated with falling inflation in the most recent period. In sum, real interest rates have risen sharply since 2015. For example, in 2006/2007 crop-year, real interest rates were around 4.9% and caused the real interest rate to fall significantly. The period from 2012 to 2015 was marked by a negative real interest rate on rural loans. Interest on investments in machinery, warehousing and installations reached 2.5% in nominal terms. In real terms the interest rate charged on investment credit was largely negative.

Nevertheless, there is a gap among the available credit and the volume contracted. The total value of resources offered increased until the 2014/2015 crop-year and then fell drastically. This fall can be explained by the recent economic and political crisis in Brazil, as well as the high interest rate in the ABC Program. Additionally, there are other issues that could explain this gap, such as greater complexity and cost of establishing the necessary facilities to implement IS, which require technical and economic expertise and other types of unattained knowledge (DE MORAES *et al.*, 2014); the absence of small-scale business models that could be used on small-scale farms (GIL *et al.*, 2015); and credit access, technical extension and labour scarcity (LATAWIEC *et al.*, 2017);

Figure 2.4 summarizes the distribution of resources contracted by purpose in

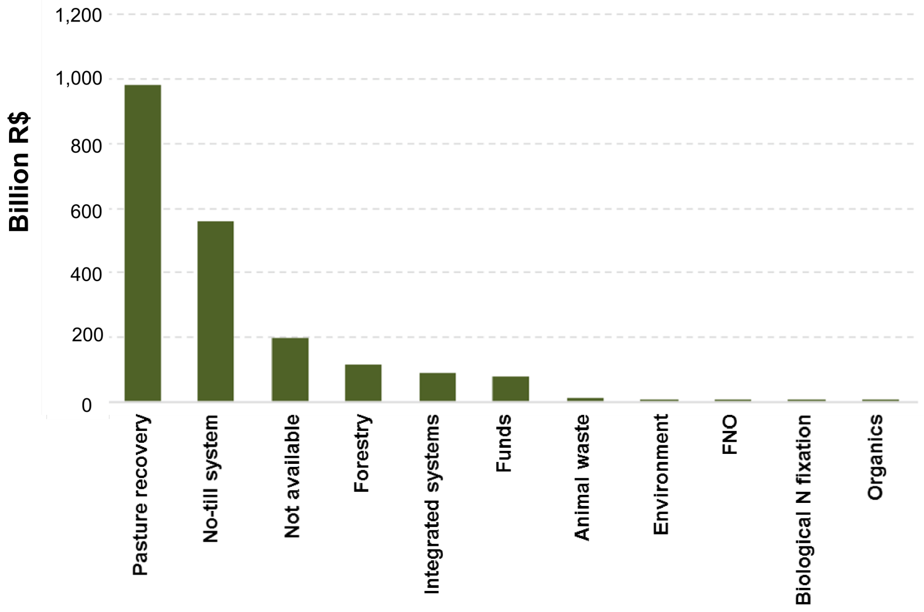

Figure 2.4: Total contracted by purpose in the 2015/2015 crop-year.
Source: (BACEN, 2017)

the 2015/2016 crop-year. Almost half of the R$ 2 billion contracted was destined for pasture recovery. Around R$ 600 million was used for no-tillage, and only around R$ 120 million destined to the IS. Considering the projects the total is 4,704, which 3,118 were applied to pasture recovery, 892 for no-till system, and 208 to IS.

The risk perceived by the economic agents tends to be high in the regions where the degradation level of pastures are greater. All the elements presented above suggest the speed of advancement of the ABC Program should be moderate. Also, it is important to consider macroeconomic changes in agricultural production. These changes have certainly affected decision-making regarding longer-term loans that include ABC lines of credit.

# Chapter 3

# General Equilibrium modeling of land use

General Equilibrium modeling, when compared to econometrics and other sector-specific approaches used to make projections of land use in Brazil, has the advantage of representing the entire economy. CGE models take into account microeconomic and macroeconomic feedbacks trough price adjustments of goods and costs of production when shocks occurs, such as a production-related technological development or a change of consumption preference. One disadvantage of a "top-down" [1] approach in CGE models of land use changes is that sectoral detail may suffer. I have built a static computable general equilibrium model, the Brazilian Economic Analysis (BREA) model, version 1, with detailed disaggregation of land use and land cover categories in Brazil.

The purpose is threefold: first, using a static CGE model is possible to investigate the direct effects and spillovers of ABC Plan actions, such as PR and IS. Policy analysis is isolated from exogenous effects such as economic growth, demand and/or preference changes, productivity gains, etc, i.e., the static model allows isolate completely the direct and spillovers effects of the ABC Plan; second, to better represent the heterogeneity of agriculture in different regions and associated land use with regional growth of the economy in a developing country like Brazil, by doing so within a CGE framework that includes potentially crucial feedback and interactions; third, to study how climate policies based on new technologies could affect land use decisions made by agents to undertake agricultural production and mitigate greenhouse gases emissions, as well as examine these two types of responses combined.

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[1] Top-down models describe the economic system in a global way through aggregates and their interrelations in the frame of a general equilibrium built on the base of microeconomic theory.

## 3.1 The BREA model

The Brazilian Economic Analysis is a static computable general equilibrium model. It is a multi-regional and multi-sector model which represents the Brazilian economy by six regions: South, Southeast, Center-West, Northeast, Northeast Cerrado (Savanna), and North (Amazon). Figure 3.1 shows the model representation.

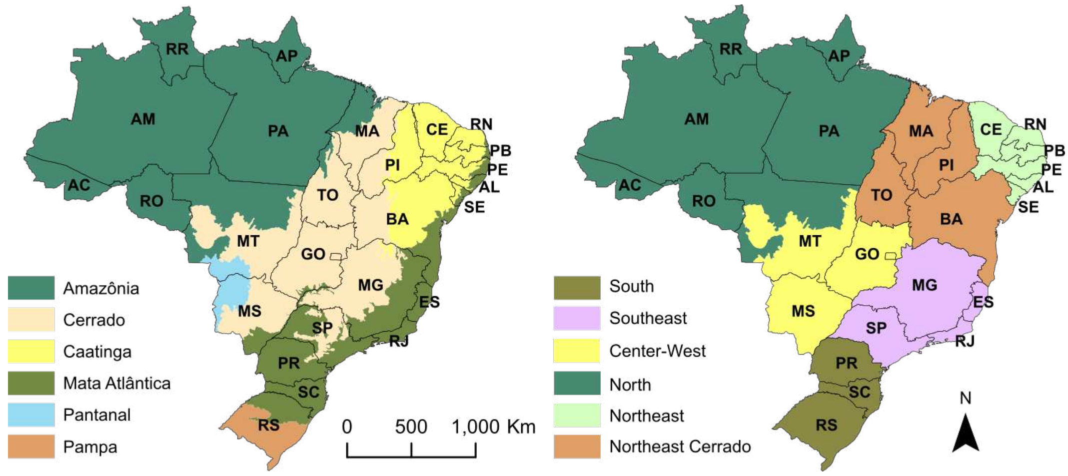

Figure 3.1: Brazilian biomes (left) and regional aggregation (right) in the model. Source: (IBGE, 2015) adapted by author and own elaboration.

Each region's final demand structure is composed of public and private – consumption and investment – expenditure across goods. The model is based on optimizing behavior and the agents produce, consume and sell services and products. Consumers with their budget constraints and preferences demand goods maximizing their utility function. Preferences are hypothetically continuous and convex, and their resulting continuous demand functions are zero degree homogeneous with regard to prices, i.e., only relative prices can be determined.

On the production side, technology is described by a production function with constant returns to scale[2] combining intermediate inputs, and primary factors (capital, labor, and land). In equilibrium the profit of firms is zero. Firms are assumed to have a specific production technology and demand factors to minimize their costs. The model enables analysis of direct and indirect effects arising from changes in public policies such as tariff shocks, tax rates, and endowments.

The model is based on GTAPinGAMS nomenclature and is written in MSPGE language, designed and solved as a nonlinear mixed complementarity problem in GAMS programming language (RUTHERFORD; PALTSEV, 2000; RUTHERFORD,

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[2] Constant returns to scale is when a firm changes their inputs or resources, with the results being exactly the same change in outputs or production. In other words, if a firm increases their inputs or resources, they will see a proportional increase in production or outputs.

2005). Figure 3.2 shows the economic structure underlying the BREA model. The symbols in this flow chart correspond to variables in the economic model. $Y_{ir}$ portrays the production of good $i$ in region $r$, $C_r$, $I_r$, and $G_r$ portray private consumption, investment, and public demand, respectively. $XR_{ir}$ and $MR_{ir}$ represent the regional trade of good $i$ in region $r$, and $M_{ir}$ the import of good $i$ into region $r$. $RA_r$ and $GOVT_r$ are the representative households and government consumers, and $FT_r$ the activity through which the "sluggish" factor of production is allocated to individual sectors. Commodity and market flows appear in solid lines and the doted lines represent the tax flows. Domestic production ($vom_{ir}$) is distributed to intermediate demand ($vdfm_{ijr}$) and to the vectors in final demand, such as household consumption ($vdpm_{ir}$), investment ($vdim_{ir}$), government demand ($vdgm_{ir}$), other demand regions in Brazil ($vxmdr_{irs}$), and exports ($vxmd_{irrow}$)[3]. The account identity in the dataset is:

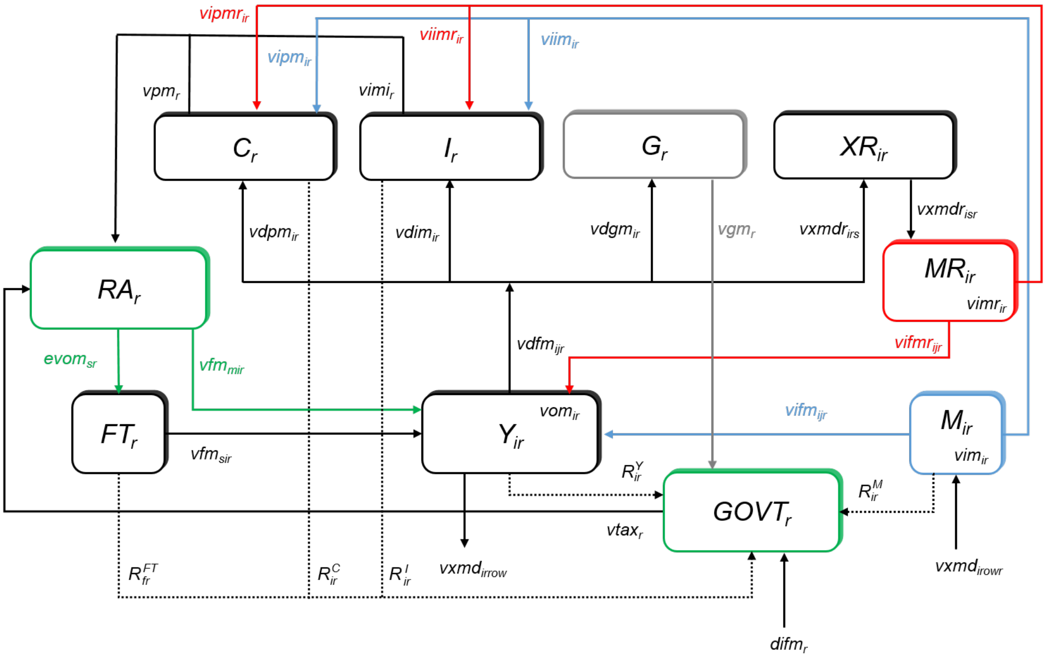

Figure 3.2: Regional economic structure.
Source: own elaboration.

$$vom_{ir} = \sum_i vdfm_{ijr} + vdpm_{ir} + vdim_{ir} + vdgm_{ir} + \sum_s vxmdr_{irs} + vxmd_{irrow} \quad (3.1)$$

Inputs to production include intermediate inputs (domestic and imported), mobile factors of production ($f \in m$) and specific factor of production ($f \in s$). Factor earnings accrue to households and factor market equilibrium is given by the identity relating the value of factor payments to factor income:

$$\sum_i vfm_{fir} = evom_{fr} \quad (3.2)$$

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[3] "row" (rest of world).

International market is driven by imported and exported goods. Imported goods have an aggregate value $vim_{ir}$ composed by intermediate demand ($vifm_{ijr}$), private consumption ($vipm_{ir}$), and investment ($viim_{ir}$). The accounting identity is:

$$vim_{ir} = \sum_j vifm_{ijr} + vipm_{ir} + viim_{ir} \tag{3.3}$$

International market clearance conditions require that region $r$ exports of good $i$ equal the imports of the same good in all trading partners. However, this relation is trivial since the model has just one outside region "row", so $vxm_{ir} = vxmd_{irrow}$.

The treatment given to the dataset for the Brazilian regions is roughly the same. The "imported goods" from one region in other regions, e.g., South region imports with origin in Southeast, have an aggregate value $vimr_{ir}$ composed by intermediate demand ($vifmr_{ijr}$), private consumption ($vipmr_{ir}$), and investment ($viimr_{ir}$). The accounting identity is:

$$vimr_{ir} = \sum_j vifmr_{ijr} + vipmr_{ir} + viimr_{ir} \tag{3.4}$$

Taxes flows in Brazil consist in a set of taxes. The indirect taxes are *services and goods circulation tax* (ICMS), *industrialized products tax* (IPI), and *others taxes net subsidies* (OILS). The indirect taxes are applied in national and imported goods such as intermediate demand ($rtfd_{ijr}$, $rtfi_{ijr}$), household consumption ($rtpd_{ir}$, $rtpi_{ir}$), and investment ($rtid_{ir}$, $rtii_{ir}$). These three indirect taxes are aggregated by the sum of intermediate demand and final demand when trade inside country is considered ($rtms_{irs}$), i.e., for inter-regional trade there is only one tax regardless the commodity consumption (Equation 3.4). Direct taxes and subsidies are applied in production such as $rto_{ir}$. Tariff on imports is $rtms_{irrow}$ and tax on factors of production is $rtf_{fir}$.

I have outlined two types of consistency conditions which are part of the database: market clearance (supply equals demand for all goods and factors) and income balance (net income equals net expenditure). The third set of identities involve net operating profits by all sectors in the economy. Considering the taxes flows as $R^Y_{ir}$ indirect taxes on production, $R^C_{ir}$ taxes on consumption, $R^I_{ir}$ on investment, and $R^M_{ir}$ on imports, the zero profit condition for each of the production sectors[4] is shown below.

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[4] $R^Y_{ir} = rto_{ir} + \sum_f rtf_{fir} + \sum_j (rtfi_{jir} + rtfd_{jir})$
$R^M_{ir} = rtms_{irrow}$
$R^C_{ir} = rtpd_{ir} + rtpi_{ir}$
$R^I_{ir} = rtid_{ir} + rtii_{ir}$

$$
\begin{aligned}
Y_{ir} &: \sum_f vfm_{fir} + \sum_j (vifm_{jir} + vdfm_{jir} + vifmr_{jir}) + R^Y_{ir} = vom_{ir} \\
M_{ir} &: vxmd_{irowr} + R^M_{ir} = vim_{ir} \\
Mr_{ir} &: \sum_j vifmr_{ijr} + vipmr_{ir} + viimr_{ir} = vimr_{ir} \\
C_r &: \sum_i (vdpm_{ir} + vipm_{ir} + vipmr_{ir} + R^C_{ir}) = vpm_r \\
G_r &: \sum_i vdgm_{ir} = vgm_r \\
I_r &: \sum_i (vdim_{ir} + viim_{ir} + viimr_{ir} + R^I_{ir}) = vimi_r \\
FT_{fr} &: evom_{fr} = \sum_j vfm_{fjr}
\end{aligned}
$$

To complete the economic structure, $difm_r$ is the sum of regional and international trade balance, and $vtax_r$ is the government transfer to the households.

### 3.1.1 Database

The model runs with several database and these are divided in two different modules: economic and land use. The economic module uses the 2009 National Accounts made available by IBGE (*Instituto Brasileiro de Geografia e Estatística*). The input-output table for Brazil is estimated according Guilhoto e Sesso Filho (2010) and disaggregated among all Brazilian municipalities by NEREUS-USP [5]. The final data is aggregated to 36 sectors and three factors of production: capital, labor, and land as shown in Table 3.1. Several different databases are combined in the land use module, which are presented further in this chapter.

### 3.1.2 Technology representation

The benchmark identities presented above indicate the market clearance, zero profit and income balance conditions which define the BREA model. These three conditions and equations do not, however, characterize the behavior of agents in the model. I start defining the competitive equilibrium in which the standard assumption of optimizing agents applies for both producers and consumers. The setting of constant returns to scale implies profit maximization is equivalent cost minimization subject to technical constraints.

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[5] <http://www.usp.br/nereus/>

Table 3.1: Regions, sectors, primary factors, and land use categories.

| **Region** | | **Sectors** | | **Primary factor inputs** | |
|---|---|---|---|---|---|
| South | STH | Mineral Iron | MIN | Capital | CAP |
| Southeast | SST | Coal | COAL | Labor | LAB |
| Center-West | CST | Mineral Extraction | NMM | Land | LND |
| North | NTH | Meats | MEAT | *Cropland* | *CROP* |
| Northeast | NST | Soy oil | OSD | *Pasture* | *PAST* |
| Northeast Cerrado | NSTC | Foods | FOOD | *Degraded pasture* | *DPAS* |
| | | Textile and wood | TEX | *Natural Forest* | *NFOR* |
| **Sectors** | | Refined oil | ROIL | *Planted Forest* | *PFOR* |
| Rice | RICE | Ethanol | ETH | *Managed Forest* | *MFOR* |
| Maize | CORN | Chemistry | CHM | *Protected areas* | *PA* |
| Cane | CANE | Fertilizer | FERT | *Natural areas* | *NAT* |
| Soy | SOY | Defensives | DFN | *Unused land* | *UNU* |
| Fruit | FRIT | Steel metal non-metallic | MMI | | |
| Other Cultures | OCUL | Machines | MAC | | |
| Forestry | FRST | Other Industry | OIND | | |
| Cattle | CTTL | Electricity | ELEC | | |
| Other live animals | OLA | Pipe gas | PGAS | | |
| Swine | SWIN | Water | WTR | | |
| Poultry | PTRY | Public Services | PSRV | | |
| Milk | MILK | Construction | CONS | | |
| Oil | OIL | Services | SERV | | |
| Gas | GAS | Transportation | TRNS | | |

Source: own elaboration.

### Production technology

The production technologies are represented by nested Constant Elasticity of Substitution (CES) functions. The nested structure allows greater flexibility for inputs substitution, which is convenient when there is a higher level of sector disaggregation, but it requires the availability of elasticities of substitution related to each nest. The common nest structure for the regional agricultural sectors (rice, corn, cane, soy, frit, ocul), livestock sectors (cttl, ola), and forestry (frst) is presented in Figure 3.3.

The structure shows how various inputs are aggregated in a nested fashion to represent the regional technology production. Components in dashed line denote separate functions. The fossil-based energy consumption is combined through a Leontief function, i.e., there is no substitution among fossil energy, they are complementary. The fossil energy bundle is combined with the electricity consumption using a CES function, which generates an *Aggregate energy* nest. The elasticity $\sigma_{en}$ controls the substitution between electricity and the *Other energy* bundle. The other intermediate inputs are combined by a Leontief function (elasticity $\sigma_{ne}$ equals to zero), and this nest is combined with the *Aggregate energy* resulting the *Energy-materials* nest. The primary factors of production, capital and labor, are combined in the top nest under elasticity $\sigma_{va}$, and combining with the *Resource-intense* nest resulting the sector output level. Note that the output is divided through a Constant

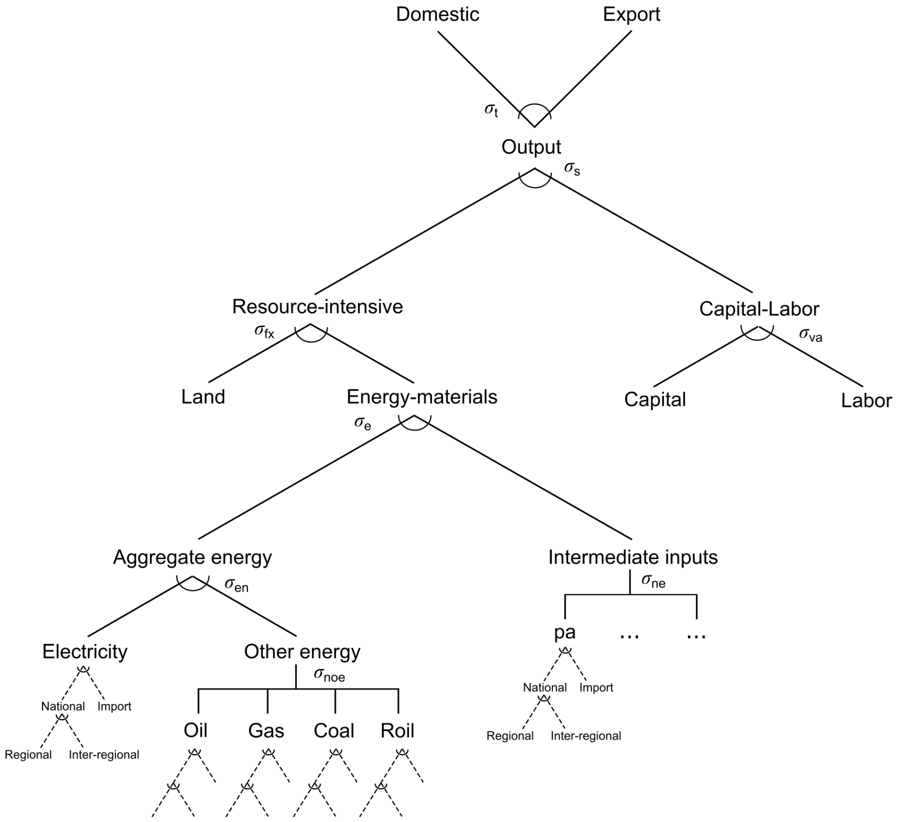

Figure 3.3: Structure of Production Sectors: agricultural, livestock, and forestry.
Source: own elaboration.

Elasticity Transformation (CET) function in domestic demand and export demand under elasticity of transformation $\sigma_t$.

The elasticity $\sigma_{fx}$ governs the substitution between *Energy-materials* and land, and $\sigma_s$ governs the substitution between the *Energy-materials-land* and the *Capital-Labor* bundles. These elasticities are set as 0.3 and 0.7, respectively (CHEN *et al.*, 2017). It means that higher prices for land can be overcome by substituting in the lower nest toward energy, fertilizer, and other materials, and in the upper nest toward capital. The actual simulated output of agricultural product per hectare of land in a scenario in each agricultural sector in BREA is a combination of endogenous intensification possibilities that depend on relative prices of inputs.

Technological change may enter in BREA model through three different ways. First, exogenous productivity growth in production factors following future trends expected in the scientific literature; second, different techniques or technology to mix inputs through substitution in the production function in each sector and induced by changes in relative prices; and third, new technology representation whose the inputs requirements and production function are specified in the model database. All three forms of technological change are pertinent in the land use modeling as described below.

In the first option, land is subject to an exogenous productivity improvement for each land type and agricultural sector. However, for a static version of the model is not trivial to justify productivity gains in primary factors, the costs, and the benefits associated to it. Besides, it is possible to intensify conventional agricultural production in BREA as land can be partially substituted by inputs and other primary factors as relative prices changes.

The production intensification is controlled primarily by two substitution elasticities in the land-use sectors as aforementioned. The representation of new technologies is also a key feature of CGE models dealing with natural resources and environmental goods and services. In the case of land-use modeling and new agricultural technologies, such as presented in the ABC plan, the BREA model is the first one to explicitly represent these technologies, as well as its adoption. Further in this chapter I will present the approach developed in BREA model to represent such technologies.

The components in dashed line in Figure 3.3 are the functions to aggregate inputs from different origins. The combination among regional and inter-regional goods gives a national composite good. Each national good is combined with imported good resulting the final good for consumption. All these combinations, regional and inter-regional, and national and imported, are based on Armington's idea of regionally differentiated products. Table C.1 presents the elasticities that drive these substitutions.

The nest structure for the other sectors, such as non-agricultural and energy sectors, is slightly different since the intermediate inputs are combined through a Leontief function in the top nest. The Figures D.1 and D.2 show these structures. Both elasticities $\sigma_s$ and $\sigma_{ne}$ in the upper nest and in the intermediate inputs nest are set to zero. The intensification in this sectors occurs only by energy consumption, and capital-labor demand. The *Aggregate energy* nest combines electricity demand and other energy sources to generate aggregate energy consumption. The elasticity in the *Resource-Intense* bundle controls the substitution between energy and capital-labor consumption. Table 3.2 shows the elasticities in nesting structure.

### Preferences and final demand

Private consumption consistent with utility maximization is portrayed by minimization of the expenditure to reach a given level of aggregate consumption. Regional final demand in the core model is characterized by a Cobb-Douglas tradeoff across composite goods which include both domestic and imported inputs. Figure 3.4 displays the nested function for consumption. The lower level of the nested structure has three different bundle of goods. The first bundle is the energy bundle, a combination of all types of energy such as electricity, oil, gas, coal, and refined

Table 3.2: Elasticities for nesting structure.

| Elasticity of substitution between | BREA | Agricultural, livestock, and forestry sectors | Energy sectors | Other sectors | Consumption |
|---|---|---|---|---|---|
| Domestic and export outputs | $\sigma_t$ | 2.0 | 2.0 | 2.0 | - |
| Resource-intense and capital-labor bundles | $\sigma_s$ | 0.7 | - | - | - |
| Resource-intense and intermediate inputs | $\sigma_s$ | - | 0.0 | 0.0 | - |
| Other consumption and transportation | $\sigma_s$ | - | - | - | 1.0 |
| Land and energy-materials bundle | $\sigma_{fx}$ | 0.3 | - | - | - |
| Capital and labor | $\sigma_{va}$ | 1.0 | 1.0 | 1.0 | - |
| Aggregate energy and intermediate inputs | $\sigma_e$ | 0.6 | - | - | - |
| Aggregate energy and capital-labor bundle | $\sigma_e$ | - | 0.8 | 1.0 | - |
| Electricity and other energy bundle | $\sigma_{en}$ | 1.5 | 1.5 | 1.5 | 0.5 |
| Intermediate inputs | $\sigma_{ne}$ | 0.0 | 0.0 | 0.0 | - |
| Fossil energy | $\sigma_{noe}$ | 0.0 | 0.0 | 0.0 | - |
| Agricultural and food goods | $\sigma_{d1}$ | - | - | - | 0.35 |
| Other goods | $\sigma_{d2}$ | - | - | - | 0.35 |

Source: research data.

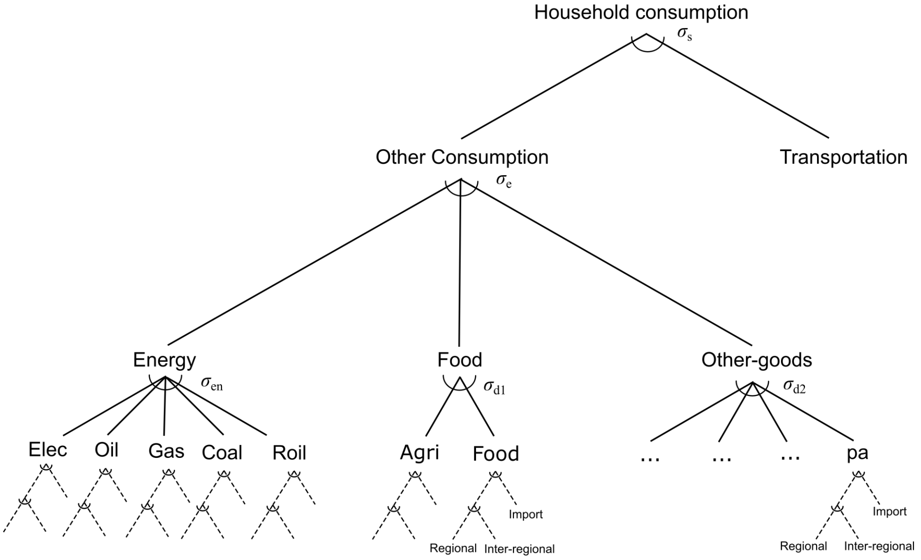

Figure 3.4: Structure of private consumption.
Source: own elaboration.

oil; the second is a combination of food and agricultural goods, and finally the third bundle is a combination of all other goods. The top level shows the household consumption of transportation. The transportation nest captures the total value spent in transportation services not including fuels.

### Government and public consumption

Regional public consumption in the BREA model is represented as a fixed coefficient aggregation of domestic goods. There is no imported consumption by government, and the regional government only demands services and goods inside each region. Figure 3.5 illustrates the functional form.

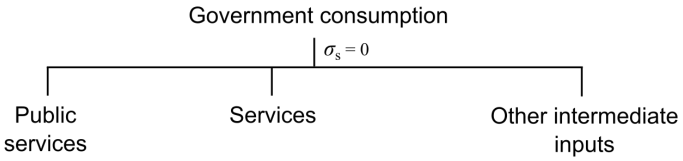

Figure 3.5: Structure of government consumption.
Source: own elaboration.

### Investment

The structure of investment is directly connected to the economic dataset structure. Each region demands service and goods in three different sources, such as regional, inter-regional, and imported. Figure 3.6 shows the regional structure of investment. In the lower nest a separate function combines regional and inter-regional goods under elasticity of substitution *esubdr* for each good *i* resulting a *National* good. This *National* good is combined with *Imported* good under elasticity of substitution *esubd* for each good *i*. Finally, in the upper nest under elasticity $\sigma_s = 1$ there is a combination of all aggregate goods resulting the regional investment.

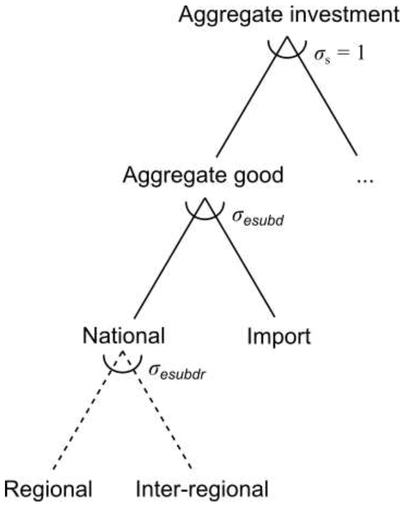

Figure 3.6: Structure of investment.
Source: own elaboration.

## 3.2 Land use

This section presents the land-use module used in BREA model, comprised of land cover and land value data sets. The representation of land-use in economic models is dependent of several factors, e.g., the quality of the input data as well as the availability of reliable land use and land cover maps. Several different data sets were revised and combined to build BREA, as those produced by IBGE, INPE (Brazilian National Institute for Space Research), MMA (Federal Ministry for the

Environment), MAPA (Federal Ministry for the Agriculture), CONAB (Brazilian Supply Company), and SOS Mata Atlântica.

The data sets from IBGE are the 2006 Agricultural Census (IBGE, 2006), the Municipal Crop Production survey (PAM) for 2009 (IBGE, 2016a), and the Municipal Livestock Production survey (PPM) for 2009 (IBGE, 2016b). The 2006 Agricultural Census provides information on establishments area, rented area, and the total value paid in rent. The PAM survey provides the information on harvested area, planted area, production value and volume of permanent and temporary crops. The PPM survey has information on herd inventories, quantity and value of animal products, and the number of milked cows.

Land use and land cover data in Brazil are organized according to the regions in the model. There are six regions: South, Southeast, Center-West, North (Amazon), Northeast, and Northeast Cerrado. The model represents the land use in 9 categories: cropland, pasture, degraded pasture, managed forest, planted forest, natural forest and natural areas, protected areas, and unused area. I start the database from the six biomes in Brazil: Amazônia (tropical rain forest), Cerrado (tropical savanna), Caatinga (semi-arid deciduous shrubland and semi-deciduous dry forests), Mata Atlântica (tropical and subtropical forest), Pantanal (wetlands), and Pampa (natural grassland).

Regarding the maps in Figure 3.1, it is important to highlight the difference between them. The first map shows the Biomes in Brazil and the second the regional representation in the model. The regional aggregation portrays a mixture of biomes and political division in Brazil. The details about the aggregation are described below.

The Amazônia biome covers an area of 419.6 Mha. It is estimated that 17% of the forest has been removed due to intense human occupation and agriculture expansion. The annual deforestation rate reached 2.7 Mha in 2004. Nevertheless, since 2005 deforestation rates dropped, and in 2016 reached 0.799 Mha. This result is an effort of command and control policies conducted by the government as well as law enforcement and creation of protected areas. The Amazônia biome is the same area as the Northern region in the model.

The Cerrado has 203.6 Mha and it covers almost 25% of the country's land area. According to MMA (2016) it is estimated that around only 100 Mha remains with original vegetation. In the model, the Cerrado biome is split into three different regions, such as Center-West, Northeast Cerrado, and part of Southeast. It is helpful to introduce it into the model to treat the dynamics of agriculture frontier in Brazil, especially in the Northeastern Cerrado[6] region.

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[6] Northeastern Cerrado is also known by Mapitoba or Matopiba, which are State's initials acronyms of Maranhão (MA), Piauí (PI), Tocantins (TO), and Bahia (BA).

The Caatinga biome has 84.4 Mha and it is represented by Northeastern Coast region. It is a seasonally dry tropical shrubland, since its flora (shrubs and trees) consists of dry forest species rather than savanna species (SANTOS *et al.*, 2011). The Mata Atlântica biome corresponds for 17% (111 Mha) of Brazilian territory, unfortunately represents the most populated area in Brazil and it has been severely degraded. It estimated only 12% (13.3 Mha) of the original forest remains (RIBEIRO *et al.*, 2009). In the model it is split in Southern, Southeastern, and a small part of Northeastern Cerrado and Northeastern Coast regions.

The Pantanal biome covers around 15.04 Mha. During 3 to 6 months some areas are flooded, reaching an amplitude from 2 to 5 meters working like a natural control of a great variety of flora and fauna. It is also an area of extensive cattle ranching, and it is estimated that more than 40% of its forests and savannas have been altered by the introduction of grass species for cattle ranching (HARRIS *et al.*, 2005). In the BREA model, Pantanal biome is incorporated in the Center-Western region. At last, Pampa biome is present only in Rio Grande do Sul State and covers 63% of the State area (17.6 Mha). Livestock production is the main economic activity followed by rice production. In the model the Pampa biome is included in the Southern region.

BREA model is an economic model capable to represent the agricultural markets and its regional differences in Brazil. Such level of regional aggregation might lose the land heterogeneity, since each biome has specific biogeochemical cycles working in different ways as a carbon sink (LIMA *et al.*, 2012). However, in some areas such as Pampa and Mata Atlântica biomes, the total agricultural area is fairly stable, and there is not concern about the the conversion of natural vegetation to livestock or crop production. The same occurs for the Southeastern region, that is a combination of three different biomes. On the other hand, the dynamic of land use changes for agriculture in Brazil is much more active and has called attention in the Northern and Northeastern Cerrado regions (LUMBRERAS *et al.*, 2015).

The representation of land use in 9 different categories starts by determining the total area of Brazil. This data is made available by state on IBGE website[7]. As a result I present below a summary of each type of land use and its definition. Table 3.4 shows the total regional areas by land use.

*Cropland* - areas planted with one of the six crops categories in the model: rice, maize, sugar cane, soybean, fruits, and other cultures. Total area for cropland is around 65 Mha. Southern, Southeastern, and Center-Western regions concentrate around 74% of total area, while the Northern and Northeastern Cerrado region – the new agricultural frontier – represents around 21%. To determine the area of cropland I use the PAM survey (IBGE, 2016a) and match the survey data with the

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[7] <http://www.ibge.gov.br/home/geociencias/cartografia/default_territ_area.shtm>

agricultural sectors in the model by commodity, state, and municipalities[8]. The areas of second and third harvest of crops in the same calendar year, such as corn, potato, peanut, and bean are not considered. I avoid the overestimation of planted area using only the data for the first crop in these cultures. Further in this chapter, I will show a special treatment for the double crop of maize.

*Pasture* - areas with natural grass or planted pasture used for livestock ranching and other live animals. The regions North and Northeast Cerrado represent 43% of pasture in the model and as aforementioned are the new agricultural frontier in Brazil. I use the data of total pasture from *Laboratório de Processamento de Imagens e Geoprocessamento* (LAPIG)[9] available by state and municipalities. The total pasture estimated is 168 Mha and 48 Mha of that is considered degraded pasture.

*Degraded Pasture* - areas with natural grass or planted pasture used for livestock ranching and other live animals with low productive capacity. I match the data for total pasture area and the herd inventories provided by PPM survey (IBGE, 2016b) by state and municipalities. The occupation rate ($or$) is the ratio of total heads and total pasture. The occupation rate determines the degradation level of pasture as well as the division among different degradation levels. Pasture areas supporting levels of 0.75 animal units or less per hectare are considered degraded areas. Table 3.3 shows the data of degraded pasture in the model representation.

Table 3.3: Total pasture, degraded pasture, occupation rate ($or$), and levels of degradation.

| **Regions** | **Pasture (1,000 ha)** | | | **Levels of degradation** | |
|---|---|---|---|---|---|
| | Total* | Degraded | Occupation rate | Very High<br>$0 \leq or \leq 0.4$ | High<br>$0.4 < or \leq 0.75$ |
| **South** | 17,740 | 5,663 | 0.59 | 403 | 5,260 |
| **Southeast** | 28,480 | 8,398 | 0.56 | 1,231 | 7,168 |
| **Center-West** | 37,743 | 1,232 | 0.65 | 10 | 1,222 |
| **North** | 34,325 | 1,834 | 0.54 | 461 | 1,373 |
| **Northeast** | 14,259 | 11,317 | 0.38 | 6,586 | 4,731 |
| **Northeast Cerrado** | 36,248 | 19,775 | 0.32 | 13,627 | 6,148 |
| **Total** | 168,794 | 48,220 | 0.51** | 22,317 | 25,903 |

Source: research data, own elaboration.
* Good pasture plus degraded pasture.
** Average of all regions.

The criteria used to determine degraded pastures suggests there are 48 Mha of this land category in Brazil. It is concentrated in two regions, Northeast and Northeast Cerrado, representing around 65% of total. The lower occupation rate

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[8] Which is the case of Mato Grosso State, divided in two different regions considering the municipalities in the Amazon biome and Cerrado biome.

[9] <https://www.lapig.iesa.ufg.br/lapig/>

is determined by the biomes of these regions. The unfavorable types of soil and weather work as limitations to improve the pasture quality.

The forest areas receive a special treatment. The objective here is to classify the forest areas in different status: natural forest, managed forest, planted forest, and protected areas. Notice that the category natural forest could be inside or outside the private rural establishments. Once outside, it could be natural forest *per se* avaliable to further conversion or protected area. If protected area, this could be a managed public forest or a full protected area; if it is natural forest inside private rural establishments, it could be managed forest, planted forest, protected area, or natural forest. I start with the data of total native vegetation available on LAPIG (LAPIG, 2016), Terra Class Cerrado (INPE, 2016), Terra Class Amazon (INPE, ), and SOS Mata Atlântica (SOS Mata Atlântica, 2016). Terra Class provides information for each biome and state, and SOS Mata Atlântica information for each state.

I match the data from LAPIG with the Terra Class data by state. The Cerrado biome has a peculiarity since it has forest and non-forest areas[10]. On the other hand, the Brazilian Forestry Service (SFB) has the National Record of Public Forests (SFB, 2016). The SFB data has information about the area of public forest under full protection and the area under some sustainable use. To complete the database I use the data from Brazilian Tree Industry (IBA) for planted forest (IBA, 2016), and for managed forest the data from Agricultural Census. In the end, the forest data is divided in natural areas; natural forest, managed forest, and protected areas, public and private; managed natural grass (public), planted forest, and unused areas.

*Managed Forest* - these areas are forests used in a sustainable way. It is divided in public and private areas. The public areas used in a sustainable way represent 164 Mha and are divided in seven types: environmental protection area, area of relevant ecological interest, national forest, extractive reserve, wildfire reserve, private natural heritage reserve and sustainable development reserve. I assume that this land category is not available to conversion to agricultural use in the model. The private managed forest is 8 Mha and it is available to be converted in the model benchmark.

*Planted Forest* - these areas are represented for a large number of planted forests with pinus and eucalyptus species. The total is 7 Mha concentrated in the Southern, Southeastern, and Northeastern Cerrado regions. In a short-rotation

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[10] The typical savanna formations are not homogenous. There is a great variation in the balance between the quantities of trees and herbaceous vegetation, forming a structural gradient that goes from the completely open *cerrado* - the clean field, predominant vegetation of grasses, without the presence of wooden elements (trees and shrubs) - to the close *cerrado*, physiognomically forestal - the *cerradão* ('big cerrado'), with a great quantity of trees and a forest type aspect. The intermediate forms are the dirty field, the *cerrado* field and the *cerrado sensu stricto*, according to a growing density of trees.

system with single or few species and uniform planting density, the production is used to supply the wood and paper industries.

*Managed natural grass* - it is a special category that does not enter in the model benchmark. It is around 9 Mha concentrated in the Cerrado biome and is present in the National Record of Public Forests (SFB, 2016), however it is difficult to ensure the real vegetation in these areas (forest or non-forest Cerrado).

*Protected areas* - the total protected area represents around 187 Mha and it is divided in public and private areas. The private areas are inside the rural establishments and represent 51 Mha. The public protected area represents around 135 Mha. There are two types of environmental protection areas in the country: areas of full protection and areas of sustainable use (allocated in managed forest category above). The full protected areas are classified in five types: ecological station, biological reserve, national park, natural monument, and wildfire refuge. Protected areas in Northern region (Amazon biome) represents 73% of total protected area in Brazil, and in the Cerrado biome is 15% of total area. These areas are not available to be converted in the model benchmark.

*Natural areas* - these areas portray the residual areas where there is a combination of different biomes and is difficult to determine the actual vegetation. In the South region is a combination of natural grass from Pampa biome, degraded forest from Mata Atlântica biome, and non-forest formation from Cerrado. The same for Center-West region, where is a combination of non-forest formation from Cerrado and wetlands from Pantanal biome. For the Northeast Cerrado it is a combination of non-forest formation from Caatinga and Cerrado biomes. The total area is around 111 Mha and this area is considered available to be converted to agriculture or pasture areas in the model.

*Unused* - the total unused area represents around 24 Mha. This area is a concentration of river basins, such as Amazon river, as well as wetlands, urban areas, roads, coast water and water bodies, degraded lands such as eroded, desertified and salinated lands.

Table 3.4: Area of BREA classes per region in Brazil (1,000 ha).

| Regions | Cropland | Good pasture | Degraded pasture | Natural areas | Natural forest* | Managed forest | Planted forest | Others categories | Total |
|---|---|---|---|---|---|---|---|---|---|
| **sth** | 19,146 | 12,077 | 5,663 | 7,566 | 2,624 | 512 | 2,153 | 7,936 | **57,677** |
| **sst** | 13,778 | 20,082 | 8,398 | 23,676 | 6,762 | 1,164 | 3,463 | 15,138 | **92,462** |
| **cst** | 14,988 | 36,510 | 1,232 | 21,143 | 11,371 | 675 | 675 | 26,436 | **113,031** |
| **nth** | 5,168 | 32,491 | 1,834 | 2,522 | 50,275 | 1,039 | 413 | 311,465 | **405,206** |
| **nst** | 3,519 | 2,942 | 11,317 | 14,070 | 4,567 | 1,605 | 8 | 2,574 | **40,601** |
| **nstc** | 8,568 | 16,472 | 19,775 | 42,059 | 28,504 | 3,479 | 906 | 22,837 | **142,600** |
| **Total** | **65,166** | **120,575** | **48,220** | **111,035** | **104,103** | **8,472** | **7,619** | **386,387** | **851,577** |

Source: research data own elaboration.

**sth**: South; **sst**: Southeast; **cst**: Center-West; **nth**: North; **nst**: Northeast; **nstc**: Northeast Cerrado.

$*$ Public and Private.

### 3.2.1 Land rent and land value

The input-output database reports economic flows in the year 2009. Regarding value-added only returns on capital and labor are present in the database. When it comes to the land use database the relevant flows are the land rents associated with a given economic activity, taking place in a given agricultural area. The land rents should be extracted from the gross operational surplus, which is the capital return in the CGE model. In addition, the manipulation of the database must satisfy a number of key equilibrium conditions, including: market clearance, income balance, and zero profit. Because of these requirements, any change in the database to represent land rents or any other new economic flow must avoid jeopardizing one or more of these equilibrium conditions. For all these reasons, my approach is instead 'sharing out' existing land rents from the original capital returns in the input-output database, according to the information provided by the 2006 Agricultural Census (IBGE, 2006) and the PAM survey (IBGE, 2016a).

In this subsection, I describe how I allocate the land rents across the sectors in the model. The procedure differs for crop and livestock, so I discuss the associated procedures first for crops and then for livestock. The sectoral value-added adjustment should preserve the estimates of primary factors shares from literature, also the assumption of indirect use of land by non-ruminants sectors (swine and poultry). Forest land rent allocation is described next, followed by an overview of the final database.

I start with the data of harvested area in the year 2009, since in the economic accounts for each region in the model, land rents are generated from the activity on a given parcel of land during the calendar year. Consequently, I am interested in the value of the land in production over the course of the entire year, not just one season. Consider the case of a farmer in the South of Brazil who grows early summer soybean with a winter crop of maize in the same area (double cropping). The economic data identify sectors in terms of crops (rice, maize, soybean, and so on), not hectares of land. The land rents should accrue to the harvested area, by crop.

The 2006 Agricultural Census (IBGE, 2006) has the information of land rents by State and economic activities. I match the economic activities with the agricultural sectors in the model, the exceptions are fruit (frit) and other cultures (ocul) sectors.[11] This mapping is used in conjunction with the following formula to split

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[11] For example, the economic activity of corn has a directly match with the corn sector. On the other hand, all the fruit production match with frit sector; all the other grain production match with ocul sector. They are a combination of different economic activities, such as fruits production and other grains, respectively.

the BREA sectoral land rents into the vegetal production sectors.

$$VRENT_{i,r} = \sum_{r}(P_{i,r} \cdot A_{i,r}) \cdot \frac{VPROD_{i,r}}{\sum_{r} VPROD_{i,r}} \tag{3.5}$$

$$i \in vagri, i \neq frit, ocul$$

where:

$VRENT_{i,r}$ is the value of total land of crop $i$ in region $r$;
$P_{i,r}$ is the per-ha price of land rent in crop $i$ in region $r$ (CONAB[12]);
$A_{i,r}$ is the harvested area (ha) of crop $i$ in region $r$ (PAM survey);
$VPROD_{i,r}$ is the value of production of crop $i$ in region $r$ (PAM survey).

For the fruit (frit) and other cultures (ocul) sectors I use a slightly different approach as aforementioned these sectors are a combination of several economic activities. For this reason, I determine the price per-ha of land rent by the ratio of the total rent payed and the total rented area in these economic activities using 2006 Census data (IBGE, 2006).

$$VRENT_{i,r} = \frac{RENT_{i,r}}{ARENT_{i,r}} \cdot A_{i,r} \tag{3.6}$$

$$i = frit, ocul$$

where:

$RENT_{i,r}$ is the value of total land rent payed in crop $i$ in region $r$ (Census);
$ARENT_{i,r}$ is the total area rented in crop $i$ in region $r$ (Census);

Table 3.5 shows the total land rents per region in BREA model. The data show the importance of agricultural production in each region, which is determined by the economic formation and weather conditions. The high values for the other cultures sector (ocul), specially in the South and Southeast regions, are consequence of its higher aggregation level. Their shorter cultivation period, specially vegetables, allows multiple cropping as a result a high density of production per area, as well as high production value per area, differently of grain production. The data reveal some points about specific crops. For example, the soybean has large shares in almost all regions except in the Northeast. In the Center-West it reaches 65% of total land rents (Figure 3.7); the maize production is well distributed throughout the country, essentially duo to the diffusion of double cropping. The same pattern with fruit production, expect for Center-West and North regions, which are dominated by soybean and livestock productions. Cane production is a traditional crop in the Southeast and Northeast regions as the rice production in the South.

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[12] *Companhia Nacional de Abastecimento*. Availabe at Costs of production website: <http://www.conab.gov.br/conteudos.php?a=1546&t=2>

Table 3.5: Total land rents per region (all R$ values are in 2009 million R$).

| Regions | rice | corn | cane | soy | frit | ocul | frst | cttl | ola |
|---|---|---|---|---|---|---|---|---|---|
| **South** | 361 | 481 | 178 | 1,627 | 362 | 2,912 | 306 | 1,932 | 206 |
| **Southeast** | 9 | 300 | 1,442 | 351 | 642 | 1,545 | 1,061 | 2,767 | 87 |
| **Center-West** | 36 | 274 | 240 | 1,809 | 16 | 373 | 56 | 1,786 | 68 |
| **North** | 38 | 78 | 53 | 380 | 19 | 103 | 134 | 1,533 | 123 |
| **Northeast** | 9 | 48 | 277 | 1 | 56 | 279 | 15 | 696 | 41 |
| **Northeast Cerrado** | 55 | 100 | 67 | 430 | 100 | 269 | 502 | 904 | 192 |

Source: reseach data own elaboration.
**rice**: rice; **corn**: maize; **cane**: sugar cane; **soy**: soybean; **frit**: fruits; **ocul**: other cultures
**frst**: forestry; **cttl**: cattle ranching; **ola**: other live animals.

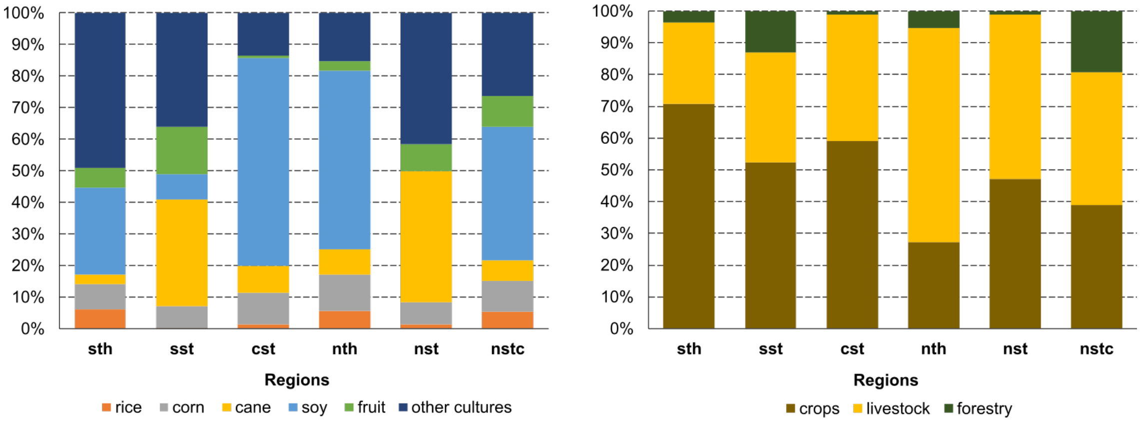

Figure 3.7: Distribution of crop sectors land rent (left) and distribution of crop, livestock, and forestry land rents (right).
**sth**: South; **sst**: Southeast; **cst**: Center-West; **nth**: North; **nst**: Northeast; **nstc**: Northeast Cerrado.
Source: research data own elaboration.

There are four livestock production sectors in BREA database: cattle (cttl), other live animals (ola), swine (swin), and poultry (ptry). The non-ruminants (swine and poultry) sectors do not use land directly in production. They consume grain and feed as intermediate inputs. These are already produced using land somewhere else in the system. Moreover, as the production intensification increases, these animals are produced in confined systems, which is more nearly akin to a manufacturing sector than a land-using sector. There is no direct competition for land among these sectors and crops, forestry and ruminants production. However, there is an indirect competition, since an increase in the poultry production, for example, will boost the feed requirements and hence increase the demand for land in feed grains. The model captures the indirect competition via the intermediate demand in non-ruminant production.

In order to determine the land rent for the other live animals (ola) sector I use an approach similar to the GTAP model (LEE *et al.*, 2009). The ola sector is a combination of several animals production (sheep, goats, horses, asses, mules, etc) and there is no good information in which type of land, pasture or natural grass, these animals are raised. With this in mind I use an index of maize yield as a predictor of land productivity in forage. For the cattle production I use an index based on per-@ price [13] , productivity, as well as the pasture and natural grass land areas. The total values paid in rent for each sector are split using theses indexes, respectively, according to the following formula:

$$VRENT_{i,r} = \sum_{r} \left( \frac{RENT_{i,r}}{ARENT_{i,r}} \cdot AP_{i,r} \right) \cdot shrent_{i,r} \tag{3.7}$$

$$shrent_{i,r} = \frac{P_{i,r} \cdot YIELD_{i,r} \cdot AP_{i,r}}{\sum_{r} (P_{i,r} \cdot YIELD_{i_r} \cdot AP_{i,r})}$$

$$i = cttl, ola$$

where:

$AP_{i,r}$ is the pasture and natural grass area (Census);

Figure 3.7 shows the shares of total land rents in each region. The livestock label includes the cattle and the other live animals sectors. The distribution of land rents across regions reveal a pattern similar to the crops distribution. Indeed, South and Southeast regions show livestock's shares around 26% and 35%, respectively. In these regions the total agricultural area is more stable, with lower capability of expansion, since these are consolidated regions with higher demand for urban areas and infrastructure, and due to institutional constraints. On the other hand, regions where the land transition is higher, as North and Northeast Cerrado, the livestock rents reach 62% and 42%, respectively.

Now I turn to the determination of land rents in the forestry sector in the model. The approach is similar to the previous presented. The areas of managed forest, planted forest, and natural forest available in 2006 Census (IBGE, 2006) determine the rent paid per hectare.

$$VRENT_{i,r} = \frac{RENT_{i,r}}{ARENT_{i,r}} \cdot AF_{i,r} \tag{3.8}$$

$$i = frst$$

$AF_{i,r}$ is the sum of managed forest, planted forest, and natural forest areas (Census);

As presented earlier, the land cover data have more area for natural forest and natural areas than showed by 2006 Census. It happens since the 2006 Census shows only reported variables inside the rural establishments. The land cover data built here bring all the information in physical hectares about natural forest and natural areas. Thus, there are no rental values to land that is not in current use.

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[13] The calculation of cattle yield uses the per-@ price of R$ 75, 225Kg per slaughtered animal, and each @ equals to 15Kg as references.

While conversion costs from managed forest to cropland and pasture, or from pasture to cropland, is captured by the land supply function, I have no information on the "value" of land not currently in use, or the cost of conversion. So, an important step to represent natural land categories and their conversion to other uses is to determine a meaningful reservation or non-use value for them. To do so, I use data from the Global Timber Market and Forestry data Project at Ohio State (SOHNGEN; TENNITY, 2007; CHEN *et al.*, 2017).

This database assumes that, at the margin, the cost of access to remote timber land must equal the value of the standing timber stock plus that of future harvests as the forest regrows (GURGEL *et al.*, 2017). I assume that natural areas rent relative to pasture is the same as natural forest relative to planted forest. The values of regional land rents by land use are shown in Table C.2.

Once I have priced natural forest and natural areas, these are incorporated in the model as part of the initial endowments of households in each region. The areas may be converted to other uses or conserved in their natural state. The reservation values of natural land enter each regional representative agent welfare function with an elasticity of substitution with other consumption goods and services (CHEN *et al.*, 2017; GURGEL *et al.*, 2017).

### 3.2.2 Land Supply

At this point the model has the key elements in order to incorporate land use in a CGE framework such as the database, the classification in different land uses, the determination of the land rents, and the land values for natural areas. Now I address the attention to important features as the mobility of land across uses, the conversion of natural land to managed uses and how technological changes drive the competition and demand for land among crops, livestock, and forestry production.

Land use is one of the key elements for equilibrium conditions in CGE models, due to land being a factor in the production of agricultural sectors. There is an increasing debate about the land supply and its capacity to feed the global population, produce bioenergy crops and mitigate GHG emissions. Several models have been developed to address these issues (GTAP-BIO, EPPA, MIRAGE-bioF, IMAGE, LEITAP, and TERM-BR) (GOLUB *et al.*, 2012; GOLUB; HERTEL, 2012; GURGEL *et al.*, 2007; LABORDE; VALIN, 2012; STEHFEST *et al.*, 2013; FERREIRA FILHO; MORAES, 2015; SILVA *et al.*, 2017).

For this reason the process to integrate land use in BREA framework should be consistent with two requirements: first, the model should retain consistency between the physical land accounting and the economic accounting in the general equilibrium setting; second, the data development should be consistent with the observation as recorded in the CGE database for the base year. Accordingly to Gurgel *et al.* (2017), failure on the first condition would mean that the land supply function could not reproduce consistently the physical accounts, in other words, the land supply function should reproduce the original total of land in physical units after the shock. Failure in the second condition would mean that the base year data would not be in equilibrium and the model would run to other equilibrium state condition consistent with the parameterization, but different from the benchmark condition.

Further adjustments are required to reflect observed behavior in land-use. Empirical evidence on land rental differentials suggests that land does not move freely between alternative uses. Beyond agronomic factors, there are many other considerations that limit land mobility within uses. These includes costs of conversion, managerial inertia, unmeasured benefits from crop rotation, institutional constraints, etc. In the model, such movement is governed by a Constant Elasticity of Transformation (CET) frontier. Thus, within a region in the model, the returns to land in different uses are allowed to differ. The CET function reflects some underlying variation in suitability of land for different uses and/or the cost or willingness of owners to switch land to another use (GURGEL *et al.*, 2017).

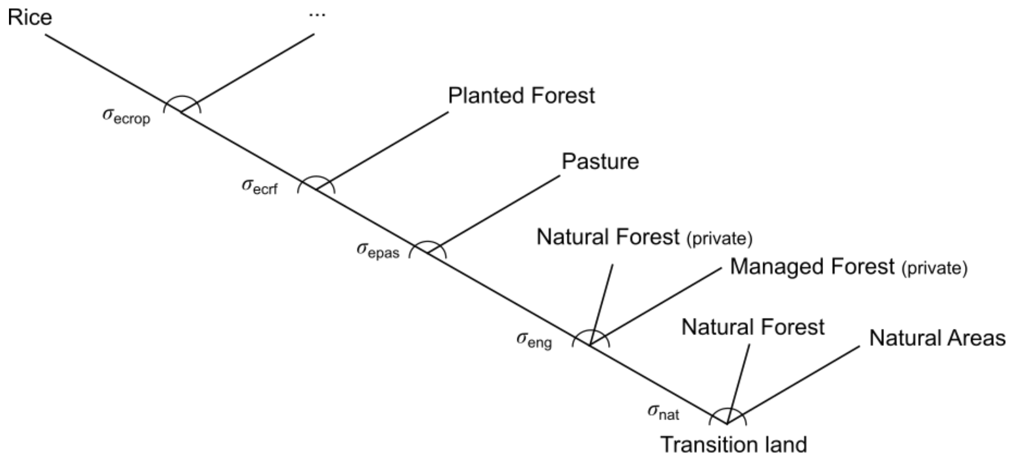

Figure 3.8: Land supply.
Source: own elaboration.

Figure 3.8 shows the nested CET structure for land supply. In this function the rent-maximizing land owner first decides on the allocation of land among natural uses. The land owner decides the allocation of land in natural areas and natural forest (public). Here, the CET structure captures the pressure for deforestation over native vegetation. The land owner then decides on the allocation of land between natural forest (private) and managed forest. Finally, the land owner decides on the allocation of land among pasture, planted forest, and cropland.

The CET parameter governs the ease of land mobility across uses within each region. The parameter in cropland, planted forest, and pasture determines the ease with which land is transformed across three economic uses, e.g., from planted forest to cropland. In the same way, the CET parameter in the cropland nest determines the ease of transformation of land from one cropping activity to another, e.g., from soybean to corn. Table C.3 shows the elasticities in the land use supply.

While the CET function is a popular device in CGE models allowing the calibration with estimated land supply elasticities, it has some limitations. The CET function allows significant differences in returns to land in the same region to persist over time, as shows Fujimori *et al.* (2014). Another important limitation of CET function is that the fundamental constraint in the CET production possibility frontier for land in a given region is not expressed in terms of physical hectares, but rather in terms of land value. This creates a difference between the physical world data and economic model which can pose problems when attempting to relate model results back to the physical environment (GOLUB; HERTEL, 2012).

To keep consistency in land-use changes measured in physical hectares, the BREA model incorporates an adjustment in the land supply. This is done by incorporating an additional constraint into the model that requires physical hectares employed in cropping, pasture, and forestry to add up to total physical area. The model applies an adjustment to the CET aggregator such that it could maintain the equivalence of input and output flows in terms of both value and physical units, respectively (CHEN *et al.*, 2013).

## 3.3 Backstop technologies

The central idea of the backstop technology is an approach for representing adoption in a CGE framework (MORRIS *et al.*, 2014). I seek a simple formulation that can be parameterized based on observations, while capturing elements of rent and real cost increases if demand suddenly increases due to a policy shock. The process is consistent with a general equilibrium framework and applied to the Brazilian Economic Analysis model.

To produce the same outputs as those from current technologies (e.g. pasture land) backstop technologies are usually more expensive to operate in the base year. Because of this, most backstop technologies have not run at commercial scales, have been adopted only marginally by some producers, or have not operated at all so far, but they may become economic in the future pending changes such as economic incentives or policy interventions. The MCP formulation presented in Section 3.1 does not allow any output from a backstop technology if it is not economic to operate.

Some backstop technologies in Table 3.6 have been run at nontrivial scales since 2012 (mostly due to incentives or support provided by the government), including

Table 3.6: Backstop technologies in the BREA model.

| **Backstop technology** | **Output** | **BREA*** |
|---|---|---|
| *Direct system* | | |
| Pasture recovery | Pasture | rec |
| *Crop-livestock-forestry systems* | | |
| Crop-livestock | Maize/Soybean and Cattle | icl (corn); isl (soy) |
| Crop-livestock-forestry | Maize/Soybean, Cattle, and Forestry | iclf (corn); islf (soy) |

* Acronyms used in the model.
Source: own elaboration.

consortium production and crop-livestock systems. BREA model represents the technology for PR considering different regional costs regardless the degradation level of pasture. Moreover, the model explicitly represents two types of integrated production: crop-livestock and crop-livestock-forestry. To the former the output is a combination of grain (maize or soybean) and cattle, while the latter is a combination of grain (maize or soybean), cattle, and forestry.

The calibration process is based on technical and engineering observed data about the costs and the output levels of these technologies (ANUALPEC, 2010; SENAR, 2013). The backstop technology for PR combines the capital-labor bundle, intermediate inputs - mainly chemicals and fertilizers - and degraded pasture land to produce pasture as output (Figure 3.9). This representation permits to aggregate value in land since the farmer could apply new agricultural techniques trough combination of chemicals and fertilizers as well as machinery to improve the pasture productivity. Consequently, the farmer has a better pasture land with higher productivity and value added.

Table 3.7 and Figure 3.9 show how the backstop technologies are connected to the technology representation in the model. The value of land portrays the ratio between the rents of degraded pastures and good pastures. In this fashion way the conversion occurs by one hectare of land each time keeping the equivalence of input and output flows in terms of both value and physical units, respectively.

Furthermore, the markups shown in Table 3.7 portray the regional difference between the calibrated costs for PR and the observed loans data that the farmers took in the ABC program. For example, for South region as a whole the total farmers' loans reach 32.3 times greater than the total cost to recovery the observed area. The model considers only the cost with chemicals and machinery to recover the pasture, however according to the ABC program the farmers could use the loan to build, for example, a fence on the property or on the recovered area, as well as other types of investments. As a result the markup values should be higher to capture these regional differences.

The IS use only pasture as land primary factor. The combination with inter-

Table 3.7: Markups for pasture recovery backstop technologies.

| **Regions** | **South** | **Southeast** | **Center-West** | **North** | **Northeast** | **Northeast Cerrado** |
|---|---|---|---|---|---|---|
| Fertilizers | 0.093 | 0.081 | 0.076 | 0.144 | 0.141 | 0.097 |
| Defensives | 0.056 | 0.049 | 0.046 | 0.087 | 0.085 | 0.058 |
| Chemicals | 0.054 | 0.047 | 0.044 | 0.083 | 0.082 | 0.056 |
| Capital | 0.141 | 0.123 | 0.115 | 0.219 | 0.215 | 0.147 |
| Labor | 0.022 | 0.019 | 0.018 | 0.033 | 0.033 | 0.022 |
| Land | 0.634 | 0.682 | 0.703 | 0.433 | 0.444 | 0.620 |
| Total | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| **Markup** | **32.3** | **49.1** | **78.6** | **61.4** | **63.4** | **120.4** |

Source: based on (ANUALPEC, 2010) and own elaboration.

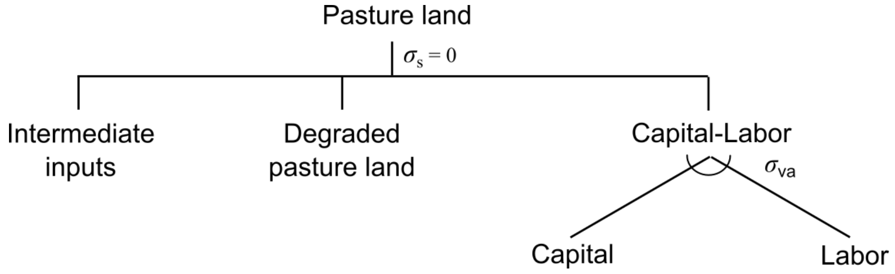

Figure 3.9: Backstop technology for pasture recovery.
Source: research data.

mediate inputs, capital, and labor produces different levels of output such as grain, beef, and forestry (Figures D.3 and D.4).

Equally important, the IS do not have markups to reflect the costs of its economic penetration. Assuring the IS can only use pasture land all the costs of PR are captured in the function shown in Figure 3.9. With this approach the functions representing the IS give the total direct investment to implement these systems. Tables C.5 and C.6 show the cost structures and the output shares of IS, respectively, in the model.

## 3.4 Strategic scenarios

The BREA model described above is calibrated with benchmark data of the Brazilian economy in 2009. I assess the economic impacts ABC Plan actions, such as PR (15 Mha) and IS (4 Mha). I evaluate the impact on land-use changes, regional economic growth, welfare, and agricultural production under different scenarios.

The range of scenarios is chosen to represent quite different approaches to policy implementation. The assessment of the likely results from the *Priority* scenario are evaluated against the *Non-Priority* scenario. The *Combined* scenario assess the costs when the assumption over priority areas for PR is relaxed. Table 3.8 summarizes all the scenarios.

### 3.4.1 Non-priority

I simulate the objective of reducing degraded pasture in 15 Mha and increasing the IS in 4 Mha by 2020. The model applies freely such technologies in different Brazilian regions. I evaluate the impact on land-use changes, sectoral production, consumption, GDP, and welfare.

### 3.4.2 Priority

In the second policy simulation, I simulate the same objective adding a constraint in the new technology adoption. Such technologies are strictly used in priority regions defined by the degraded level of pasture present in the model benchmark and shown in Table 3.3. The technologies for IS are calibrated based on the observed data rather than freely as in the previous scenario. Simulating this combination offers insights into comparing the policy design in terms of costs and effectiveness.

### 3.4.3 Combined

In the third scenario, I combine the non-priority policy for degraded pasture with the increasing of IS based on observed data. I relax the constraint over priority areas. Their combination offers insights about how much could be spend in PR when the constraint is relaxed. It also offers the possibility to explore synergies between two different policy instruments.

Table 3.8: Policy Scenarios.

| Scenario | Description |
|---|---|
| *Non-priority* | ABC Plan commitment in area through 2020: recover 15 Mha of degraded pasture; increase the production of crop-livestock and/or crop-livestock-forestry in 4 Mha. The priority areas are chosen freely as well as the IS. |
| *Priority* | ABC Plan commitment in area through 2020: recover 15 Mha of degraded pasture considering the priority areas based on degradation level of pasture; increase the production of crop-livestock and/or crop-livestock-forestry in 4 Mha based on observed data. |
| *Combined* | ABC Plan commitment in area through 2020. The assumption over priority areas is relaxed. The recovery of 15 Mha is freely and the increase of IS in 4 Mha is based on observed data. |

Source: own elaboration.

### 3.4.4 Shock Procedures

In practice the shock enters into the model via subsidy of the regional governments to the backstop technologies ($eb_r$). It is possible to capture the penetration costs of each action as they become available to farmers. These technologies are calibrated based on observed data, technical reports, and agricultural engineering data to represent all the ABC costs as well as the penetration of the new agricultural practices in the economic system.

I add three constraints in the model solution. One for PR with upper limit to 15 Mha which can be controlled by region according to scenario implementation (3.9). Other two constraints one for each IS, which can be controlled by region (3.10).

$$\sum_r (eb_r \times A_r) = \sum_r A_r^{ABC} \tag{3.9}$$

$$\sum_{bti,r} (eb_{bti,r} \times A_{bti,r}) = \sum_{bti,r} A_{bti,r}^{ABC} \tag{3.10}$$

$$bti = \{icl, isl, islf\} \tag{3.11}$$

where $eb_r$ and $eb_{bti,r}$ are the level of PR and IS backstop technologies, respectively; $A_r$ and $A_{bti,r}$ are the areas calibrated in the backstop technologies and they are equal to 1 ha, since the conversion occurs by one hectare of land each time, or in the case of IS only one hectare of pastureland is used each time; and $A_r^{ABC}$ is the total area to be recovered (15 Mha), and $A_{bti,r}^{ABC}$ is the total area of IS (4 Mha), both exogenous and can be controlled by region according to the scenario simulated.

The subsidy enters in the top level of each $eb_r$ function stimulating the adoption of PR and IS technologies. Also, given the costs similarity between the IS with maize or soybean with forestry component the model only projects area for IS with soybean, otherwise the computational time increases turning the optimization problem unsolvable. The model adjusts endogenously both levels of $eb_r$ and $eb_{bti,r}$ to achieve the desirable areas of PR and IS technologies. In addition, the model projects the economic cost of each technology by the total demand of intermediate inputs underlying each backstop technology.

## 3.5 Macroeconomic closure

The macroeconomic closure concerns an important step in CGE modeling. The model is solved statically three times one for each scenario and after I interpret the results considering several macroeconomic assumptions as: ($i$) the factors' supply are fixed and there is no factor mobility - capital and labor - across regions; (*ii*) land is a sector-specific factor; (*iii*) there is no unemployment and the factors' price are flexible; (*iv*) the investment level is fixed, as well as balance of payments. As a result, changes in the real exchange rate must occur to accommodate export and import adjustments. These assumptions imply a "middle run" model closure where the ABC actions are projected by 2020.

Additionally, the government expenditure could change if price changes and the tax revenue is dependent of the production level and consumption. Land-use changes are projected based on demand and production costs observed considering the adoption of PR and IS technologies to achieve the ABC targets by 2020, i.e., the model might not follow the observed trend of land-use change across Brazilian regions.

Finally and equally important caveat concerns the double cropping representation in the scenario designing. The double cropping representation is inactive under all scenarios. Thus, the model is not capturing the trade-off between intensifying production in the same area (summer soybean and winter crop of maize) to increase food production and agricultural income, and setting aside the cultivated land during winter to recover some of the agronomic properties of the soil.

# Chapter 4

# Results and discussion

In this chapter I extend the discussion to provide the findings of this thesis research. The chapter presents outcomes of the model application with new technologies detail and scenario and policy modeling described in chapter 3. The presentation is organized in three sections: Section 4.1 deals with the land-use changes outcomes both aggregated and by regions, Section 4.2 concerns the regional production changes and the IS production level, Section 4.3 shows the policy costs and macroeconomic results, such as GDP changes and welfare, and finally, Sections 4.4 and 4.4.1 concern the discussion and policy implications, respectively. Within each section, the distinctions between the scenarios are discussed followed by any important differences between the model response across scenarios.

## 4.1 Land-use changes

A better representation of land in a CGE framework allows investigation of its use as an input to economic activities, as well as environmental consequences of using land since the natural areas - forest and non-forest - are represented in the database. The land-use and land-use changes are driven not only by increasing the demand for food, fuel and fiber, and the maintenance of natural environmental, but also by the agricultural aptitude of these areas, as well as the willingness to convert them. Table 4.1 summarizes the key base results, which I discuss in detail below.

Considering PR the regional technology costs are driven by the land rents. The ratio between the rents of degraded pastures and good pastures represents how much economic effort must be applied to recovery these areas. For instance, ratios of 0.70 and 0.44 for Center-West and North regions, respectively, show lower investment to recovery the same quantity of area in Center-West when compare to North (as shown in Table 3.7). IS such as crop-livestock and crop-livestock-forestry only demand good pasture land as sector-specific primary factor, i.e., these systems

Table 4.1: Summary of key base results (all R$ values are in 2009 R$).

| | | **Scenarios** | | |
|---|---|---|---|---|
| **Metric** | **Unit** | **Non-priority** | **Priority** | **Combined** |
| *Land-use changes* | | | | |
| Cropland | 1,000 ha | -664 | -1,381 | -2 |
| Pasture | 1,000 ha | 10,314 | 10,881 | 9,597 |
| Degraded pasture | 1,000 ha | -15,000 | -15,000 | -15,000 |
| Natural forest | 1,000 ha | 485 | 597 | 471 |
| Natural forest (private) | 1,000 ha | 1,323 | 1,456 | 1,260 |
| Managed forest | 1,000 ha | 49 | 229 | 54 |
| Planted forest | 1,000 ha | 507 | 179 | 500 |
| Natural areas | 1,000 ha | 2,987 | 3,039 | 3,120 |
| *Integrated systems* | | | | |
| maize-livestock | 1,000 ha | 1,164 | 461 | 269 |
| soybean-livestock | 1,000 ha | 2,476 | 3,179 | 3,371 |
| soybean-livestock-forestry | 1,000 ha | 360 | 360 | 360 |
| *Policy costs* | | | | |
| Welfare | million R$ | 7,959 | -724 | 8,027 |
| Total pasture recovery | million R$ | 26,626 | 31,288 | 26,685 |
| Recovery per hectare | R$/ha | 1,774 | 2,086 | 1,779 |
| Total integrated systems | million R$ | 5,939 | 7,789 | 7,732 |
| Total ABC Plan | million R$ | 32,565 | 39,077 | 34,417 |
| GDP change | % | -0.963 | -1.185 | -1.110 |

Source: research outcomes.

compete for land with cattle (cttl) and other live animals (ola) sectors. In this case, the farmers are willing to apply these technologies only in high productivity or recovered areas, given the investment volume and the profitability time, specially the case of IS with forest component. Consequently, the IS are not considered a recovery strategy in this research, even though these systems have shown recovery and mitigation potentials (DE MORAES *et al.*, 2014).

The aggregated value of land-use change by category is presented in Figure 4.1 under different scenarios. It shows some insights about the implementation of the ABC Plan in Brazil. Duo to the policy implementation the results of degraded pasture recovered under all scenarios are the same (15 Mha). First, the outcomes show an increase in pasture land around 10 Mha under *Non-priority* and *Priority* scenarios, and a slightly smaller area (9.6 Mha) under *Combined* scenario. Since the land is a sector-specific primary factor its final allocation is dependent of the competition by different uses. It means that not necessarily all 15 Mha of recovered pasture would be converted in pasture land. The pasture area reduces 4.1 Mha, 4.7 Mha, and 5.4 Mha under *Priority*, *Non-priority*, and *Combined* scenarios, respectively. The PR process increases the supply of land with high productivity and reduce the land demand for traditional livestock system. Also, the action directly affects soybean and maize sectors. As a result, more land is available for other uses and sectors.

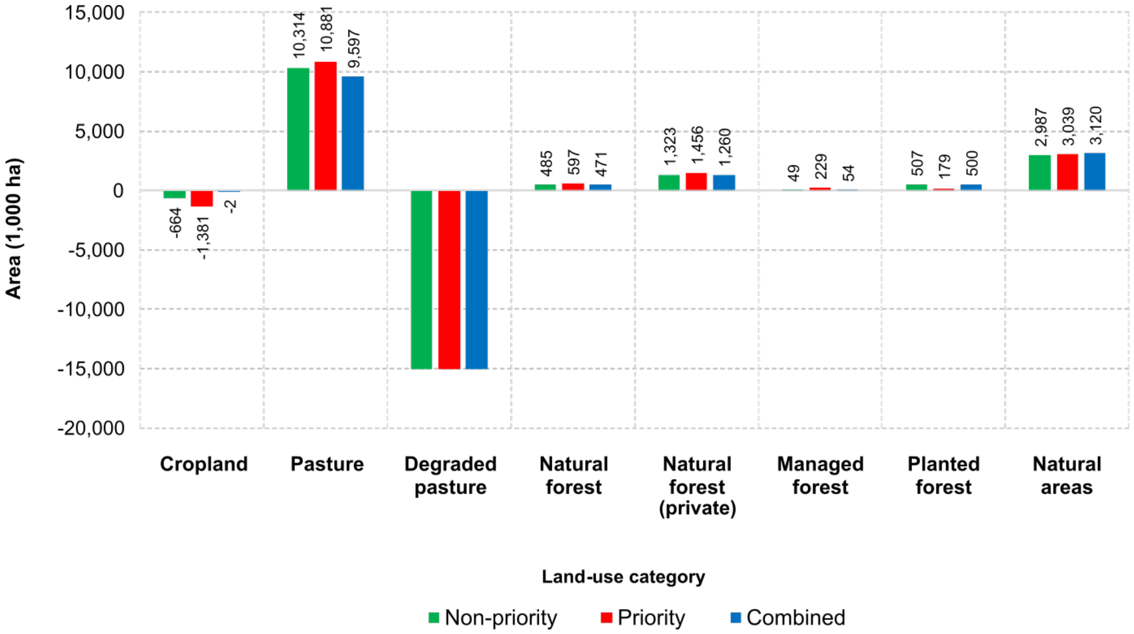

Figure 4.1: Aggregated land-use change under different scenarios.
Source: research outcomes.

Second, the outcomes under all scenarios show an increase around 4.8 Mha in natural and forest areas (public and private), which approximately 38% occurs in forest areas, specially those areas inside the private establishments. Considering managed and planted forest areas together the aggregated outcomes show a small increase by 0.556 Mha and 0.554 Mha under *Non-priority* and *Combined* scenarios, respectively, and 0.408 Mha under *Priority* scenario. These results indicate a lower pressure over natural and forest areas across different scenarios. The growth of areas for managed and planted forest is a consequence of the investments in IS that boost the forestry sector both single and/or integrated production. Also, indicate a synergy between the PR and forest actions to control deforestation and to improve planted forest. As the recovered areas of pasture increase there is more suitable land available for integrated production, and less pressure to clear new natural land.

Third, there is a decrease in cropland use indicating a intensification process across commodities production (grains) despite the regional outcomes. Under *Priority* and *Non-priority* scenarios the value of cropland use decreases 1.4 Mha and 0.664 Mha, respectively. Under *Combined* scenario the change is only 2,000 ha. This result is a consequence of how the scenarios were designed and highlights important synergies between the two actions. Under *Priority* scenario the volume of IS allocated in the South, Center-West, and North regions are greater than the recovered pasture. It implies a strong intensification across different commodities in these regions to accommodate the production of IS. By contrast, the greater volume of recovered pasture in the South and Southeast regions under *Combined* scenario does not guarantee intensification in the production of grains, since increases the areas allocated to traditional sectors, such as rice and fruits in the South, and sugarcane in the Southeast. At regional level both actions should be combined for best results. These results suggest a synergy between the two ABC Plan actions, such as PR and IS with production intensification. As the supply of recovered areas increases, such areas are destined to the production of IS with maize or soybean, livestock and/or forestry. As a result, the single production of soybean and maize demands less land determining the negative change in this land-use category regardless the other crop sectors. Indeed, there are two factors that governs the intensification of production. On the one hand, the livestock sectors demand less land per output and, by other side, soybean and maize are produced in an IS with livestock and/or forest. Also there are indirect environmental externalities, such as less land-use transitions since only pasture land is used both for crops and livestock, as well as control of deforestation, biodiversity conservation, ecosystem services, since reduce the pressure over natural and forest areas.

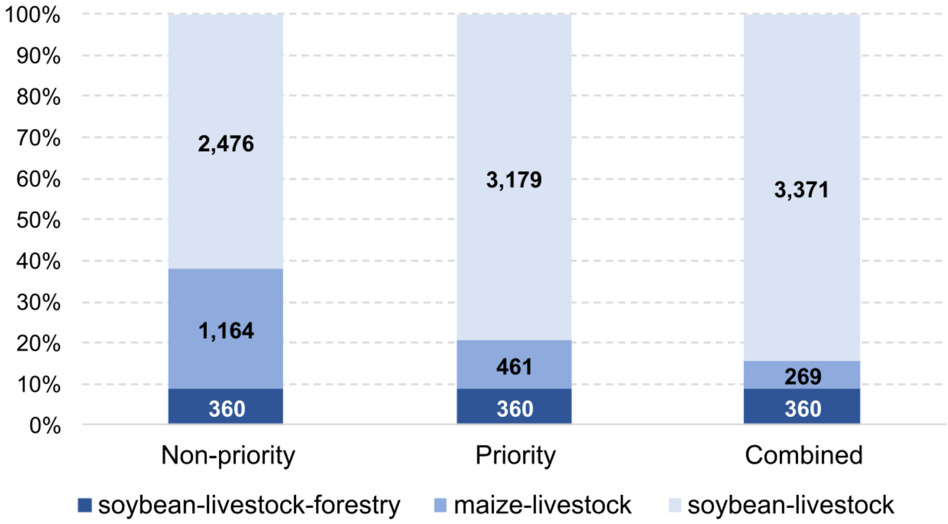

Figure 4.2: Share of total and area of each integrated system under different scenarios (1,000 ha).
Source: research outcomes.

Figure 4.2 shows the areas of IS under different scenarios. As aforementioned, because of solver restrictions the areas of soybean-livestock-forestry integration are the same across scenarios (360,000 ha). Nevertheless, the areas of IS with maize or soybean and livestock represent more than 90% of total observed data. The outcomes for these IS differ across scenarios. The area with maize-livestock fall significantly from 1.2 Mha under *Non-priority* scenario to 461,000 ha and 269,000 ha under *Priority* and *Combined* scenarios, respectively. The addition of a restriction to recover pasture (*Priority* scenario) increases the allocated area with soybean integration. The same occurs under *Combined* scenario. In the base year the total cost per hectare of soybean-livestock integration is, on average, 25% lower than maize-livestock integration. The lower cost and the regional restrictions forced under

*Priority* and *Combined* scenarios increase the soybean area relatively to maize area.

### 4.1.1 Regional land-use changes

Regional outcomes of land-use changes are summarized in Figure 4.3. The results diverges across regions since each regional economic structure responds differently to the policy implementation. At the same time, the regions are connected in the model by regional trade. It suggests if there is an increase/decrease in deforestation in the innovating region in response to higher/lower land productivity, the agricultural and food markets are likely induce "leakage" effects via trade, whereby the innovating region relieves/increases pressures on forests elsewhere.

Under *Non-priority* scenario South and Southeast regions show the largest shares of recovered areas. These regions have lower recovery costs and large areas with degraded pasture which mean more suitability to actions present in the ABC Plan. Also, these regions have an increase in natural and forest areas under all scenarios. Besides reducing the pressure on native vegetation in these regions, the forestry systems appear as a long-term activity as livestock and crops are begin intensified by the ABC Plan actions. Note that the cropland use increases due to increased production in regional traditional activities in these regions such as rice and fruits in the South, and sugarcane in the Southeast. In the South and Southeast regions the process of recover degraded pasture slow the pressure over natural areas and settle area for other agricultural activities, such as crops and planted forest. The same dynamic occurs under *Priority* and *Combined* scenarios.

However, the innovating process promoted by the ABC Plan actions has different outcomes for regions in the agricultural frontier. Center-West and North regions show a decrease in the natural and forests areas, as well as in the forestry systems under all scenarios. The exception occurs in the North with small increase in the natural forest inside private rural establishments. Also, in these regions pasture land increases more than the recovered pasture under all scenarios. The same occurs in the Northeast Cerrado. This outcome is unique when compare to the other regions. North, Center-West, and Northeast Cerrado have the largest shares of pasture land and the livestock ranching is an important economic activity, so the farmers have an incentive even with the ABC actions to increase the pasture land more than the recovered pasture. Regardless the integrated production, these results suggest the maintenance of pasture as the main land use in these regions increasing the pressure on native vegetation. Also, the single livestock production increases in Center-West, North, and Northeast Cerrado regions reinforcing these results.

The land-use changes are less sensible in the Northeast region when compare to other regions in the model. Only under *Priority* scenario the land-use change has

Figure 4.3: Land-use changes by region under different scenarios.
Source: research outcomes.

a strong response to the policy implementation. There is an increase in the cropland use due to increased production of sugarcane. At the same time, the results indicate that forestry systems - managed and planted forests - are not an economic options in this region, given the regional costs, climate conditions, and distance from timber and wood industries. The results show the regional dependency of specific policies for this region, which historically is the poorest region in Brazil. Also, the Caatinga biome represents a challenge to the agricultural development in Brazil, because the region is a seasonally dry tropical forest and consists of dry forest species rather than savanna species.

As shown in Figure 3.1 the Caatinga biome is also a large share of the Northeast Cerrado region. Since the model still does not capture biome agricultural aptitude these areas may be influencing the results of natural and florest areas in this region.

However, the results for this region are extremely important and the ABC actions have different regional outcomes. Actually, in this region the agricultural dynamic occurs in the Cerrado biome. Regardless the consolidate agriculture in the Tocantins (TO) State, the West part of Bahia (BA), and South of Maranhão (MA) and Piauí (PI) States are considered the most important region for land-use change, agriculture and other uses. As mentioned above, the Northeast Cerrado region shows an increase in the pasture land greater than the recovered pasture. At the same time, an increase in the natural and forest areas, and a small increase in the forestry systems. Although the pasture continuing the main land-use in this region, the results indicate a good opportunity for agricultural intensification through IS, and reduce the pressure on natural areas in Cerrado biome.

Figure 4.4 shows the outcomes of land-use by IS and regions. These type of technologies are not active in the benchmark equilibrium, consequently the results show absolute value of area. Looking carefully the regional outcomes are extremely dependent on how the policy scenario is designed and the parameters associated to them.

Under *Non-priority* scenario, which allows the free policy implementation, the Northeast Cerrado region has the largest areas of IS (74%), followed by North region (26%). The large areas of pasture and degraded pasture associated to low prices of intermediate inputs and primary factors attract the available resources for implementing the IS. The restriction added under *Priority* and *Combined* scenarios interrupt the flow of resources towards the Northeast Cerrado region. As a result, the area of IS drops drastically from 2.7 Mha to 145,000 ha. Also, the IS in the North region decrease from 956,000 ha to 899,000 Mha representing around 24.7% of total IS area.

The participation of other regions, such as South, Center-West reaches 41.6% and 27.3% of total IS areas, respectively. The Southeast has only 2.4% of total. These results are strictly correlated to the observed data of IS in Brazilian regions. However, the scenarios simulation shows that the implementation constraint increases the volume of resources allocated to carry out the crop-livestock and crop-livestock-forestry technologies.

The first insight here concerns about the flow of resources to Northeast Cerrado and North regions under *Non-priority* scenario. Indeed, this scenario has the lowest cost for IS implementation around R$ 5.9 billion as shown in Table 4.1. However, the model does not capture the implicit costs to carry out theses technologies, such as land tenure, propriety rights, and infrastructure, specially for transportation, which is extremely important for agricultural production.

Nevertheless, the other two scenarios show that technologies migrate to South,

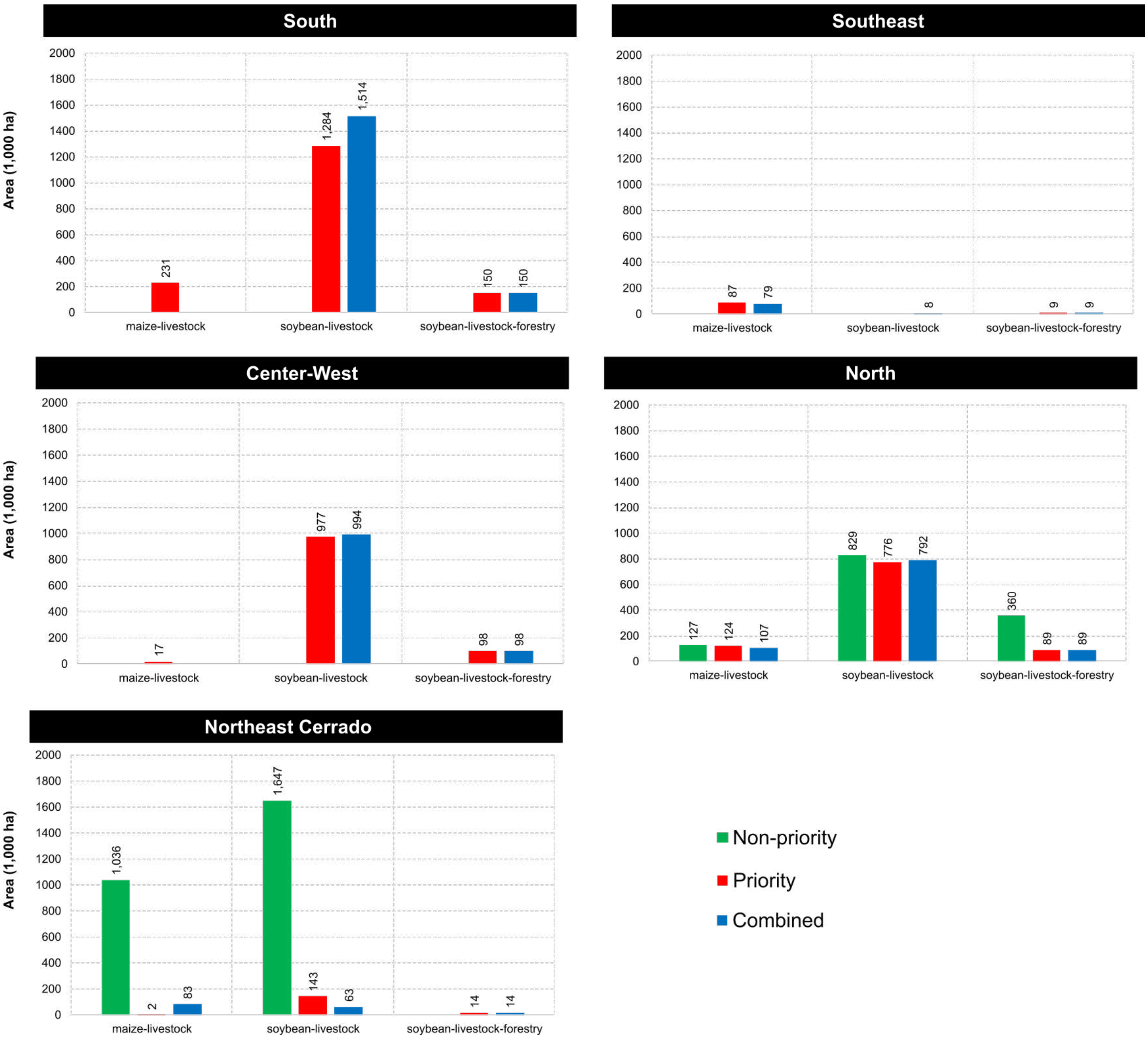

Figure 4.4: Area of each integrated systems by region under different scenarios. Source: research outcomes.

Center-West, and North regions, increasing the IS implementation costs around R$ 7.7 billion. These regions show higher prices for intermediate inputs and primary factors, specially land, which reflect in the policy costs. Also, in regions such as Center-West and Southeast, these new technologies are in competition with traditional agricultural activities, which are technology-intensive with high specialization. It might create barriers to the entry of low-carbon technologies. Further, section 4.3 shows the outcomes correlated to the policy costs.

In the next subsection I show the regional production results for crops and livestock by region. The productivity comparison of single crops and IS demonstrates that the sustainable agriculture evolution in Brazil depends on the low-carbon practices and intensification present in the ABC Plan.

## 4.2 Regional production changes

This subsection concerns the regional production changes by region under different scenarios implemented in the model. In a CGE framework is expected, after a policy simulation, production changes across regions and sectors. The simulation of different actions present in the ABC Plan, such as PR and IS, stimulates specific sectors as intermediate inputs, and production factors. Analyzing all the sectoral outcomes by region and scenarios is somewhat burdensome. Here, I present the insights behind the main results for the agricultural sectors. An important outcome considering regional production is the value of production per hectare. I show below an index comparing the IS production values per hectare with the single production values per hectare. The outcomes for non-agricultural sectors are discussed briefly in the end of this section and shown in Table E.3.

### 4.2.1 Agricultural production

Table 4.2 summarizes the outcomes of production changes for agricultural sectors by regions under different scenarios. As expected, the single production of maize and soybean, which are directly affected by the penetration of the new technologies, have the largest changes among the crops in all regions. The same effect is observed in the cattle sector, the exception occurs in the Center-West and North regions where the single production of cattle increases.

Indeed, as the degraded pasture becomes good pasture land increases the supply of high productivity areas available both for crops and IS. The relative prices also changes, as a result the price of degraded areas is greater than the price of pasture land. Consequently, becomes more expensive keep using degraded pasture and landholders have an incentive to use pasture land. The opportunity costs to use each type of land are reflected in the single production changes.

Equally important, the production values of IS support these outcomes. Table 4.4 shows outcomes for each IS and output, such as maize, soybean, cattle, and forestry. The index compares the production value per ha in each IS with the production value per ha in the benchmark single production. The indexes are greater than one in all technologies. The lowest value is around 1.02 for soybean-livestock integration in the Southeast, and the highest around 1.2 for soybean-livestock-forestry integration in the Northeast Cerrado. These results clearly highlight the productivity gains of IS. In the latter case the production value per ha of IS is 20% greater than single production, and the former around 2%. There are a positive interactions between the crops and livestock increasing the organic matter in the soil. As a result, the productivity gains have the effect of land-saving as presented in the previous subsection and potencially reducing the pressure for opening new natural areas and natural forests (public and private).

It is worth mentioning other important outcomes of the regional production. There is a decrease in the production of other live animals sector, and an increase of production in the cattle sector in the Center-West and North regions. Since both use pasture as land primary factor, the results suggest a shift in favor of cattle production. In the Northeast region the sugarcane activity increases more than 10% under *Priority* scenario; in the Southeast region the sugarcane production also increases (2.6% and 2.8% under *Non-priotiry* and *Combined* scenarios, respectively). These results highlight the regional importance of some crops and livestock in Brazilian regions, such as sugarcane and cattle productions. These sectors keep the competitiveness over the other activities even in a presence of the IS, as a result the spatial distribution of agricultural activities in Brazil remains after the policy intervention.

### 4.2.2 Non-agricultural production

The technology for PR combines the capital-labor bundle, intermediate inputs - mainly chemicals and fertilizers - and degraded pasture land to produce pasture as an output. Equally important, the IS demand good pasture land, i.e., these new systems are in direct competition for land with the traditional livestock sectors.

An expected result is an increase in demand for sectors directly linked to the backstop technologies, such as chemical, defensives, and fertilizers, as well as capital and labor. So, there are spillover effects that can be spatial, since the Brazilian regions respond differently to the ABC policy, and spillover effects that can be sectoral, since the linkages among sectors are more or less intense, e.g., vegetal production and the food industry.

As shown in Table E.3 the policy intervention boost the chemicals sectors to attend the new demands. The growth in these industries is exaggerated and a great extent is a limitation of CGE analysis using a static model. In the benchmark base year the production of chemicals and fertilizers are extremely low in some regions, such as North and Northeast. Given the economic incentive or policy intervention those sectors face a great new demand that boost the value of production. By other side, it suggests that the policy designing should take account measures associated to other industries beyond agricultural sectors to overcome these economic limitations.

Furthermore, all regions increase the demand of fossil energy, such as oil and/or coal, specially Northeast and Northeast Cerrado regions. In the same way, the regions increase the demand of fuel in the refined oil and ethanol sectors. For the meats sector there is a migration of demand to the North and Center-West regions,

Table 4.2: Production changes (%) of agricultural sectors by region under different scenarios.

| Regions | South | | | Southeast | | | Center-West | | | North | | | Northeast | | | Northeast Cerrado | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenarios** | **N-P** | **P** | **C** | **N-P** | **P** | **C** | **N-P** | **P** | **C** | **N-P** | **P** | **C** | **N-P** | **P** | **C** | **N-P** | **P** | **C** |
| **Rice** | 1.7 | 3.3 | 3.2 | 1.4 | 1.8 | 1.1 | -1.7 | 3.2 | -0.2 | 0.9 | 2.9 | -0.3 | -3.2 | -5.0 | -3.6 | -2.8 | -11.6 | -7.5 |
| **Maize** | -0.1 | -11.7 | 2.7 | -2.6 | -7.6 | -6.2 | -4.2 | -5.2 | -1.4 | -46.2 | -44.5 | -38.4 | -5.0 | -2.6 | -3.6 | -81.6 | -2.4 | -9.9 |
| **Sugarcane** | 4.1 | 2.4 | 6.6 | 2.6 | 0.2 | 2.8 | -4.7 | -0.2 | -2.8 | 1.4 | 1.8 | 2.0 | -0.4 | 11.8 | -0.3 | 1.4 | 4.0 | -2.8 |
| **Soybean** | 3.2 | -13.6 | -9.6 | -4.5 | -9.1 | -7.4 | -9.1 | -14.3 | -17.4 | -36.6 | -29.7 | -33.0 | -16.9 | -17.8 | -18.3 | -54.6 | -18.4 | -14.7 |
| **Fruits** | 3.5 | 3.2 | 5.0 | 2.0 | 1.6 | 2.1 | -1.5 | 0.8 | -1.0 | -1.1 | 0.2 | -1.1 | -2.6 | -3.8 | -2.7 | -0.8 | -1.6 | -2.2 |
| **Other cultures** | 7.1 | 4.9 | 9.9 | 4.8 | 1.4 | 4.4 | -5.8 | -1.0 | -5.1 | -5.9 | -3.5 | -6.5 | -2.6 | 1.2 | -3.1 | -3.6 | -4.1 | -7.6 |
| **Forestry** | -1.3 | -6.5 | -5.1 | 7.3 | 2.4 | 8.0 | -7.8 | -8.9 | -12.3 | -25.8 | -8.5 | -12.3 | -5.7 | -2.6 | -5.5 | -0.1 | 1.9 | -2.2 |
| **Cattle** | -25.9 | -10.5 | -34.9 | -18.0 | -3.5 | -19.3 | 9.7 | 1.5 | 7.4 | 3.4 | 0.6 | 3.5 | 12.2 | -10.7 | 12.3 | 6.6 | -8.0 | 13.1 |
| **Other live animals** | 8.2 | -0.9 | 7.8 | 1.2 | -3.1 | 0.8 | -8.0 | -6.6 | -8.1 | -5.7 | -5.4 | -5.5 | -1.1 | 11.8 | -1.2 | 0.3 | 28.2 | 2.2 |

N-P: non-priority; P: priority; C: combined.
Source: research outcomes.

Table 4.3: Indexes of production value per hectare by integrated systems compared to single production (*Combined* scenario).

| **IS technology** | **maize-livestock** | | **soybean-livestock** | | **soybean-livestock-forestry** | | |
|---|---|---|---|---|---|---|---|
| | **maize** | **cattle** | **soybean** | **cattle** | **soybean** | **cattle** | **forestry** |
| **South** | 1.095 | 1.097 | - | - | 1.090 | 1.088 | 1.089 |
| **Southeast** | 1.023 | 1.021 | 1.018 | 1.017 | 1.024 | 1.025 | 1.023 |
| **Center-West** | - | - | 1.041 | 1.039 | 1.016 | 1.015 | 1.015 |
| **North** | 1.074 | 1.080 | 1.085 | 1.087 | 1.056 | 1.057 | 1.056 |
| **Northeast** | - | - | - | - | - | - | - |
| **Northeast Cerrado** | 1.181 | 1.182 | 1.188 | 1.185 | 1.195 | 1.197 | 1.194 |

Source: research outcomes.

since this sector face a significantly decrease in the production value in the South and Southeast regions.

The sector of public services also show significantly decrease in the production value, specially in the South, Northeast and Northeast Cerrado regions. These results are connected to the scenarios implemented. As the subsidy destined for ABC technologies increases, the supply of other public services suffer. On the other hand, the regional government demands decrease to adjust the subsidy levels in the new public budgets, consequently these movements are reflected in the regional GDP changes, as shown in the next section.

## 4.3 Macroeconomic changes and Policy costs

### 4.3.1 Welfare and GDP

To measure the policy costs of different actions present in the ABC Plan, I first compare the total cost PR and IS under different scenarios (Table 4.1). The comparison is the sum of changes in consumer welfare by region, measured as the Hicksian equivalent variation (EV) from economic theory[1]. Welfare loss only occurs under the *Priority* scenario (R$ -724 million), and the welfare gain significantly higher under *Non-priority* and *Combined* scenarios (R$ 7,959 and R$ 8,027 million, respectively).

A better metric to compare the efficiency of PR policy is the welfare changes per hectare of recovered area (Figure 4.5). In this case the reference is 19 Mha (15 Mha of PR and 4 Mha of IS). Comparing different scenarios there is an increase in the final consumption under *Non-priority* and *Combined* scenarios, despite the losses of Northeast and Northeast Cerrado regions. Under *Priority* scenario only Southeast

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[1] Hicksian equivalent variation is the maximum amount the consumers are willing to pay to avoid a price change. In the present context, it is equivalent to increase/decline in household consumption due to pasture recovery and integrated systems policies.

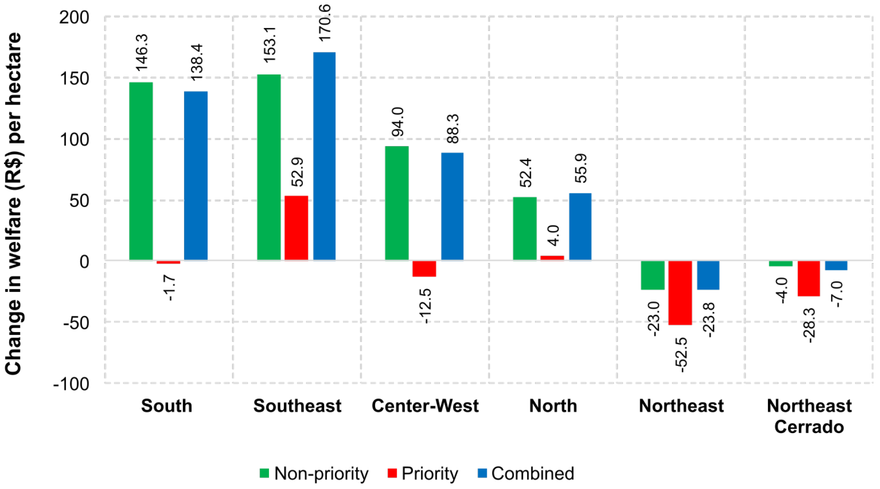

Figure 4.5: Change in consumption per hectare recovered an integrated systems under different scenarios (R$/ha).
Source: research data.

region has an increase in final consumption. This resonates with economic theory's support for the efficiency of economy-wide agricultural policies. Simulating both the *Non-priority* and *Combined* with free movement of resources for pasture recovery results in the migration of investments to more economically dynamic regions. The allocation of investments in priority areas shows welfare losses, consequently reducing the policy efficiency.

The regional GDP outcomes follow the regional changes in welfare. Table 4.4 shows the GDP changes by components under different scenarios. The agricultural policy as a government subsidy for PR makes the fall in public consumption a determining factor for the regional GDP losses. Under *Priority* scenario the losses in North and Northeast Cerrado are significantly higher, -5.05% and -4.87%, respectively. Also, in the same scenario the GDP of Center-West region decline -1.03%. In the South, Southeast, and North regions the outcomes are lower -0.66%, -0.24%, and -0.14%, respectively.

Considering the average of GDP changes, the outcomes for *Non-priority*, *Priority*, and *Combined* scenarios are -1.15%, -2.0%, and -1.4%, respectively. Considering these outcomes and comparing the movement from *Priority* to the other two scenarios is possible to avoid, on average, GDP losses around 43% and 30% under *Non-priority* and *Combined* scenarios, respectively.

The outcomes of GDP changes reinforce those obtained for welfare. The economic and political efforts to apply these policies are greater, since some regions are fragile and vulnerable both to the policy implementation and to the spillover effects. As aforementioned, the Northeast and Northeast Cerrado regions are economic and environmental fragile compare to other regions in the country. In terms of effectiveness the application of the investment in other regions, such as South and Southeast,

Table 4.4: GDP changes (%) by component under different scenarios.

| GDP component | South | Southeast | Center-West | North | Northeast | Northeast Cerrado |
|---|---|---|---|---|---|---|
| *Non-priority* | | | | | | |
| **C** | 0.79 | 0.28 | 1.26 | 1.00 | -0.25 | -0.05 |
| **G** | -12.67 | -5.22 | -1.61 | -4.71 | -4.98 | -8.24 |
| **I** | 0 | 0 | 0 | 0 | 0 | 0 |
| **X** | 1.44 | 0.74 | -1.89 | -1.25 | 0.49 | -1.57 |
| **M** | 0.83 | 0.11 | -0.16 | 0.91 | 0.11 | 1.59 |
| **GDP** | **-1.45** | **-0.68** | **-0.27** | **-0.89** | **-1.52** | **-2.06** |
| *Priority* | | | | | | |
| **C** | -0.01 | 0.10 | -0.17 | 0.08 | -0.57 | -0.32 |
| **G** | -3.99 | -1.89 | -2.14 | -0.59 | -17.17 | -22.09 |
| **I** | 0 | 0 | 0 | 0 | 0 | 0 |
| **X** | 0.58 | 0.37 | -0.16 | 0.08 | 3.90 | 3.85 |
| **M** | 0.76 | 0.17 | 0.97 | 0.58 | 2.59 | 2.93 |
| **GDP** | **-0.66** | **-0.24** | **-1.03** | **-0.14** | **-5.05** | **-4.87** |
| *Combined* | | | | | | |
| **C** | 0.75 | 0.31 | 1.18 | 1.06 | -0.26 | -0.08 |
| **G** | -13.14 | -5.34 | -3.42 | -6.15 | -5.32 | -9.62 |
| **I** | 0 | 0 | 0 | 0 | 0 | 0 |
| **X** | 1.39 | 0.77 | -1.93 | -0.98 | 0.56 | 0.52 |
| **M** | 1.32 | 0.15 | 0.98 | 1.00 | 0.17 | 0.86 |
| **GDP** | **-1.62** | **-0.68** | **-1.13** | **-1.18** | **-1.62** | **-2.15** |

Source: research outcomes.
**C**: consumption; **G**: government expense; **I**: investment; **X**: export; **M**: import.

achieves better results. However, around 29% of the IS loans are allocated in the Norh and Northeast Cerrado (24% and 5%, respectively). Indeed, the model is suggesting that there are several barriers to expand this policy across different regions, such as land tenure, propriety rights, climate risks affecting investments, scarcity of labour, financial constraints, access to technical extension services, etc.

Additionally, the GDP change outcomes are extremely sensible to the calibration data in the benchmark. The cost data of PR per ha present in the credit database (BACEN, 2017) are extremely higher compare to the calibrated costs in the model, which are based on ANUALPEC (2010). These caveat has a severe impact over the markups for PR technology functions shown in Table 3.7, which in turn increase the regional costs for PR as well as the GDP changes outcomes.

### 4.3.2 Policy costs

In order to measure the policy costs I seek to identify the total monetary value invested to carry out the PR as well as the IS under different scenarios. As a result, the total value spent on intermediate inputs and primary factors gives the total volume of resources invested in each technology. The land rents are not considered as cost measures to apply these technologies. Considering this caveat, the approach is more feasible, since the farmers take the loans available in the ABC Program to purchase inputs, machinery, as well as hire labor force to apply these agricultural practices.

The key outcomes for policy costs are shown in Table 4.1. Under *Non-priority* and *Combined* scenarios the total cost of PR is almost the same, around R$ 26.6 billion, reaching R$ 1,774 and R$ 1,738 per hectare, respectively. However, under the *Priority* scenario the total cost is 17% higher reaching R$ 31.2 billion, which R$ 2,086 per hectare. Also, Table E.1 shows the outcomes disaggregated by different technologies. The values of PR portray the largest shares of costs in all regions exception in Center-West under *Priority* scenario.

Regarding the total IS cost the lowest value reaches R$ 5.9 billion under the *Non-priority* scenario. The total costs under other scenarios are around R$ 7.7 billion. The technology of soybean-livestock portray higher cost compare to the maize-livestock integration.

The total cost of the ABC plan according to the modeling reaches R$ 32.5 billion and R$ 34.4 billion under *Non-priority* and *Combined* scenarios. The value increases to R$ 39 billion under the *Priority* scenario. Considering only the economic aspects, these values are significantly lower to that estimated (around R$ 37 billion for PR and R$ 57 billion for the IS) by the policy makers in the development of the ABC Plan (MAPA, 2012). Also, regarding the values of benefited projects in the

ABC Plan since 2010 reach around R$ 13 billion. This value is far behind those determined by the model. It means that a higher effort should be done to boost the recovered areas in Brazil until 2020. Otherwise, the voluntary commitment for PR and IS may not be achieve.

## 4.4 Discussion

Within this study I analyze the economic effects of two technologies, such as PR and IS in the livestock, soybean, and maize sectors and related repercussions on land-use changes, GDP, and sectoral productions. The implementation of such a policy is assumed along three scenarios: free movement of investments to apply the PR and IS technologies, investment constraint in the priority areas defined by the level of degraded pasture in each region and IS observed data, and a combination of both scenarios. In addition, I provide a complementary analysis by comparing the production values per ha in the IS and single crops.

An important consideration is to treat both technologies as agricultural intensification technologies, consequently land-sparing technologies. Land-sparing concept is based on aggregate increases in agricultural yields over time can reduce the overall area of agriculture lands from what would have been needed without the increase in yields (COHN *et al.*, 2011). On possible way of land-sparing is the use of degraded land which is the case of pasture with low productivity in Brazil. On the other hand, the intensification generally refers to changes in agricultural production practices that lead to more agricultural outputs per area of land input. Such a shift can come from the introduction of new technologies or varieties of crops, and resource management practices. (BYERLEE *et al.*, 2014).

The land-use changes results show a land sparing process at National level as shown in Section 4.1. The PR process increases the supply of high productivity land, as a result farmers have an incentive to intensify the production. The IS emerge as a great opportunity to be implemented in those areas. The IS allow double or triple production in the same area - crop and livestock or crop, livestock and forestry - compared to single production systems. As a mitigation strategy the IS increase carbon stock in the soil and reduce the CH4 and N2O emissions, and as adaptation strategy increase fertility and organic matter in the soil. This favors the biomass production allowing higher stocking rates in pasture and productivity in crops, as well as reducing the pressure to expand agricultural area. The results show a productivity gain up to 20% compared to single production. It implies in a high economic return and soil conversation over the long run with a increased system's total productivity. Additionally, at National level the intensification process reduces the pressure over natural areas and natural forests. This synergistic response of both actions is indicated in the literature (Sá *et al.*, 2017) and confirmed using a CGE model that explicitly represents their implementation. These results show that the agriculture is in the center of the solutions of the global climate changes and advance food security. The agricultural intensification and environmental preservation to achieve a sustainable production of beef and grains are dependent of IS' implementation and diffusion.

Even though the ABC Plan defines these technologies as a mitigation technologies, the results evidence that the PR associated to the IS acts sparing land and increasing the productivity. The land-sparing process due to livestock intensification is well know in the literature. There are evidences from different pathways for this process, such as cropland intensification reducing deforestation (MACEDO *et al.*, 2012), investments in agricultural R&D to increase the technological level in the livestock sector (GOUVELLO, 2010; STEVENSON *et al.*, 2013; VILLORIA, 2017), tax and subsidy policies directly in livestock sector promoting incentives to a semi-intensive production (COHN *et al.*, 2014), and improvements in pasture and herd productivities (STRASSBURG *et al.*, 2014; SILVA *et al.*, 2017). One main conclusion in all of this literature is that new agricultural practices and investments in agricultural R&D slow down deforestation rates in the presence of increasing demand for agricultural goods.

A very detail comparison between models is compromised given different approaches and methods. The relative magnitude of CGE models responses varies widely across models, reflecting differences in model structure, land supply function, and parameterization. At the same time, it is important to highlight that Cohn *et al.* (2014) show that policy-driven intensification within pasture-based cattle production systems could reduce the pasture area by 16-21 Mha, and 15-17 Mha of forest could spared from deforestation. Also, Silva *et al.* (2017) show that an increase in the total factor productivity due to policy-driven intensification could reduce the pasture area around 13 Mha keeping the forest and natural areas constant, as well as could increase the cropland use by 8 Mha. The results here show a decrease in pasture area around 5 Mha, and an increase by 4.8 Mha in forest and natural areas, as well as a decrease in cropland area up to 1.4 Mha. Such differences are due to model closure, investment dynamic, and time horizon between models. This research contributes to the literature showing that technology-driven intensification could reduce the area allocated to cropland use differently from previous works. Equally important, the Brazilian regions, specially those in the agriculture frontier respond in a different way compared to those regions with more stable land use.

Center-West and North regions responds to the policy increasing the area allocated to pasture. Although the outcomes are suggesting an economic specialization in these regions, there are several other issues concern the livestock intensification, such as the maintenance of pressure on forest and natural areas, high levels of GHG emissions from cattle, and policy effectiveness. In the Northeast Cerrado region the results might be underestimated given the natural areas of Caatinga biome which are unsuitable for agriculture. Therefore, the results show that there is a limit for livestock intensification as a land-sparing strategy at regional level, differently that proposed by Strassburg *et al.* (2014) which the intensification could be spread in whole country. These outcomes can be mitigated by moving from a pasture-based to IS, consequently reducing the land occupation in the current system (GERSSEN-GONDELACH *et al.*, 2017; COHN *et al.*, 2014)

Other important concern in this type of policy is the "rebound effect", which is the response of economic agents to new technologies and practices that lower production costs and output prices (HERRERO *et al.*, 2016). As shown in Tables E.4, E.5, and E.6 the effect of lower prices given the technology adoption, specially in the food sector, is not sufficient to increase the demand and off-set the policy results. This result is according to previous studies (COHN *et al.*, 2014; SILVA *et al.*, 2017; STEVANOVIĆ *et al.*, 2017).

I address attention here to the agricultural and non-agricultural production changes and their "leakage" via regional trade. The results shown in Section 4.2 suggest a specialization in grain production in the South and Southeast regions, since the cropland use increase in these regions. On the other hand, in the Center-West, North, and Northeast Cerrado regions the results suggest a specialization in livestock production, since the pasture area increases more than recovered pasture. These movements across regions directly increase the production of chemicals, fertilizers, defensives, which in turn increase the demand of fossil fuels, since these industries are energy-intensive. Such sectoral spillovers evidence a trade-off between mitigation technologies focus on environmental outcomes and economic growth promoted by energy-intensive and fossil-energy industries. The new level of production in these sectors directly impact the intensity of GHG emissions in energy sector and it might off-set the mitigation potential in the agriculture and livestock sectors. It is an important policy implication that I discuss in the next subsection.

### 4.4.1 Policy implications

The concept of the ABC Policy is based on a paradigm change in the Brazilian agriculture. This movement represents a shift in the pattern of agricultural production in the country. High specialized farmers, whether in livestock or grains (soybean or maize), now need to adopt new technologies that diversify agricultural production and maximize environmental benefits. A complete policy assessment needs to take into account the costs and the benefits, winners and losers. In this way, this research contributes to the ABC Policy debate identifying these costs and benefits, as well as the economic leakages.

In terms of total costs, the model projects R$ 36-39 billion, which R$ 26.6-31.2 billion for PR, and R$ 5.9-7.7 billion for IS technologies. The greatest expenses would occur under *Priority* scenario. In this scenario the definition of priority areas is based on the level of degraded pasture measured by the occupation rate. Thus, the areas to be recovered are not necessarily the areas with the greatest potential for economic return, which are the case of Northeast and Northeast Cerrado regions with large presence of Caatinga biome. This result confirms the previous study which discuss the major risks, barriers, and economic return of priority areas based only on the level of degraded pasture (ABC, 2017a).

The GDP and welfare results show that there is an economic leakage in direction of other regions such as South, Southeast, and Center-West regions, i.e., the ABC Plan as an agro-environmental policy increases the regional disparity in Brazil. The income flow migrates to these regions increasing the consumption per hectare in detriment of Northeast and Northeast Cerrado regions. It is an important result and shows that the policy design in Brazil should consider the intrinsic characteristics of each region.

Other concern since the beginning of ABC Plan was the low uptake of loans even with subsidized interest rates (ANGELO, 2012). Several studies try to identify these socio-economic barriers to explain this result (GIL *et al.*, 2015; ABC, 2017b; LATAWIEC *et al.*, 2017). According to these studies such barriers are: the implementation of IS requires technical and economic expertise and other types of unattained knowledge (DE MORAES *et al.*, 2014); lack of qualify labour, high financial costs and credit access (LATAWIEC *et al.*, 2017); the absence of small-scale business models that could be used on small-scale farmers (GIL *et al.*, 2015); concern the banking procedures, such as bank's bureaucracy, problems with documentation, specially technical project, and short grace period (LATAWIEC *et al.*, 2017). On the other hand, there is positive relationship between the access to the credit provided by ABC Program and environmental outcomes. According to Oliveira Silva *et al.* (2017) access to ABC credit reduces emissions intensity by around 20% when compared to the same pasture management practice, assuming that producers risk investing their own capital to optimally manage pastures in the scenario without ABC credit.

The Caatinga biome presents great challenges for the development of Brazilian agriculture and livestock raising, which are reinforced by climate change. Regions such as Northeast and Northeast Cerrado deserves special treatment by all stakeholders and policy markers. The policy should be developed together with modern compensation mechanisms for the most economically fragile. Regardless income transfers from socioeconomic programs, other instruments should be used to compensate the income changes in the short-run.

Such mechanisms might be based on investments to increase the information and knowledge about the benefits provided by ecosystems, and areas with good management. Improvements in the credit access by reducing the bank's bureaucracy, as well as complex technical projects. At the same time, reinforce command and control policies designed for propriety rights and land tenure to reduce the land speculation, where cattle ranching is a means to secure land. In the long-run such mechanisms might increase the productive capacity in these regions by the absorption of new technologies, as well as new value-chain structure. Also, it might increase the resilience to climate change and economic fluctuations.

Finally, it is clearly that the definition of priority areas is one of the central issues about the ABC Plan. It is the starting point for several socio-economic leakages concerning this agro-environmental policy. Investments in IS, especially those with forestry component, should be apply in areas with timber and wood industries to absorb the forestry production, otherwise the expenses in ABC program continue to generate a lower economic return to Brazil as a whole. This is only one example, beyond other presented above. Governments, stakeholders, and policy makers should be clear that the agricultural policies play an important role in the implementation of such strategies, and by providing subsidies for the adoption of new technologies, investing in R&D, and creating suitable market conditions could enhance the ABC Plan outcomes.

# Chapter 5

# Conclusions

In the preceding chapters, I have laid out the complexities arising from the interaction of agro-environmental policy with country specific challenges faced by the policymakers in Brazil. To address the dual challenges of maintaining economic growth while limiting agricultural area expansion, deforestation, and GHG emissions, Brazil's climate commitments to the COP-15 include both economy-wide and sector specific policies. Analyzing the impact of these policies on land-use changes, consumer welfare, regional production, and GDP, the interests of different stakeholder groups can help adjust policies to improve their efficiency in achieving desired outcomes.

I have explored theoretical arguments for addressing climate change when considered with and without political economy constraints as well as the synergies and trade-offs of mitigation and adaptation options. Recognizing the importance of the economic evaluation of an agro-environmental policy, such as the ABC Plan economic and environmental aspects of pasture recovery and integrated systems applied to agriculture have been discussed.

To analyze the efficiency and economic impacts of Brazil's agro-environmental policy within the theoretical framework of mitigation and adaptation, I have employed a CGE model of the Brazilian economy with detailed representation of the agricultural sectors and several land-use categories. The design of the model and the research questions are based both on theory as well as qualitative inputs on policy preferences and possibilities. In particular, I have endeavored to analyze how sector specific agro-environmental policy on a variety of parameters in achieving desired levels of pasture recovery and integrated systems.

The modeling results provide important quantitative insights and help identify stakeholders that stand to benefit or lose, along with the extent of impact on them. Comparing the outcomes of the ABC policy simulated under different scenarios, I have found that the investments applied in the priority areas defined by the level of degraded pasture result in the highest decline in consumer welfare. Further, regional GDP changes indicate that the ABC policy increase the disparity among Brazilian regions. It means that there are several barriers to maximize the outcomes across different regions. The redefinition of priority areas based on economic aspects beyond the degraded level and mitigation potential is crucial to achieve better policy results. Also, improvements in the credit access by reducing the bank's bureaucracy, as well as complex technical projects. I have found that a policy without the indication of priority areas is more effectiveness and less expense per recovered hectare.

Under different simulated scenarios I have endeavored to analyze the land-use changes by regions. Both simulations, with priority areas or not, have shown that the PR associated to the IS technologies are land-sparing technologies. As the productivity of recovered areas increase settle area for new production systems, such as IS. IS technologies have presented a great opportunity for livestock intensification as well as reduce the pressure to clear new natural areas and forest areas in Brazil. In fact, the model projects an increase of natural forest inside the rural establishments indicating a growth in the agricultural income. Despite the regional costs of implementing each IS the integration with soybean has shown economic advantages across regions, specially without priority policy.

Nevertheless, I also have found that the farmers in the agricultural frontier, as in the Center-West and North regions, have an incentive to increase the pasture area given the ABC policy. It is an important result for the literature concerning agriculture intensification and land-sparing, since show that there is a limitation in how much land could be spare given the production intensification. As a result, the knowledge that agricultural intensification could be spread in Brazil as a whole is not confirmed in my research.

At regional land-use level the outcomes have suggested a agricultural specialization. It is the case of livestock production in the Center-West and North regions, rice in the South, and sugarcane in the Southeast and Northeast regions. Such specialization promoted by the ABC policy increases the demand over chemicals, defensives, and fertilizers sectors, as well as the demand of fossil energy, such as oil and/or coal. This result indicates a trade-off between mitigation technologies focus on environmental outcomes and sectoral economic growth. It suggests to different stakeholders groups more attention should be done to the policy designing. Policies should have take account different measures associated to other industries beyond agricultural sectors to overcome a possible off-set in the ABC actions mitigation potential. Also, a previously assessment of sector-specific policies should be done, specially for the energy sector, both electricity and fossil-energy.

Finally, the model has projected the total cost around R$ 39 billion, which R$

7.8 billion for IS in the *Priority* scenario. Without the identification of priority areas the total costs has reached around R$ 34 billion. These values are significantly lower compared to those projected in the original text of ABC Plan (around R$ 37 billion for PR and R$ 57 billion for IS). The actual adoption level of resources present in the ABC Program is also lower compared to the value projected by the model. By the end of 2015/2016 crop-year the volume of credit taken by farmers reached R$ 13.8 billion, including all actions present in ABC Plan and not only PR and IS. These expenditures represent only 16% of the total amount foreseen in the original text of the ABC Plan to be used for PR and IS. Regarding the results of this research, the total expenses of the ABC Program observed until the end of 2015/2016 crop-year represent between 35-40% of the value projected by the model, which in turn simulates only expenses in PR and IS. The conclusion is that if the adoption of ABC Program continues in a lower rate the goals of ABC Plan until 2020 will not be met.

This research scratch the surface of this complex issue, but these contributions can hopefully still have a positive impact. Even though, there are still countless open questions to be investigated, plenty of unresolved issues, and plenty of work still to be done on the topics of agricultural technologies for livestock intensification and climate change. There are other ABC actions that must be analyzed, such as no-till technology, nitrogen biological fixation, as well as animal waste treatment. All of these technologies have a higher mitigation potential, however there are not concrete answers concerning all the environmental and economics costs and benefits of such actions. Other issues concerning data's quality need attention, such as a correct and complete assessment of how much is the reduction potential of GHG emissions for each technology, a better track on land-use change emissions, as well as improvement in the quality of IS costs data and rural credit data must be done. CGE models are an important tools to answer all these issues, and a full integration of Economic system and Earth system will provide a complete assessment of this policy. A CGE static model is an important limitation. Even though a static CGE model allows a policy analysis isolating exogenous effects, such as economic growth, demand and/or preference changes, productivity gains, a better treatment of capital accumulation and investment using a dynamic CGE model might overcome the GDP losses in the long-run.

# Appendix A

# Welfare discussion

The welfare metric has presented above only considers the household consumption level. Looking carefully the welfare and GDP results shown in Figure 4.5 and Table 4.4, respectively, it is possible to identify a positive relationship between welfare and the consumption change. In this case, a positive change in household consumption leads a positive result in welfare and so on. These results are consequence of how the adoption of PR and IS technologies are implemented in BREA model.

I have assumed that the government finances the adoption of PR and IS technologies, i.e, each regional government is willingness to increase the public deficit to finance the regional innovation on agricultural sectors. As a result, the government faces a trade-off between its consumption and technology development. In fact, as presented in Table 4.4 the regional governments have a significantly losses in their consumption, specially in the Northeast and Northeast Cerrado regions. These regions have higher costs for PR compare to the other regions, such as South and Southeast.

The welfare metric in the core of BREA model is defined by the following expression:

```
* Welfare changes
ev("ch_%",r) = round(100*[c.l(r) - 1],3);
ev("ch_$",r) = round(vpm(r)*[c.l(r) - 1],3);
```

where `ch_%` portrays the percentage change in welfare; `ch_$` the value change in million R$; `c.l(r)` is the household consumption level after the policy implementation; and `vpm(r)` is the regional household consumption in the benchmark equilibrium.

A different approach is to hold the level of regional government consumption constant. In this case, there is no public deficit to finance PR and IS technologies and all policy costs are paid by households. The trade-off between consumption and technology adoption is now transfered to the households.

In practice, the PR and IS implementation in the BREA model is the same, i.e., the regional governments subsidy the technology adoption in each region. However, I add a *lump-sum* transfer directly from households to government keeping constant the level of public consumption. Only a few lines in the MPSGE code are changed to allow this *lump-sum* transfer. An auxiliary variable `tau(r)` governs these transfers. Additionally, there is a small change in the household and government demand blocks. In the former, the auxiliary variable `tau(r)` multiplies `vpm(r)` and `pc(r)` transferring resources to the latter keeping constant the level of government consumption (`g(r)`).

```
$auxiliary:
tau(r) ! Lumpsum replacement tax rate

$demand:hh(r)
e:pc(r) q:(-vpm(r)) r:tau(r)

$demand:govt(r)
e:pc(r) q:vpm(r) r:tau(r)

$constraint:tau(r)
g(r) =e= 1;
```

Following, I only present the welfare, GDP, and land use change results under the *Government neutral* assumption. Table A.1 shows a comparison between welfare results in the original projection and the Government neutral assumption. The welfare results are sensible to the household consumption level and under this assumption the households face a trade-off between private consumption and the adoption of new technologies. As a result, the welfare outcomes change for all regions under all scenarios.

Regions with the highest adoption rate of PR and IS technologies have a significant welfare loss. This is the case of South and Southeast regions under *Non-priority* and *Combined* scenarios, and Northeast and Northeast Cerrado under *Priority* scenario. These results imply a new level of aggregate welfare different from the original results. Under *Non-priority* scenario the total welfare changes from a positive value of R$ 7.9 billion to a loss of R$ 29.9 billion. The same occurs under *Combined* scenario, which changes from R$ 8 billion to a loss of R$ 34.8 billion. The *Priority* scenario still has the highest level of welfare loss (R$ 37.2 billion).

Table A.2 shows the decomposition of GDP results under the government neutral assumption. There are changes in values of private consumption compared

Table A.1: Comparison between welfare results.

| **Welfare** | **South** | **Southeast** | **Center-West** | **North** | **Northeast** | **Northeast Cerrado** | **Brazil** |
|---|---|---|---|---|---|---|---|
| *Non-priority* | | | | | | | |
| **%** | 0.79 | 0.28 | 1.26 | 1.00 | -0.25 | -0.05 | |
| **Million R$** | 2,779 | 2,910 | 1,786 | 995 | -436 | -76 | 7,959 |
| *Priority* | | | | | | | |
| **%** | -0.01 | 0.10 | -0.17 | 0.08 | -0.57 | -0.32 | |
| **Million R$** | -32 | 1,005 | -238 | 76 | -997 | -538 | -724 |
| *Combined* | | | | | | | |
| **%** | 0.75 | 0.31 | 1.18 | 1.06 | -0.26 | -0.08 | |
| **Million R$** | 2,629 | 3,242 | 1,678 | 1,063 | -452 | -133 | 8,027 |
| *Non-priority (Government neutral)* | | | | | | | |
| **%** | -2.29 | -1.15 | -0.50 | -1.19 | -2.04 | -2.69 | |
| **Million R$** | -8,040 | -11,978 | -709 | -1,187 | -3,552 | -4,473 | -29,938 |
| *Priority (Government neutral)* | | | | | | | |
| **%** | -1.15 | -0.48 | -2.72 | -0.49 | -7.13 | -6.86 | |
| **Million R$** | -4,043 | -5,002 | -3,864 | -490 | -12,441 | -11,422 | -37,262 |
| *Combined (Government neutral)* | | | | | | | |
| **%** | -2.52 | -1.16 | -2.51 | -1.53 | -2.23 | -2.93 | |
| **Million R$** | -8,870 | -12,158 | -3,556 | -1,528 | -3893 | -4,877 | -34,882 |

Source: research outcomes.

to the original results. Actually, the *lump-sum* transfers force a decrease in the private consumption to finance the public deficit keeping constant the government consumption. This new assumption has a weak impact on the GDP change results, i.e., there are transfers of policy costs from government to the households and the significant changes are on the private consumption, and the final GDP changes are close to the original projections.

Finally, Tables A.3 and A.4 show the land-use changes results for Brazil and by regions under all scenarios, respectively. At aggregate level (Brazil) the results keep the same direction, except the cropland use. There is an increase by 41,000 hectares instead a previous decrease by 2,000 hectares. At regional level, there are few changes on land-use values only under *Priority* scenario. It is the case of South region for *managed forest* use; North region for *natural forest* and *natural areas*; and Northeast Cerrado for *cropland* use, which is the largest change around 61,000 hectares.

Under the government neutral assumption welfare results have changed for all regions. The initial assumption concerning regional government would be willing to increase the public deficit to finance the PR and IS technologies adoption could mislead the welfare outcomes. However, when the government faces the trade-off between consumption and finance the technologies is possible to identify the regions most benefited by the ABC Plan, which are the case of South, Southeast, and Center-West regions. At the same time, other important result concerns the land-use change. Under a different assumption the results do not change to the point of modifying the intensification trajectory promoted by PR and IS technologies.

Table A.2: Decomposition of GDP results under model projection (left) and government neutral assumption (right).

| **GDP components** | **South** | **Southeast** | **Center-West** | **North** | **Northeast** | **Northeast Cerrado** | **South** | **Southeast** | **Center-West** | **North** | **Northeast** | **Northeast Cerrado** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Non-priority* | | | | | | | *Non-priority (Government neutral)* | | | | | |
| **C** | 0.79 | 0.28 | 1.26 | 1.00 | -0.25 | -0.05 | -2.29 | -1.15 | -0.50 | -1.19 | -2.04 | -2.69 |
| **G** | -12.67 | -5.22 | -1.61 | -4.71 | -4.98 | -8.24 | -0.47 | -0.26 | 0.17 | 0.61 | -0.37 | 0.78 |
| **I** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **X** | 1.44 | 0.74 | -1.89 | -1.25 | 0.49 | -1.57 | -0.13 | 0.32 | -1.88 | -0.96 | -1.16 | -3.85 |
| **M** | 0.83 | 0.11 | -0.16 | 0.91 | 0.11 | 1.59 | -0.38 | -0.35 | -0.74 | -0.09 | -0.78 | 0.54 |
| **GDP** | **-1.45** | **-0.68** | **-0.27** | **-0.89** | **-1.52** | **-2.06** | **-1.54** | **-0.70** | **-0.23** | **-0.61** | **-1.34** | **-1.91** |
| *Priority* | | | | | | | *Priority (Government neutral)* | | | | | |
| **C** | -0.01 | 0.10 | -0.17 | 0.08 | -0.57 | -0.32 | -1.15 | -0.48 | -2.72 | -0.49 | -7.13 | -6.86 |
| **G** | -3.99 | -1.89 | -2.14 | -0.59 | -17.17 | -22.09 | 0.21 | -0.01 | 0.61 | 0.55 | -0.70 | -0.37 |
| **I** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **X** | 0.58 | 0.37 | -0.16 | 0.08 | 3.90 | 3.85 | 0.32 | 0.42 | -0.60 | 0.93 | -3.45 | -2.50 |
| **M** | 0.76 | 0.17 | 0.97 | 0.58 | 2.59 | 2.93 | 0.34 | 0.01 | 0.00 | 0.46 | -1.01 | 0.02 |
| **GDP** | **-0.66** | **-0.24** | **-1.03** | **-0.14** | **-5.05** | **-4.87** | **-0.71** | **-0.24** | **-0.93** | **-0.02** | **-4.56** | **-4.67** |
| *Combined* | | | | | | | *Combined (Government neutral)* | | | | | |
| **C** | 0.75 | 0.31 | 1.18 | 1.06 | -0.26 | -0.08 | -2.52 | -1.16 | -2.51 | -1.53 | -2.23 | -2.93 |
| **G** | -13.14 | -5.34 | -3.42 | -6.15 | -5.32 | -9.62 | -0.21 | -0.25 | 0.71 | 0.41 | -0.39 | -0.02 |
| **I** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **X** | 1.39 | 0.77 | -1.93 | -0.98 | 0.56 | 0.52 | -0.27 | 0.35 | -2.72 | -0.91 | -1.26 | -1.71 |
| **M** | 1.32 | 0.15 | 0.98 | 1.00 | 0.17 | 0.86 | 0.03 | -0.33 | -0.35 | -0.12 | -0.79 | -0.38 |
| **GDP** | **-1.62** | **-0.68** | **-1.13** | **-1.18** | **-1.62** | **-2.15** | **-1.72** | **-0.71** | **-0.95** | **-0.83** | **-1.46** | **-1.99** |

Source: research results.

**C**: consumption; **G**: government expenses; **I**: investment; **X**: exports; **M**: imports.

Table A.3: Land-use change for Brazil under different scenarios (1,000 ha).

| **Brazil** | **Original results** | | | **Government neutral** | | |
|---|---|---|---|---|---|---|
| ***Land use*** | **N-P** | **P** | **C** | **N-P** | **P** | **C** |
| *Cropland* | -664 | -1,381 | -2 | -698 | -1,322 | 41 |
| *Pasture* | 10,314 | 10,881 | 9,597 | 10,122 | 10,610 | 9,331 |
| *Degraded pasture* | -15,000 | -15,000 | -15,000 | -15,000 | -15,000 | -15,000 |
| *Natural forest* | 485 | 597 | 471 | 513 | 676 | 575 |
| *Natural forest priv.* | 1,323 | 1,456 | 1,260 | 1,360 | 1,499 | 1,338 |
| *Managed forest* | 49 | 229 | 54 | 59 | 249 | 47 |
| *Planted forest* | 507 | 179 | 500 | 499 | 152 | 474 |
| *Natural areas* | 2,987 | 3,039 | 3,120 | 3,145 | 3,136 | 3,194 |

Source: research outcomes.
**N-P**: non-priority; **P**: priority; **C**: combined.

Table A.4: Regional land-use change under different scenarios (1,000 ha).

| **Regions** | **Original results** | | | **Government neutral** | | |
|---|---|---|---|---|---|---|
| ***Land use*** | **N-P** | **P** | **C** | **N-P** | **P** | **C** |
| **South** | | | | | | |
| *Cropland* | 1,904 | -263 | 1,374 | 1,954 | -262 | 1,425 |
| *Pasture* | 614 | 1,477 | 1,128 | 602 | 1,473 | 1,118 |
| *Degraded pasture* | -3,722 | -1,755 | -3,951 | -3,727 | -1,755 | -3,955 |
| *Natural forest* | 10 | 5 | 13 | 10 | 6 | 13 |
| *Natural forest priv.* | 304 | 164 | 384 | 302 | 173 | 383 |
| *Managed forest* | 34 | 2 | 32 | 30 | -1 | 27 |
| *Planted forest* | 136 | -5 | 119 | 114 | -22 | 90 |
| *Natural areas* | 720 | 373 | 902 | 715 | 388 | 901 |
| **Southeast** | | | | | | |
| *Cropland* | 1,081 | 241 | 1,047 | 1,052 | 225 | 1,023 |
| *Pasture* | 1,104 | 1,232 | 1,083 | 1,092 | 1,205 | 1,062 |
| *Degraded pasture* | -5,102 | -2,610 | -5,188 | -5,117 | -2,610 | -5,212 |
| *Natural forest* | 301 | 117 | 314 | 307 | 123 | 321 |
| *Natural forest priv.* | 293 | 121 | 307 | 301 | 130 | 317 |
| *Managed forest* | 118 | 45 | 126 | 120 | 43 | 127 |
| *Planted forest* | 411 | 160 | 441 | 418 | 154 | 447 |
| *Natural areas* | 1,793 | 695 | 1,870 | 1,827 | 731 | 1,915 |
| **Center-West** | | | | | | |
| *Cropland* | -853 | -965 | -1,372 | -778 | -901 | -1,340 |
| *Pasture* | 2,080 | 1,445 | 2,550 | 1,900 | 1,327 | 2,514 |
| *Degraded pasture* | -815 | -390 | -830 | -835 | -390 | -827 |
| *Natural forest* | -82 | -16 | -66 | -55 | -3 | -64 |
| *Natural forest priv.* | -29 | 30 | 1 | -8 | 42 | 4 |
| *Managed forest* | -33 | -30 | -47 | -33 | -32 | -50 |
| *Planted forest* | -37 | -32 | -52 | -37 | -35 | -56 |
| *Natural areas* | -230 | -44 | -184 | -154 | -8 | -181 |
| **North** | | | | | | |
| *Cropland* | -829 | -660 | -740 | -755 | -694 | -736 |
| *Pasture* | 2,031 | 1,193 | 1,818 | 1,965 | 1,148 | 1,683 |
| *Degraded pasture* | -1,214 | -570 | -1,242 | -1,193 | -570 | -1,264 |
| *Natural forest* | 48 | -15 | 74 | 21 | 36 | 163 |
| *Natural forest priv.* | 166 | 105 | 165 | 145 | 141 | 222 |
| *Managed forest* | -142 | -40 | -59 | -128 | -48 | -58 |
| *Planted forest* | -63 | -12 | -21 | -57 | -16 | -20 |
| *Natural areas* | 3 | -1 | 5 | 1 | 2 | 10 |
| **Northeast** | | | | | | |
| *Cropland* | 43 | 318 | 52 | 27 | 304 | 40 |
| *Pasture* | 643 | 1,905 | 679 | 627 | 1,907 | 675 |
| *Degraded pasture* | -997 | -3,525 | -1,066 | -965 | -3,525 | -1,059 |
| *Natural forest* | 8 | 34 | 8 | 8 | 33 | 9 |
| *Natural forest priv.* | 126 | 372 | 135 | 131 | 383 | 143 |
| *Managed forest* | -13 | 84 | -9 | -16 | 101 | -12 |
| *Planted forest* | 0 | 0 | 0 | 0 | 1 | 0 |
| *Natural areas* | 190 | 811 | 201 | 188 | 796 | 205 |
| **Northeast Cerrado** | | | | | | |
| *Cropland* | -2,009 | -54 | -364 | -2,199 | 7 | -370 |
| *Pasture* | 3,841 | 3,628 | 2,338 | 3,937 | 3,549 | 2,279 |
| *Degraded pasture* | -3,150 | -6,150 | -2,722 | -3,163 | -6,150 | -2,682 |
| *Natural forest* | 200 | 472 | 128 | 222 | 481 | 134 |
| *Natural forest priv.* | 462 | 663 | 269 | 489 | 629 | 269 |
| *Managed forest* | 86 | 168 | 11 | 86 | 186 | 14 |
| *Planted forest* | 59 | 66 | 13 | 61 | 70 | 14 |
| *Natural areas* | 511 | 1,206 | 326 | 567 | 1,227 | 343 |

Source: research outcomes.
**N-P**: non-priority; **P**: priority; **C**: combined.

# Appendix B

# Double cropping

Double cropping means planting several crops in the same area and crop-year. In Brazilian agriculture it is a common practice in cultures of maize, peanut, potato, and bean. In some regions, such as Southeast and Northeast Cerrado, potato and bean have area of a third crop in the same crop-year. However, the most important for double cropping in the country is the one related to maize production. The activity to plant summer soybean (rainy season) with a winter crop of maize has become well established in some regions - South (Paraná State) and Center-West - over the last ten years and is therefore a key driver in the expansion of maize production.

There are two main determinants for such dynamic: the no-till practice for soybean production decreased the time between the harvest of summer soybean and the sowing of maize. The second technical progress which made it much easier to directly plant maize after soybean is herbicide resistance varieties. As there is no time to control weeds before seeding, it can be done in the maize crop rather easily (WILDEGGER; BALIEIRO, 2015).

Double cropping increases the utilization of farm's primary factors - land, machinery, labor, and equipment - improving also agronomical conditions due to the implementation of more crops in the rotation avoiding soybean after soybean, and enables no-till by keeping the soil covered throughout the year. Nevertheless, double cropping is not widespread throughout Brazil since the productivity is greatly affected by rainfall and limitations of solar radiation and temperature at the final stage of the cycle.

In the past 30 crop-years (1985/86-2015/16) the annual growth rate of planted area of maize's second crop was 11%, reaching in 2015/16 around 10.5 Mha. At the same time, the first crop was -2.8%, reaching in the same crop-year 5.3 Mha. The same pattern occurs in the volume of production, 15.7% and 0.9%, for second and first crops, respectively. The growth of maize's second crop follows the trend in the soybean production. For the same period the soybean's annual growth rates were 4.2% and 6.8% for area and volume of production, respectively. Figure B.1 shows the growth of planted area in Brazil.

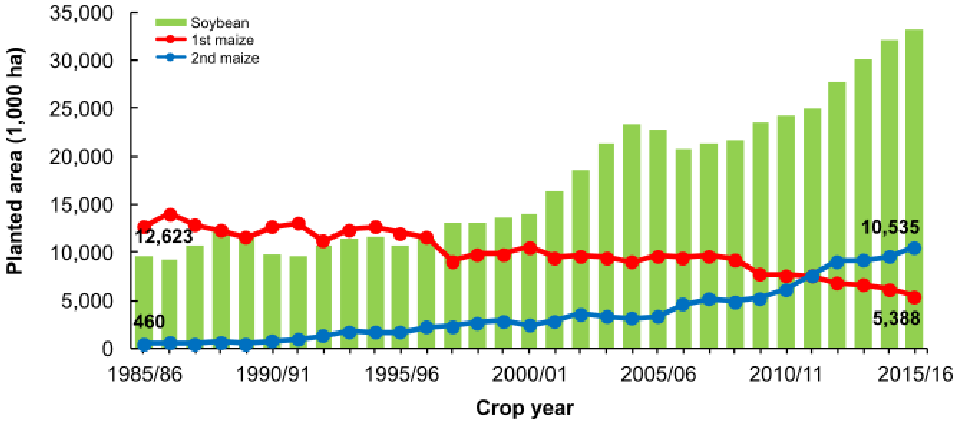

Figure B.1: Planted area of maize - $1^{st}$ and $2^{nd}$ crops - and soybean in Brazil. Source: (CONAB, 2016) adapted by author.

Table B.1 shows the double cropping total planted area. I aggregate the double crop areas of peanut, potato, and bean in the other cultures sector (ocul). The double crop of these cultures are not explicitly represented in the model. BREA model explicitly represents the double cropping of maize production where the purpose is twofold: first, introduce this novelty in CGE modeling of land use and increase the capability of the model to represent the dynamics of the Brazilian agriculture, and second, represents the connection between the two cultures, but not their substitution since the production take place in the same area. Aforementioned the second crop of maize has increased considerably in the past 30 years, and has potential to increase more since the climate conditions permit.

Table B.1: Double cropping planted area of maize and other cultures calibrated in the BREA model.

| **Regions** | **Maize** (1,000 ha) | | | **Other cultures*** (1,000 ha) | | | |
|---|---|---|---|---|---|---|---|
| | **Total** | **$1^{st}$ crop** | **$2^{nd}$ crop** | **Total** | **$1^{st}$ crop** | **$2^{nd}$ crop** | **$3^{th}$ crop** |
| **South** | 3,928 | 2,029 | 1,899 | 737 | 395 | 336 | 5 |
| **Southeast** | 2,132 | 1,597 | 534 | 693 | 377 | 196 | 120 |
| **Center-West** | 5,460 | 392 | 5,068 | 347 | 78 | 183 | 86 |
| **North** | 1,381 | 302 | 1,079 | 136 | 46 | 86 | 4 |
| **Northeast** | 1,036 | 695 | 341 | 828 | 605 | 223 | 0 |
| **Northeast Cerrado** | 1,905 | 1,381 | 523 | 936 | 540 | 393 | 3 |
| **Total** | **15,842** | **6,397** | **9,445** | **3,677** | **2,042** | **1,416** | **219** |

Source: PAM survey (IBGE, 2016a).
* Peanut, potato, and bean.

When this representation is active the technology of soybean production has a slightly change in comparison to previously presented. The soybean's land endowment increases by the value of maize's second crop. This value is also an output in the soybean production system. The objective here is represent some dependency of the area allocated to maize and soybean production, while maintaining the zero profit condition in the soybean sector. The elasticity of transformation ($\sigma_t = 0$) ensures non-substitution between soybean's production value and maize's area, keeping the consistency in area. On the other hand, the elasticity of substitution ($\sigma_{fx} = 0.3$) between land and energy-materials bundle captures the expansion/contraction of maize's second crop, i.e., if the soybean's area expands the available area for second crop of maize also expands. Figure B.2 panel (a) shows this representation. In panel (b) the maize's land endowment is now divided in two different values: the first and second crops. The value of second crop comes exactly from the output of soybean production system.

In order to represent the potential growth of land for double cropping, i.e., the expansion of maize area over soybean area, I determine the potential growth in maize area based on historical data for the six regions in the model. For example, in South region the potential growth is 30% over soybean area as shown in Table C.4. The difference between the observed area of maize's second crop and the potential area to expand is the fallow area. The fallow area could be converted to maize area or could be fallow area for winter season. To represent such dynamic a CET function controls the supply of total double cropping area, i.e., the sum of soybean, maize's second crop and fallow areas. Panel (c) in Figure B.2 shows how the total area is converted to fallow area and double cropping area. Also the fallow area could be converted directly to maize area through a backstop technology.

The fallow area enters in the household utility function as a consumption good in the same way as the natural areas and the natural forest. It means that the society values the environmental benefit coming from leaving some soybean area setting aside after summer harvesting. Household decide the final destination of these areas, i.e., the trade-off to keep the natural and fallow areas or convert them to agricultural use. With this approach the BREA model has a satisfactory representation of double cropping since the area destined to second crop of maize could increase when the soybean area expands. At the same time, the maize area could expand over the actual area as represented by a nested CES function. Equally important, there is no risk of considering some substitution between areas of soybean and second crop of maize, as both take place in the same area. Finally, it captures the trade-off between intensifying production in the same area to increase food production and agricultural income, and setting aside the cultivated land during winter to recover some of the agronomic properties of the soil.

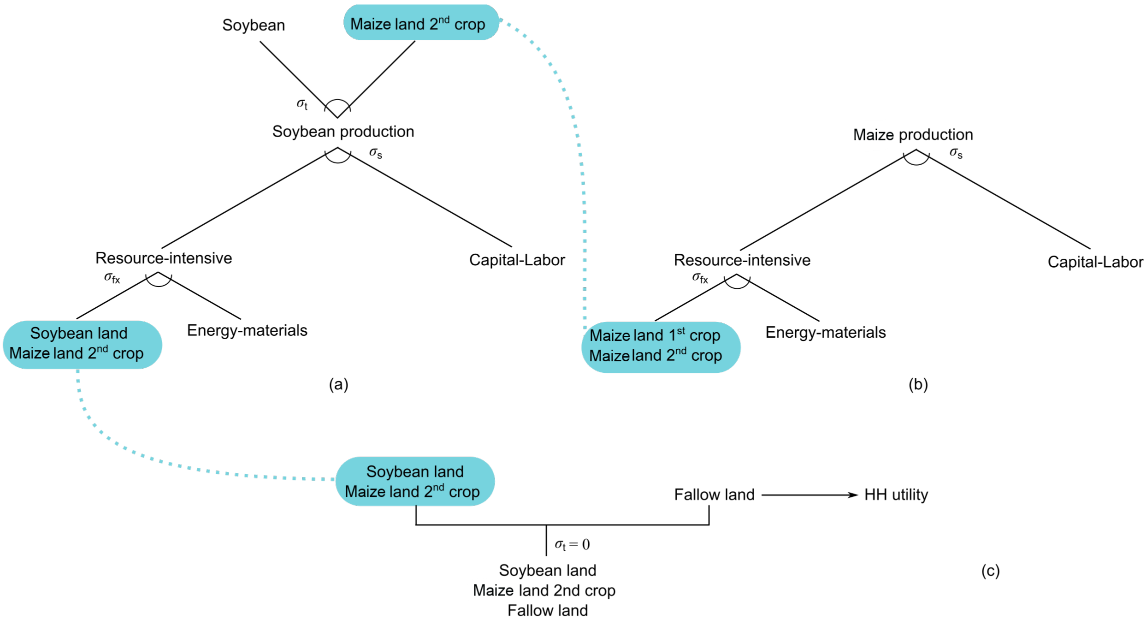

Figure B.2: Double cropping representation in the BREA model.
Source: own elaboration.

# Appendix C

# Elasticities and parameters

Table C.1: Elasticities calibrated in the BREA model.

| **Sectors** | *esubd* | *esubdr* | *esubva* | *esubm* |
|---|---|---|---|---|
| **Rice** | 3.771 | 7.541 | 0.469 | 5.725 |
| **Maize** | 1.283 | 2.566 | 0.238 | 2.555 |
| **Sugarcane** | 2.700 | 5.400 | 0.264 | 5.400 |
| **Soybean** | 2.974 | 5.948 | 0.521 | 5.959 |
| **Fruits** | 1.850 | 3.700 | 0.264 | 3.700 |
| **Other cultures** | 2.965 | 5.931 | 0.264 | 6.118 |
| **Forestry** | 2.500 | 5.000 | 0.200 | 5.000 |
| **Cattle** | 2.000 | 4.000 | 0.264 | 4.000 |
| **Other live animals** | 1.283 | 2.566 | 0.238 | 2.555 |
| **Swine** | 1.283 | 2.566 | 0.238 | 2.555 |
| **Poultry** | 1.283 | 2.566 | 0.238 | 2.555 |
| **Milk** | 3.650 | 7.300 | 0.699 | 7.300 |
| **Oil** | 5.200 | 10.400 | 0.200 | 10.400 |
| **Gas** | 17.200 | 34.400 | 0.200 | 34.400 |
| **Mineral iron** | 2.145 | 4.291 | 0.787 | 3.071 |
| **Coal** | 3.050 | 6.100 | 0.200 | 6.100 |
| **Mineral extraction** | 2.145 | 4.291 | 0.787 | 3.071 |
| **Meats** | 4.140 | 8.281 | 1.120 | 8.360 |
| **Soybean oil** | 3.552 | 7.103 | 1.260 | 7.340 |
| **Foods** | 1.753 | 3.505 | 1.120 | 3.644 |
| **Wood and textile** | 3.634 | 7.267 | 1.260 | 7.297 |
| **Refined oil** | 2.100 | 4.200 | 1.260 | 4.200 |
| **Ethanol** | 5.200 | 10.400 | 0.200 | 10.400 |
| **Chemicals** | 3.300 | 6.600 | 1.260 | 6.600 |
| **Fertilizers** | 3.552 | 7.103 | 1.260 | 7.340 |
| **Defensives** | 3.552 | 7.103 | 1.260 | 7.340 |
| **Steel non-metallic** | 3.541 | 7.083 | 1.260 | 7.378 |
| **Machines** | 4.050 | 8.100 | 1.260 | 8.100 |
| **Other industry** | 3.552 | 7.103 | 1.260 | 7.340 |
| **Electricity** | 2.800 | 5.600 | 1.260 | 5.600 |
| **Pipe gas** | 2.800 | 5.600 | 1.260 | 5.600 |
| **Water** | 2.800 | 5.600 | 1.260 | 5.600 |
| **Public services** | 1.900 | 3.800 | 1.260 | 3.800 |
| **Construction** | 1.900 | 3.800 | 1.400 | 3.800 |
| **Services** | 1.900 | 3.800 | 1.381 | 3.800 |
| **Transportation** | 1.900 | 3.800 | 1.680 | 3.800 |

Source: based on GTAP9 database.

Table C.2: Land values of natural forest and natural areas (2009 million R$).

| Regions | Natural forest | Natural forest (private) | Natural areas |
|---|---|---|---|
| **South** | 2.34 | 54.71 | 159.21 |
| **Southeast** | 172.71 | 121.25 | 444.05 |
| **Center-West** | 59.30 | 30.23 | 190.56 |
| **North** | 690.87 | 188.38 | 21.48 |
| **Northeast** | 1.03 | 6.97 | 136.02 |
| **Northeast Cerrado** | 357.51 | 260.78 | 205.08 |

Source: own elaboration.

Table C.3: Elasticities for the land supply function.

| Regions | $\sigma_{nat}$ | $\sigma_{ng}$ | $\sigma_{epas}$ | $\sigma_{ecrf}$ | $\sigma_{ecrop}$ |
|---|---|---|---|---|---|
| **South** | 0.20 | 0.35 | 0.50 | 0.75 | 1.00 |
| **Southeast** | 0.20 | 0.35 | 0.50 | 0.75 | 1.00 |
| **Center-West** | 0.20 | 0.35 | 0.50 | 0.75 | 1.00 |
| **North** | 0.20 | 0.35 | 0.50 | 0.75 | 1.00 |
| **Northeast** | 0.20 | 0.35 | 0.50 | 0.75 | 1.00 |
| **Northeast Cerrado** | 0.20 | 0.35 | 0.50 | 0.75 | 1.00 |

Source: own elaboration.
$\sigma_{nat}$: substitution between
$\sigma_{ng}$: substitution between
$\sigma_{epas}$: substitution between
$\sigma_{ecrf}$: substitution between
$\sigma_{ecrop}$: substitution between

Table C.4: Percentage change (%) for double cropping expansion under different assumptions (op1 and op2).

| Regions | op1 | op2 |
|---|---|---|
| **South** | 30 | 22 |
| **Southeast** | 42 | 30 |
| **Center-West** | 60 | 45 |
| **North** | 55 | 40 |
| **Northeast** | 33 | 20 |
| **Northeast Cerrado** | 30 | 21 |

Source: based on (CONAB, 2016).

Table C.5: Cost structure for integrated system backstop technologies.

| **Regions** | **South** | **Southeast** | **Center-West** | **North** | **Northeast** | **Northeast Cerrado** |
|---|---|---|---|---|---|---|
| *Integrated maize-livestock system* | | | | | | |
| Fertilizers | 0.324 | 0.325 | 0.338 | 0.334 | - | 0.327 |
| Defensives | 0.278 | 0.279 | 0.290 | 0.287 | - | 0.281 |
| Chemicals | 0.153 | 0.153 | 0.159 | 0.158 | - | 0.154 |
| Capital | 0.077 | 0.077 | 0.080 | 0.079 | - | 0.078 |
| Labor | 0.121 | 0.121 | 0.126 | 0.124 | - | 0.122 |
| Pasture | 0.048 | 0.046 | 0.007 | 0.017 | - | 0.038 |
| *Integrated maize-livestock-forestry system* | | | | | | |
| Fertilizers | 0.330 | 0.329 | 0.338 | 0.336 | - | 0.332 |
| Defensives | 0.283 | 0.282 | 0.290 | 0.289 | - | 0.285 |
| Chemicals | 0.156 | 0.155 | 0.159 | 0.159 | - | 0.156 |
| Capital | 0.078 | 0.078 | 0.080 | 0.080 | - | 0.079 |
| Labor | 0.123 | 0.122 | 0.126 | 0.125 | - | 0.123 |
| Pasture | 0.030 | 0.034 | 0.006 | 0.011 | - | 0.025 |
| *Integrated soybean-livestock system* | | | | | | |
| Fertilizers | 0.283 | 0.289 | 0.296 | 0.294 | - | 0.297 |
| Defensives | 0.367 | 0.375 | 0.384 | 0.381 | - | 0.385 |
| Chemicals | 0.069 | 0.070 | 0.072 | 0.071 | - | 0.072 |
| Capital | 0.014 | 0.015 | 0.015 | 0.015 | - | 0.015 |
| Labor | 0.199 | 0.203 | 0.208 | 0.206 | - | 0.209 |
| Pasture | 0.068 | 0.049 | 0.026 | 0.032 | - | 0.022 |
| *Integrated soybean-livestock-forestry system* | | | | | | |
| Fertilizers | 0.293 | 0.293 | 0.298 | 0.299 | - | 0.298 |
| Defensives | 0.379 | 0.380 | 0.386 | 0.387 | - | 0.387 |
| Chemicals | 0.071 | 0.071 | 0.072 | 0.072 | - | 0.072 |
| Capital | 0.015 | 0.015 | 0.015 | 0.015 | - | 0.015 |
| Labor | 0.205 | 0.206 | 0.209 | 0.210 | - | 0.210 |
| Pasture | 0.037 | 0.035 | 0.020 | 0.017 | - | 0.017 |

Source: based on (SENAR, 2013) and own elaboration.

Table C.6: Output shares for backstop technologies in the model.

| **Regions** | **South** | **Southeast** | **Center-West** | **North** | **Northeast** | **Northeast Cerrado** |
|---|---|---|---|---|---|---|
| *Pasture recovery* | | | | | | |
| Pasture | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| *Integrated maize-livestock system* | | | | | | |
| Maize | 0.752 | 0.754 | 0.949 | 0.905 | - | 0.788 |
| Cattle | 0.248 | 0.246 | 0.051 | 0.095 | - | 0.212 |
| *Integrated soybean-livestock system* | | | | | | |
| Soybean | 0.646 | 0.739 | 0.799 | 0.820 | - | 0.877 |
| Cattle | 0.354 | 0.261 | 0.201 | 0.180 | - | 0.123 |
| *Integrated maize-livestock-forestry system* | | | | | | |
| Maize | 0.471 | 0.550 | 0.875 | 0.607 | - | 0.529 |
| Forestry | 0.374 | 0.270 | 0.078 | 0.330 | - | 0.329 |
| Cattle | 0.156 | 0.180 | 0.047 | 0.063 | - | 0.142 |
| *Integrated soybean-livestock-forestry system* | | | | | | |
| Soybean | 0.350 | 0.531 | 0.600 | 0.424 | - | 0.682 |
| Forestry | 0.459 | 0.281 | 0.249 | 0.483 | - | 0.222 |
| Cattle | 0.191 | 0.188 | 0.151 | 0.093 | - | 0.096 |

Source: based on (SENAR, 2013) and own elaboration.

# Appendix D

# Other technological structures

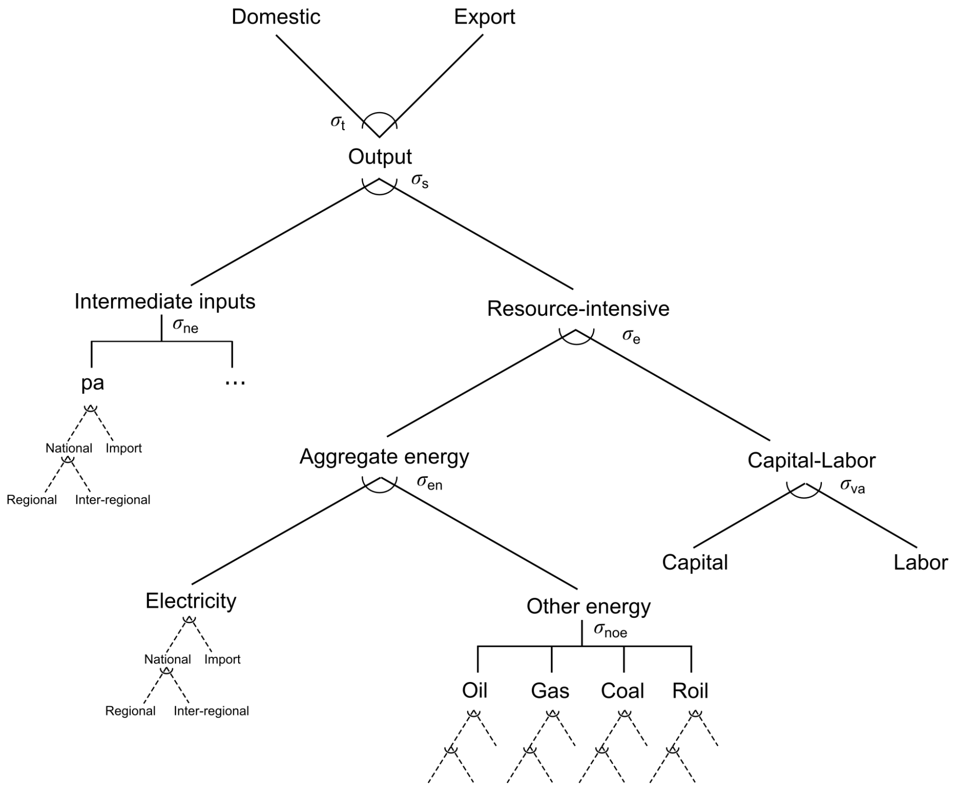

Figure D.1: Structure of Production Sectors: Oil, Coal, Roil, and Gas sectors.

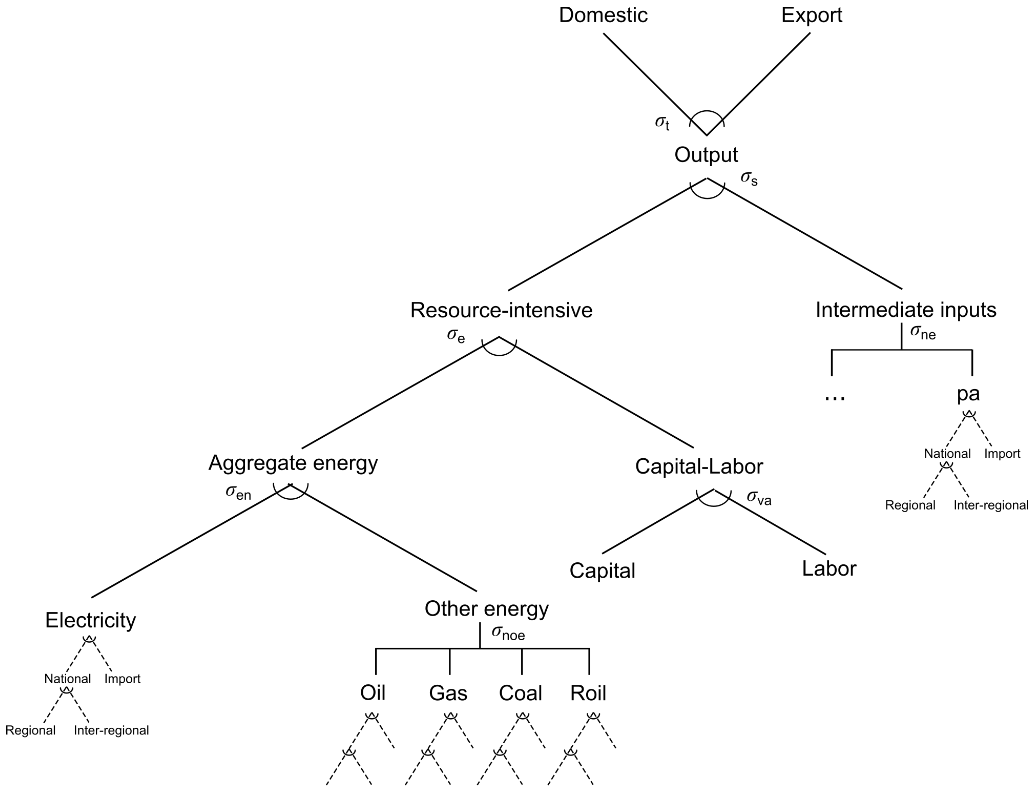

Figure D.2: Structure of Production Sectors: non-agricultural-energy sectors.

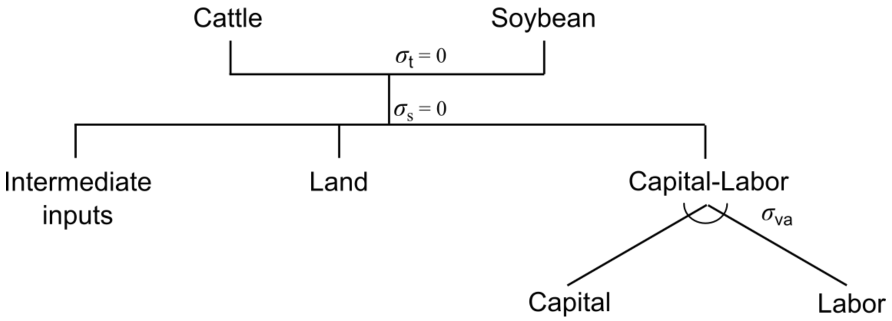

Figure D.3: Backstop technology for crop-livestock production into an integrated system.

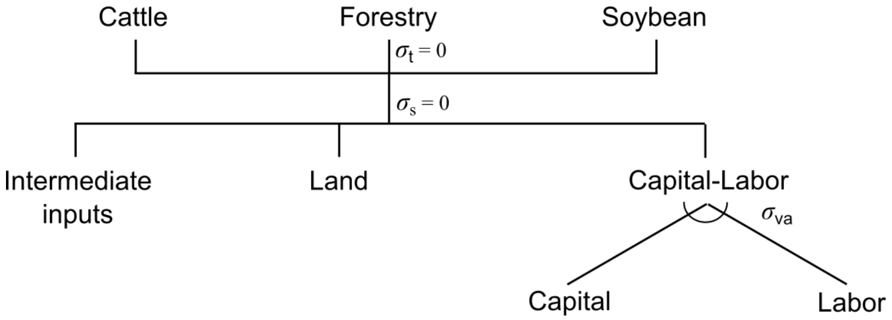

Figure D.4: Backstop technology for crop-livestock-forestry production into an integrated system.

# Appendix E

# Other results

Table E.1: Policy costs by regions and technologies under different scenarios (million R$).

| **Regions** | **South** | **Southeast** | **Center-West** | **North** | **Northeast** | **Northeast Cerrado** | **Brazil** |
|---|---|---|---|---|---|---|---|
| *Non-priority* | | | | | | | |
| **rec** | 6,005 | 8,824 | 947 | 2,097 | 3,254 | 5,499 | 26,626 |
| **icl** | - | - | - | 341 | - | 914 | 1,255 |
| **isl** | - | - | - | 1,175 | - | 2,520 | 3,695 |
| **islf** | - | - | - | 989 | - | - | 989 |
| *Priority* | | | | | | | |
| **rec** | 2,837 | 4,526 | 454 | 987 | 11,656 | 10,828 | 31,288 |
| **icl** | 616 | 201 | 117 | 331 | - | 2 | 1,268 |
| **isl** | 2,363 | | 1,755 | 1,100 | - | 243 | 5,461 |
| **islf** | 523 | 26 | 232 | 247 | - | 32 | 1,060 |
| *Combined* | | | | | | | |
| **rec** | 6,374 | 8,972 | 964 | 2,146 | 3,479 | 4,751 | 26,685 |
| **icl** | 3,032 | 190 | - | 289 | - | 80 | 3,591 |
| **isl** | - | 19 | 1,800 | 1,134 | - | 105 | 3,057 |
| **islf** | 544 | 27 | 233 | 247 | - | 31 | 1,083 |

Source: research results.
**rec**: pasture recovery; **icl**: maize-livestock; **isl**: soybean-livestock; **islf**: soybean-livestock-forestry.

Table E.2: Welfare changes by regions under different scenarios.

| Welfare | South | Southeast | Center-West | North | Northeast | Northeast Cerrado |
|---|---|---|---|---|---|---|
| *Non-priority* | | | | | | |
| **%** | 0.79 | 0.28 | 1.26 | 1.00 | -0.25 | -0.05 |
| **Million R$** | 2,779 | 2,910 | 1,786 | 995 | -436 | -76 |
| *Priority* | | | | | | |
| **%** | -0.01 | 0.10 | -0.17 | 0.08 | -0.57 | -0.32 |
| **Million R$** | -32 | 1,005 | -238 | 76 | -997 | -538 |
| *Combined* | | | | | | |
| **%** | 0.75 | 0.31 | 1.18 | 1.06 | -0.26 | -0.08 |
| **Million R$** | 2,629 | 3,242 | 1,678 | 1,063 | -452 | -133 |

Source: research outcomes.

Table E.3: Production changes (%) of non-agricultural sectors by region and scenarios.

| Regions | South | | | Southeast | | | Center-West | | | North | | | Northeast | | | Northeast Cerrado | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenarios** | **N-P** | **P** | **C** | **N-P** | **P** | **C** | **N-P** | **P** | **C** | **N-P** | **P** | **C** | **N-P** | **P** | **C** | **N-P** | **P** | **C** |
| Swine | -2.2 | 0.2 | -2.1 | -2.8 | -1.0 | -3.0 | 0.2 | 1.2 | 0.8 | 1.4 | 1.0 | 1.2 | 0.1 | -2.4 | -0.2 | 2.9 | -1.3 | -0.1 |
| Poultry | -2.3 | 0.3 | -2.0 | -2.9 | -0.5 | -3.0 | 0.8 | 1.3 | 1.4 | -0.1 | 0.5 | -0.1 | -1.0 | -0.4 | -1.1 | 0.5 | -3.4 | -2.0 |
| Milk | -10.0 | 0.7 | -8.9 | -3.7 | -1.2 | -4.1 | 7.7 | 2.3 | 8.2 | 9.5 | 2.3 | 9.1 | 8.4 | -6.6 | 8.4 | 10.1 | -1.9 | 8.8 |
| Oil | 13.0 | 0.5 | 10.8 | 0.5 | -1.5 | 0.3 | -0.7 | -3.0 | -1.2 | 2.4 | -2.6 | 6.4 | 5.1 | 19.1 | 5.2 | 5.0 | 33.1 | 11.5 |
| Gas | -6.8 | -10.4 | -8.2 | 1.4 | -6.7 | 0.4 | -2.8 | -6.8 | -3.6 | -3.4 | -7.0 | -2.1 | 9.3 | 44.4 | 9.1 | -0.3 | 21.5 | 5.8 |
| Mineral iron | -0.5 | 0.5 | -0.2 | 4.4 | 4.7 | 5.2 | 5.3 | 9.8 | 9.4 | -0.6 | 2.9 | -1.2 | 11.4 | 32.8 | 12.7 | 1.2 | -3.4 | 1.6 |
| Coal | 1.4 | 1.2 | 1.4 | 0.5 | 2.2 | 1.5 | 0.5 | 6.8 | 5.1 | 0.7 | -0.6 | 6.0 | 5.2 | 23.4 | 6.6 | 1.3 | 16.1 | 5.1 |
| Mineral extraction | 4.3 | 3.0 | 3.9 | 5.3 | 5.5 | 5.9 | 5.1 | 10.9 | 9.8 | 2.7 | 3.0 | 4.4 | 9.2 | 22.1 | 9.9 | 1.8 | 1.1 | 2.7 |
| Meats | -6.6 | -0.5 | -6.6 | -9.9 | -2.7 | -10.3 | 3.1 | 1.8 | 3.6 | 4.1 | 1.4 | 4.0 | 7.3 | -12.5 | 7.1 | 14.9 | -1.0 | 12.8 |
| Soybean oil | 4.5 | 8.0 | 13.2 | -1.5 | -2.5 | -2.8 | -1.7 | 4.2 | 2.6 | 14.5 | 9.4 | 10.9 | -0.5 | -1.1 | -2.3 | 31.3 | -1.6 | -3.8 |
| Foods | 1.1 | 0.7 | 1.6 | -0.4 | -0.3 | -0.4 | 0.4 | 0.3 | 0.7 | -0.1 | -0.7 | -0.1 | 0.8 | 3.1 | 0.8 | 1.5 | 0.7 | 0.0 |
| Textile | 2.9 | -0.1 | 2.4 | 0.2 | -0.2 | 0.3 | -0.5 | 0.3 | -0.1 | -0.2 | -0.6 | 0.6 | -1.2 | 2.9 | -1.1 | -0.2 | 5.5 | 1.3 |
| Refined Oil | 0.3 | 0.7 | 0.4 | 0.9 | 0.9 | 1.0 | 1.3 | 1.7 | 1.7 | 1.0 | 1.4 | 1.1 | 0.1 | -1.7 | 0.1 | 1.2 | 1.2 | 1.0 |
| Ethanol | 2.5 | 3.9 | 4.8 | 2.8 | 1.6 | 2.9 | -2.0 | 3.0 | 0.8 | 6.6 | 7.4 | 9.5 | 7.3 | 41.9 | 7.6 | 3.2 | 12.4 | 0.0 |
| Chemicals | 5.8 | 3.6 | 7.1 | 1.9 | 1.4 | 2.3 | 2.9 | 8.7 | 9.2 | 19.9 | 10.9 | 18.9 | 6.6 | 23.4 | 7.3 | 9.6 | 18.9 | 8.2 |
| Fertilizers | 21.7 | 23.4 | 35.2 | 25.2 | 13.6 | 25.8 | 8.3 | 66.1 | 67.5 | 645.9 | 364.5 | 550.8 | 65.6 | 232.4 | 70.2 | 150.8 | 212.0 | 93.4 |
| Defensives | 37.1 | 67.7 | 89.7 | 14.7 | 7.4 | 15.0 | 32.5 | 428.6 | 434.9 | 1E+06 | 9E+05 | 1E+06 | 1E+03 | 4E+03 | 1E+03 | 150.7 | 167.5 | 72.9 |
| Steel non-met | 2.5 | 0.2 | 2.1 | 0.5 | 0.2 | 0.5 | -0.2 | 1.0 | 0.4 | 0.0 | -0.3 | 0.7 | 0.5 | 3.6 | 0.6 | -1.9 | 1.5 | -0.4 |
| Machines | 1.8 | 0.1 | 1.5 | -0.5 | 0.0 | -0.3 | -1.6 | 0.3 | -1.2 | -2.3 | -0.6 | -1.6 | -0.8 | 5.0 | -0.4 | -2.7 | 3.8 | -0.8 |
| Other industries | 2.8 | -0.1 | 2.2 | 0.4 | 0.0 | 0.4 | -0.3 | -0.1 | -0.2 | -0.6 | -0.8 | 0.3 | 0.1 | 4.7 | 0.2 | -0.3 | 5.6 | 1.2 |
| Electricity | -0.4 | 0.2 | -0.3 | 0.0 | 0.1 | 0.0 | 1.1 | 1.8 | 1.6 | 0.9 | 0.9 | 0.8 | -1.1 | -4.9 | -1.2 | 0.1 | -0.8 | -0.1 |
| Pipe gas | -0.2 | 1.5 | 0.1 | 0.5 | 1.5 | 0.5 | 1.8 | 4.0 | 2.6 | 1.6 | 2.3 | 1.5 | -0.8 | -4.5 | -0.9 | 0.4 | -0.9 | -0.2 |
| Water | 0.7 | 0.6 | 0.7 | 0.3 | 0.5 | 0.3 | 1.2 | 2.3 | 1.8 | 1.1 | 1.1 | 1.3 | -0.8 | -3.3 | -0.9 | 0.3 | 0.7 | 0.3 |
| Public services | -10.8 | -3.7 | -11.5 | -4.4 | -1.7 | -4.5 | -1.5 | -2.2 | -3.3 | -4.1 | -0.9 | -4.9 | -3.6 | -13.1 | -3.8 | -7.1 | -17.8 | -7.7 |
| Construction | -0.4 | -0.4 | -0.5 | -0.1 | -0.2 | -0.1 | -0.1 | -0.2 | -0.3 | -0.2 | -0.3 | -0.2 | -0.2 | -0.8 | -0.2 | -0.4 | -0.1 | -0.2 |
| Services | 0.5 | -0.1 | 0.5 | 0.1 | 0.0 | 0.1 | 0.4 | 0.2 | 0.6 | 0.6 | 0.1 | 0.7 | -0.4 | -0.9 | -0.4 | -0.2 | -0.3 | -0.3 |
| Transportation | 1.0 | 0.3 | 1.2 | 0.7 | 0.2 | 0.7 | 0.4 | 0.9 | 1.1 | 1.2 | 0.5 | 1.3 | 0.4 | 1.8 | 0.4 | 0.7 | 1.9 | 0.6 |

Source: research results.

Table E.4: Percentage change in price by sector under *Non-priority* scenario.

| Sectors | South | Southeast | Center-West | North | Northeast | Northeast Cerrado |
|---|---|---|---|---|---|---|
| **Rice** | -1.0 | -1.0 | -0.3 | -0.8 | -0.1 | -0.1 |
| **Maize** | -3.4 | -2.7 | -1.2 | -8.0 | -1.4 | -12.3 |
| **Cane** | -2.6 | -2.4 | -0.7 | -1.7 | -1.5 | -2.0 |
| **Soybean** | -4.1 | -3.5 | -2.1 | -8.5 | -1.7 | -11.7 |
| **Fruits** | -1.9 | -1.5 | -0.2 | -0.3 | 0.2 | -0.4 |
| **Other cultures** | -3.3 | -2.4 | -0.6 | -0.6 | -1.1 | -0.9 |
| **Forestry** | -2.0 | -4.2 | -0.9 | -2.7 | -1.2 | -2.7 |
| **Cattle** | 21.8 | 17.3 | 7.8 | 8.0 | 6.7 | 6.0 |
| **Other live animals** | -6.9 | -4.0 | 0.9 | -0.3 | -2.4 | -2.9 |
| **Swine** | -0.1 | 0.0 | -0.1 | -0.6 | 0.0 | -0.9 |
| **Poultry** | 0.0 | -0.1 | -0.1 | -0.3 | -0.1 | -0.7 |
| **Milk** | 6.9 | 5.4 | 3.3 | 3.0 | 2.9 | 2.4 |
| **Oil** | -1.4 | -0.2 | -0.1 | -0.4 | -0.6 | -0.6 |
| **Gas** | 0.0 | -0.2 | -0.1 | -0.1 | -0.5 | -0.2 |
| **Mineral iron** | 0.4 | 0.2 | -0.1 | 0.7 | -0.9 | 0.8 |
| **Coal** | -0.7 | -0.3 | -0.1 | -0.4 | -0.4 | -0.3 |
| **Mineral extraction** | -0.9 | -0.3 | -0.1 | -0.2 | -0.2 | 0.5 |
| **Meats** | 4.6 | 5.1 | 3.4 | 3.2 | 3.0 | 1.8 |
| **Soybean oil** | -3.3 | -2.6 | -2.3 | -4.3 | -2.8 | -7.0 |
| **Foods** | -1.1 | -0.6 | -0.6 | -0.5 | -0.9 | -1.1 |
| **Textile** | -0.8 | -0.4 | -0.3 | -0.3 | -0.2 | -0.3 |
| **Refined Oil** | 0.0 | -0.1 | -0.2 | -0.1 | 0.0 | 0.0 |
| **Ethanol** | -1.0 | -1.2 | -0.6 | -1.0 | -1.3 | -1.3 |
| **Chemicals** | -0.4 | -0.2 | -0.1 | -0.1 | -0.1 | -0.1 |
| **Fertilizers** | -0.1 | -0.1 | -0.1 | 0.0 | 0.1 | 0.0 |
| **Defensives** | -0.4 | -0.3 | -0.2 | -0.3 | -0.4 | -0.3 |
| **Steel non-metallic** | -0.5 | -0.2 | -0.1 | -0.1 | -0.2 | 0.1 |
| **Machines** | -0.6 | -0.3 | -0.1 | -0.1 | -0.2 | 0.0 |
| **Other industries** | -0.7 | -0.3 | -0.2 | -0.2 | -0.3 | -0.2 |
| **Electricity** | 0.2 | 0.1 | 0.0 | 0.0 | 0.4 | 0.3 |
| **Pipe gas** | 0.5 | 0.1 | -0.1 | 0.0 | 0.6 | 0.5 |
| **Water** | 0.0 | 0.0 | -0.1 | 0.0 | 0.4 | 0.3 |
| **Public services** | -1.5 | -0.7 | -0.1 | -0.5 | -1.2 | -0.9 |
| **Construction** | -0.2 | -0.2 | -0.1 | -0.1 | 0.0 | 0.0 |
| **Services** | -0.3 | -0.1 | -0.1 | 0.0 | 0.1 | 0.2 |
| **Transportation** | -0.2 | -0.3 | -0.1 | -0.1 | -0.1 | 0.1 |

Source: research outcomes.

Table E.5: Percentage change in price by sector under *Priority* scenario.

| **Sectors** | **South** | **Southeast** | **Center-West** | **North** | **Northeast** | **Northeast Cerrado** |
|---|---|---|---|---|---|---|
| **Rice** | -0.6 | -0.4 | -0.4 | -0.6 | 0.9 | 2.2 |
| **Maize** | -3.6 | -2.0 | -2.4 | -7.3 | -1.4 | -1.3 |
| **Cane** | -1.5 | -1.1 | -0.8 | -1.1 | -3.1 | -1.7 |
| **Soybean** | -5.6 | -2.5 | -4.0 | -7.0 | -0.9 | -1.8 |
| **Fruits** | -1.1 | -0.6 | -0.3 | -0.1 | 1.3 | 0.6 |
| **Other cultures** | -2.0 | -1.1 | -0.6 | -0.3 | -1.1 | -0.1 |
| **Forestry** | -1.5 | -2.1 | -1.3 | -1.2 | -0.5 | -2.0 |
| **Cattle** | 1.9 | 3.0 | 0.6 | 0.7 | 5.7 | 4.6 |
| **Other live animals** | -2.5 | -1.9 | -0.1 | -0.2 | -7.8 | -13.1 |
| **Swine** | -0.6 | -0.4 | -0.7 | -0.8 | 0.1 | 0.0 |
| **Poultry** | -0.5 | -0.4 | -0.7 | -0.6 | -0.2 | 1.1 |
| **Milk** | 0.5 | 0.9 | 0.2 | 0.2 | 1.6 | 0.8 |
| **Oil** | -0.1 | 0.1 | 0.0 | 0.2 | -2.0 | -3.1 |
| **Gas** | 0.2 | 0.0 | 0.0 | 0.1 | -1.5 | -1.1 |
| **Mineral iron** | 0.3 | 0.3 | -0.1 | 0.3 | -3.0 | 2.5 |
| **Coal** | 0.0 | 0.0 | 0.0 | 0.4 | -1.1 | -1.9 |
| **Mineral extraction** | 0.0 | 0.0 | -0.1 | 0.3 | -0.4 | 1.3 |
| **Meats** | 0.3 | 0.6 | 0.1 | 0.1 | 1.9 | 0.4 |
| **Soybean oil** | -3.6 | -2.3 | -3.1 | -3.7 | -2.5 | -2.1 |
| **Foods** | -0.9 | -0.5 | -0.7 | -0.4 | -1.7 | -1.0 |
| **Textile** | -0.1 | -0.1 | -0.2 | 0.0 | -0.6 | -0.9 |
| **Refined Oil** | 0.0 | 0.0 | -0.2 | -0.1 | 0.5 | 0.3 |
| **Ethanol** | -0.7 | -0.7 | -0.6 | -0.6 | -3.1 | -1.7 |
| **Chemicals** | 0.0 | 0.0 | -0.1 | 0.0 | -0.2 | -0.6 |
| **Fertilizers** | 0.1 | 0.1 | 0.0 | 0.1 | 0.6 | 0.1 |
| **Defensives** | 0.0 | -0.1 | -0.1 | 0.0 | -0.7 | -1.0 |
| **Steel non-metallic** | 0.0 | 0.1 | 0.0 | 0.1 | -0.3 | 0.0 |
| **Machines** | 0.0 | 0.0 | 0.0 | 0.1 | -0.6 | -0.4 |
| **Other industries** |  | 0.0 | 0.0 | 0.1 | -0.7 | -0.9 |
| **Electricity** | 0.2 | 0.2 | 0.0 | 0.1 | 1.4 | 0.6 |
| **Pipe gas** | 0.2 | 0.1 | -0.2 | -0.1 | 2.3 | 1.6 |
| **Water** | 0.2 | 0.1 | 0.0 | 0.1 | 1.5 | 0.4 |
| **Public services** | -0.1 | -0.2 | 0.0 | 0.2 | -4.0 | -4.4 |
| **Construction** | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 | -0.5 |
| **Services** | 0.1 | 0.1 | -0.1 | 0.1 | 0.4 | 0.2 |
| **Transportation** | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | -0.2 |

Source: research outcomes.

Table E.6: Percentage change in price by sector under *Combined* scenario.

| **Sectors** | **South** | **Southeast** | **Center-West** | **North** | **Northeast** | **Northeast Cerrado** |
|---|---|---|---|---|---|---|
| **Rice** | -1.3 | -1.0 | -0.6 | -0.7 | -0.1 | 0.6 |
| **Maize** | -4.1 | -3.2 | -1.7 | -6.8 | -1.3 | -1.9 |
| **Cane** | -3.1 | -2.5 | -1.0 | -1.7 | -1.6 | -1.2 |
| **Soybean** | -7.7 | -4.0 | -4.4 | -7.5 | -1.8 | -2.4 |
| **Fruits** | -2.4 | -1.6 | -0.4 | -0.3 | 0.2 | 0.0 |
| **Other cultures** | -4.1 | -2.5 | -0.9 | -0.7 | -1.2 | -0.4 |
| **Forestry** | -2.6 | -4.3 | -1.6 | -1.3 | -1.2 | -2.1 |
| **Cattle** | 21.3 | 18.0 | 7.8 | 8.5 | 6.9 | 6.7 |
| **Other live animals** | -7.1 | -4.2 | 0.7 | -0.7 | -2.6 | -4.0 |
| **Swine** | -0.2 | 0.0 | -0.3 | -0.6 | 0.0 | 0.0 |
| **Poultry** | -0.1 | -0.1 | -0.3 | -0.3 | -0.1 | 0.4 |
| **Milk** | 6.7 | 5.5 | 3.3 | 3.1 | 3.0 | 2.7 |
| **Oil** | -1.2 | -0.1 | -0.1 | -0.8 | -0.7 | -1.3 |
| **Gas** | 0.1 | -0.2 | -0.1 | -0.1 | -0.5 | -0.5 |
| **Mineral iron** | 0.4 | 0.2 | -0.1 | 1.0 | -1.0 | 1.0 |
| **Coal** | -0.6 | -0.2 | -0.1 | -0.9 | -0.4 | -0.8 |
| **Mineral extraction** | -0.7 | -0.3 | -0.2 | -0.4 | -0.2 | 0.5 |
| **Meats** | 4.6 | 5.2 | 3.4 | 3.3 | 3.1 | 2.1 |
| **Soybean oil** | -4.9 | -3.0 | -3.5 | -4.4 | -2.9 | -2.3 |
| **Foods** | -1.4 | -0.7 | -0.8 | -0.6 | -0.9 | -0.7 |
| **Textile** | -0.7 | -0.4 | -0.3 | -0.4 | -0.2 | -0.5 |
| **Refined Oil** | 0.0 | -0.1 | -0.2 | -0.1 | 0.0 | 0.0 |
| **Ethanol** | -1.1 | -1.3 | -0.8 | -1.2 | -1.4 | -1.0 |
| **Chemicals** | -0.3 | -0.2 | -0.1 | -0.2 | -0.1 | -0.3 |
| **Fertilizers** | 0.0 | -0.1 | -0.1 | 0.0 | 0.1 | 0.0 |
| **Defensives** | -0.4 | -0.4 | -0.2 | -0.4 | -0.4 | -0.5 |
| **Steel non-metallic** | -0.4 | -0.2 | -0.1 | -0.1 | -0.2 | 0.0 |
| **Machines** | -0.5 | -0.3 | -0.1 | -0.1 | -0.2 | -0.2 |
| **Other industries** | -0.6 | -0.3 | -0.2 | -0.3 | -0.3 | -0.5 |
| **Electricity** | 0.3 | 0.1 | -0.1 | 0.0 | 0.4 | 0.2 |
| **Pipe gas** | 0.5 | 0.1 | -0.2 | 0.0 | 0.6 | 0.6 |
| **Water** | 0.0 | 0.0 | -0.1 | -0.1 | 0.4 | 0.2 |
| **Public services** | -1.3 | -0.7 | -0.1 | -1.1 | -1.2 | -1.7 |
| **Construction** | -0.1 | -0.2 | -0.1 | -0.1 | 0.0 | -0.2 |
| **Services** | -0.2 | -0.1 | -0.1 | -0.1 | 0.1 | 0.1 |
| **Transportation** | -0.1 | -0.3 | -0.1 | -0.2 | -0.1 | -0.1 |

Source: research outcomes.

Table E.7: Indexes of production value per hectare by integrated systems compared to single production (*Non-Priority* scenario).

| **IS technology** | **maize-livestock** | | **soybean-livestock** | | **soybean-livestock-forestry** | | |
|---|---|---|---|---|---|---|---|
| | **maize** | **cattle** | **soybean** | **cattle** | **soybean** | **cattle** | **forestry** |
| **South** | - | - | - | - | - | - | - |
| **Southeast** | - | - | - | - | - | - | - |
| **Center-West** | - | - | - | - | - | - | - |
| **North** | 1.074 | 1.080 | 1.085 | 1.087 | 1.056 | 1.056 | 1.057 |
| **Northeast** | - | - | - | - | - | - | - |
| **Northeast Cerrado** | 1.181 | 1.182 | 1.188 | 1.185 | - | - | - |

Source: research outcomes.

Table E.8: Indexes of production value per hectare by integrated systems compared to single production (*Priority* scenario).

| **IS technology** | **maize-livestock** | | **soybean-livestock** | | **soybean-livestock-forestry** | | |
|---|---|---|---|---|---|---|---|
| | **maize** | **cattle** | **soybean** | **cattle** | **soybean** | **cattle** | **forestry** |
| **South** | 1.092 | 1.089 | 1.095 | 1.097 | 1.09 | 1.088 | 1.089 |
| **Southeast** | 1.023 | 1.021 | - | - | 1.024 | 1.025 | 1.023 |
| **Center-West** | 0.985 | 0.979 | 1.041 | 1.039 | 1.016 | 1.015 | 1.015 |
| **North** | 1.074 | 1.08 | 1.085 | 1.087 | 1.056 | 1.057 | 1.056 |
| **Northeast** | - | - | - | - | - | - | - |
| **Northeast Cerrado** | 1.181 | 1.182 | 1.188 | 1.185 | 1.195 | 1.197 | 1.194 |

Source: research outcomes.

# Appendix F

# Algebraic representation of BREA

The BREA model is written in Mathematical Programming System for General Equilibrium (MPSGE) (RUTHERFORD, 1999). The MPSGE uses all the information available, such as the benchmark data, functional forms for production, transformation, and utility, as well as the substitution possibility among goods and inputs to create the mathematical formulation to solve the system as a nonlinear mixed complementarity problem.

Three inequalities must be satisfied: zero profit, market clearance, and income balance. A set with three non-negative variables is determined as a solution in a mixed complementarity problem: price, quantity level, and income level. The Tables F.1, F.2, and F.3 show the sets, variables, and parameters in the model. The zero profit equations portray the technological structure for each sector. To build this system of equations I use the cost and demand functions in a calibrated share form. This approach considers that the unity price for each activity must be equal to the costs of production (intermediate inputs and production factors).

Table F.1: Sets and subsets in the model.

| Notation | Description |
|---|---|
| $i, j, k \in I$ | Sectors and goods |
| $r, s$ | Regions |
| $agri \subset I$ | Agricultural sectors |
| $agrilu \subset I$ | Agricultural sectors land use |
| $e \subset I$ | Energy sectors |
| $ne \subset I$ | Non-energy sectors |
| $elec \in I$ | Electricity sector |
| $noe \subset I$ | Non-elec energy sectors |
| $f \in F$ | Factors of production |
| $mf \subset F$ | Mobile factors |
| $sf \subset F$ | Sluggish factor |

Table F.2: Initial parameters in the model

| Notation | Description |
|---|---|
| $\theta_{ijr}$ | Share of intermediate good $i$ in sector $j$ in region $r$ |
| $\theta_{jr}^{O}$ | Share of resource-intense bundle in sector $j$ in region $r$ |
| $\theta_{jr}^{f}$ | Share of production factor $f$ in sector $j$ in region $r$ |
| $\theta_{jr}^{RI}$ | Share of aggregate-energy nest in resource-intense bundle in sector $j$ in region $r$ |
| $\theta_{jr}^{AE}$ | Share of electricity in aggregate-energy bundle in sector $j$ in region $r$ |
| $\theta_{jr}^{EM}$ | Share of aggregate-energy bundle in energy-materials nest in sector $j$ in region $r$ |
| $\theta_{ijr}^{YR}$ | Share of regional good $i$ in Armington aggregation in sector $j$ in region $r$ |
| $\theta_{ijr}^{A}$ | Share of national good $i$ in Armington aggregation in sector $j$ in region $r$ |
| $\theta_{ir}^{CR}$ | Share of regional consumption good $i$ in Armington aggregation in region $r$ |
| $\theta_{ir}^{CA}$ | Share of national consumption good $i$ in Armington aggregation in region $r$ |
| $\theta_{ir}^{IR}$ | Share of regional investment good $i$ in Armington aggregation in region $r$ |
| $\theta_{ir}^{I}$ | Share of national investment good $i$ in Armington aggregation in region $r$ |
| $\theta_{ir}^{c}$ | Share of final consumption good $i$ in bundle $c$ of region $r$ |
| $\theta_{ir}^{G}$ | Share of final public consumption good $i$ in region $r$ |
| $\omega_{r}^{L}$ | Labor endowment in region $r$ |
| $\omega_{r}^{K}$ | Capital endowment in region $r$ |
| $\omega_{r}^{f}$ | Land endowment in region $r$ |

Table F.3: Endogenous variables

| Notation | Description |
|---|---|
| $p_{jr}^{Y}$ | Production price of good $j$ in region $r$ |
| $p_{jr}^{f}$ | Land price in sector $j$ in region $r$ |
| $p_{jr}^{EM}$ | Energy-materials bundle price in sector $j$ in region $r$ |
| $p_{jr}^{KL}$ | Capital-labor bundle price in sector $j$ in region $r$ |
| $p_{jr}^{AE}$ | Aggregate-energy bundle price in sector $j$ in region $r$ |
| $p_{ijr}^{A}$ | Price of composite good $i$ in sector $j$ in region $r$ |
| $\theta_{ijr}^{A}$ | Share of national good $i$ in Armington aggregation in sector $j$ in region $r$ |
| $\theta_{ir}^{CR}$ | Share of regional consumption good $i$ in Armington aggregation in region $r$ |
| $\theta_{ir}^{CA}$ | Share of national consumption good $i$ in Armington aggregation in region $r$ |
| $\theta_{ir}^{IR}$ | Share of regional investment good $i$ in Armington aggregation in region $r$ |
| $\theta_{ir}^{I}$ | Share of national investment good $i$ in Armington aggregation in region $r$ |
| $\theta_{ir}^{c}$ | Share of final consumption good $i$ in bundle $c$ of region $r$ |
| $\theta_{ir}^{G}$ | Share of final public consumption good $i$ in region $r$ |
| $\omega_{r}^{L}$ | Labor endowment in region $r$ |
| $\omega_{r}^{K}$ | Capital endowment in region $r$ |
| $\omega_{r}^{f}$ | Land endowment in region $r$ |

## F.1 Zero profit condition

### F.1.1 Agricultural production

$$\Pi^{Y}_{jr} = p^{Y}_{jr} - \left\{ \theta^{O}_{jr} \left[ \theta^{f}_{jr} (p^{f}_{jr})^{1-\sigma_{fx}} + (1-\theta^{f}_{jr})(p^{EM}_{jr})^{1-\sigma_{fx}} \right]^{\frac{1-\sigma_s}{1-\sigma_{fx}}} + (1-\theta^{O}_{jr})(p^{KL}_{jr})^{1-\sigma_s} \right\}^{\frac{1}{1-\sigma_s}} = 0 \tag{F.1}$$

$$\forall j \in agrilu, f \in sf$$

### F.1.2 Non-agricultural and Energy production

$$\Pi^{Y}_{jr} = p^{Y}_{jr} - \left\{ \theta^{O}_{jr} \left[ \theta^{RI}_{jr} (p^{AE}_{jr})^{1-\sigma_e} + (1-\theta^{RI}_{jr})(p^{KL}_{jr})^{1-\sigma_e} \right]^{\frac{1}{1-\sigma_e}} + (1-\theta^{O}_{jr}) \sum_{i \in ne} \theta_{ijr} p^{A}_{ijr} \right\} = 0 \tag{F.2}$$

$$\forall j \in I, j \notin agrilu$$

### F.1.3 Capital-Labor nest

$$\Pi^{KL}_{jr} = p^{KL}_{jr} - w_r^{\alpha_{jr}} r_r^{1-\alpha_{jr}} = 0 \qquad \forall j \in I \tag{F.3}$$

### F.1.4 Aggregate Energy nest

$$\Pi^{AE}_{jr} = p^{AE}_{jr} - \left[ \theta^{AE}_{jr} (p^{A}_{kjr})^{1-\sigma_{en}} + (1-\theta^{AE}_{jr}) \left( \sum_{i \in e} \theta_{ijr} p^{A}_{ijr} \right)^{1-\sigma_{en}} \right]^{\frac{1}{1-\sigma_{en}}} = 0 \tag{F.4}$$

$$\forall j \in I, k = elec$$

### F.1.5 Energy-materials nest

$$\Pi^{EM}_{jr} = p^{EM}_{jr} - \left[ \theta^{EM}_{jr} (p^{AE}_{jr})^{1-\sigma_e} + (1-\theta^{EM}_{jr}) \left( \sum_{i \in ne} \theta_{ijr} p^{A}_{ijr} \right)^{1-\sigma_e} \right]^{\frac{1}{1-\sigma_e}} = 0 \tag{F.5}$$

$$\forall j \in vagri$$

### F.1.6 Armington structure

**Inter-regional aggregation**

$$\Pi^{YR}_{ijr} = p^{YR}_{ijr} - \left[\theta^{YR}_{ijr}(p^{Y}_{ir})^{1-\sigma_{esubdr}} + (1-\theta^{YR}_{ijr})(p^{MR}_{ir})^{1-\sigma_{esubdr}}\right]^{\frac{1}{1-\sigma_{esubdr}}} = 0 \tag{F.6}$$

$$\forall i, j \in I$$

**National and import aggregation**

$$\Pi^{A}_{ijr} = p^{A}_{ijr} - \left[\theta^{A}_{ijr}(p^{YR}_{ijr})^{1-\sigma_{esubd}} + (1-\theta^{A}_{ijr})(p^{M}_{ir})^{1-\sigma_{esubd}}\right]^{\frac{1}{1-\sigma_{esubd}}} = 0 \tag{F.7}$$

$$\forall i, j \in I$$

**Inter-regional consumption aggregation**

$$\Pi^{CR}_{ir} = p^{CR}_{ir} - \left[\theta^{CR}_{ir}(p^{Y}_{ir})^{1-\sigma_{esubdr}} + (1-\theta^{CR}_{ir})(p^{MR}_{ir})^{1-\sigma_{esubdr}}\right]^{\frac{1}{1-\sigma_{esubdr}}} = 0 \tag{F.8}$$

$$\forall i \in I$$

**National and import consumption aggregation**

$$\Pi^{CA}_{ir} = p^{CA}_{ir} - \left[\theta^{CA}_{ir}(p^{CR}_{ir})^{1-\sigma_{esubd}} + (1-\theta^{CA}_{ir})(p^{M}_{ir})^{1-\sigma_{esubd}}\right]^{\frac{1}{1-\sigma_{esubd}}} = 0 \tag{F.9}$$

$$\forall i \in I$$

**Inter-regional investment aggregation**

$$\Pi^{IR}_{ir} = p^{IR}_{ir} - \left[\theta^{IR}_{ir}(p^{Y}_{ir})^{1-\sigma_{esubdr}} + (1-\theta^{IR}_{ir})(p^{MR}_{ir})^{1-\sigma_{esubdr}}\right]^{\frac{1}{1-\sigma_{esubdr}}} = 0 \tag{F.10}$$

$$\forall i \in I$$

**National and import investment aggregation**

$$\Pi_r^I = p_r^I - \prod_i \left\{ \left[\theta_{ir}^I (p_{ir}^{IR})^{1-\sigma_{esubd}} + (1-\theta_{ir}^I)(p_{ir}^M)^{1-\sigma_{esubd}}\right]^{\frac{1}{1-\sigma_{esubd}}} \right\}^{\delta_i} = 0 \qquad \text{(F.11)}$$

$$\forall i \in I, \qquad \sum_i \delta_i = 1$$

### F.1.7 Household utility

$$\Pi_r^U = p_r^U - (p_r^{OC})^{\beta_r} (p_{ir}^A)^{1-\beta_r} = 0 \qquad \text{(F.12)}$$

$$i = trns$$

$$\Pi_r^{OC} = p_r^{OC} - \prod_{c=1}^{3} (p_r^c)^{\delta_c} = 0$$

**Energy demand**

$$\Pi_r^c|_{c=1} = p_r^c - \left[\sum_{i \in e} \theta_{ir}^c (p_{ir}^{CA})^{1-\sigma_e}\right]^{\frac{1}{1-\sigma_e}} = 0, \qquad \sum_{i \in e} \theta_{ir}^c = 1 \qquad \text{(F.13)}$$

**Food and agricultural demand**

$$\Pi_r^c|_{c=2} = p_r^c - \left[\sum_{i \in food, agri} \theta_{ir}^c (p_{ir}^{CA})^{1-\sigma_{d1}}\right]^{\frac{1}{1-\sigma_{d1}}} = 0, \qquad \sum_{i \in food, agri} \theta_{ir}^c = 1 \qquad \text{(F.14)}$$

**Other demand**

$$\Pi_r^c|_{c=3} = p_r^c - \left[\sum_k \theta_{kr}^c (p_{kr}^{CA})^{1-\sigma_{d2}}\right]^{\frac{1}{1-\sigma_{d2}}} = 0, \qquad \text{(F.15)}$$

$$\forall k \notin e, agri, k \neq food, trns, \qquad \sum_k \theta_{kr}^c = 1$$

### F.1.8 Government

$$\Pi_r^G = p_r^G - \sum_i \theta_{ir}^G p_{ir}^Y = 0 \tag{F.16}$$

## F.2 Market Clearance condition

### F.2.1 Labor, capital, and land

$$\omega_r^L = \sum_j Y_{jr} \frac{\partial \Pi_{jr}^Y}{\partial w_r} \tag{F.17}$$

$$\omega_r^K = \sum_j Y_{jr} \frac{\partial \Pi_{jr}^Y}{\partial r_r} \tag{F.18}$$

$$\omega_r^f = \sum_j Y_{jr} \frac{\partial \Pi_{jr}^Y}{\partial p_r^f} \qquad \forall j \in agrilu, f \in sf \tag{F.19}$$

### F.2.2 Sectoral production

$$Y_{jr} = A_{jr} \frac{\partial \Pi_{jr}^A}{\partial p_{jr}^Y} \tag{F.20}$$

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