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The Impacts of Climate Change on Agricultural Production, Land Use and Economy of the Legal Amazon Region Between 2030 and 2049

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Abstract

Global warming and climate impact on agricultural output, land use and food production. This paper seeks to verify the economic impacts of climate change in the Legal Amazon region, especially on agricultural production, land use, GDP and job creation. We employ the Computable General Equilibrium (CGE) model, REGIA - Inter-regional General Equilibrium Model for the Brazilian Legal Amazon, to assess changes in agricultural production and land use in the region due to climate change scenarios proposed by the IPCC (Intergovernmental Panel on Climate Change). The results indicate a drop in economic indicators in the Legal Amazon leading to a loss in real GDP in the order of 1.18% in 2049 due to decrease in production and employment in the agricultural sector. Deforestation will increase due to the gradual replacement of pasture areas by crop fields. Such changes are not homogeneous in the space, affecting more the states of Mato Grosso, Tocantins and Pará, whose economy are dependent upon agriculture.

JEL Classification: R11; R13

Keywords: Climate Change; Food Production; Legal Amazon; Computable General Equilibrium

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1. Introduction

Anthropogenic emissions of greenhouse gases (GHGs) triggered a gradual process of global warming and climate change that intensified with the advent of industrialization. This process brings with it broad impacts on the biodiversity and ecosystems that exist on the planet and therefore incites new challenges.

Studies reported by the Intergovernmental Panel on Climate Change (IPCC, 2007) indicate that, in Brazil, there will be an average temperature increase of 1.43° C and an average rainfall reduction of 1.44% during the years 2030 and 2049. Such data were used by Assunção and Chein (2016) to project the loss of agricultural productivity in the country, indicating an average reduction of productivity by 18% nationally, but with a wide regional variation (-40% to + 15%).

Due to the change in agricultural productivity, a new configuration of the geography of agricultural production is shaped in the country, with benefits and losses depending on the culture and region analyzed (Assad and Pinto, 2008). The effects of this new configuration are not restricted to production itself, but affect the economy, impacting GDP, employment, income, consumption, migration flows, and food security.

The Legal Amazon region, located at a low latitude, will suffer the effects of climate change in a more intense way. According to the Fourth Assessment Report (AR4) of the IPCC (2007), *the region may undergo a process of substituting tropical forest for savanna-type vegetation, and semi-arid vegetation for arid vegetation*, creating perverse effects of heating feedback, given the fundamental role played by the Amazon forest in the absorption of carbon dioxide.

Since the Legal Amazon region is extensive and characterized by the heterogeneity of aspects that respond differently to climate change, the assessment of the impacts on the regional economies becomes essential for formulating adaptive policies and mitigating their effects. Thus, this paper aims to project the economic and land use impacts of climate change on the Legal Amazon region using the REGIA model, an interregional CGE model for Brazil, specifically modeled for the regions of the Legal Amazon. The climate change scenarios on agricultural productivity were based on the information provided by Assunção and Chein (2016) for the period 2030 to 2049.

The study is divided into 4 sections. In section 1, the aspects related to climate change and the economic characteristics of the Legal Amazon will be presented. Section 2 presents the REGIA model and the methodology used in the study. Section 3 presents the results obtained, and final considerations.

2. The Legal Amazon: climate change and economic characteristics

According to the IPCC‘s Fifth Assessment Report, it is very likely that the rise in the global average temperature was caused by the emission of greenhouse gases (GHG) by man. This warming has led to a process of change in rainfall levels and the hydrological cycle with impacts on the availability of water resources at a global level.

> Warming in the climate system is unequivocal and since 1950 many changes have been observed throughout the climate system that are unprecedented over decades to millennia. Each of the last three decades has been successively warmer at the Earth’s surface than any preceding decade since 1850 (. . .) “Observations of changes in the climate system are based on multiple lines of independent evidence. Our assessment of the science finds that the atmosphere and ocean have warmed, the amount of snow and ice has diminished, the global mean sea level has risen, and the concentrations of greenhouse gases have increased” (. . .) (IPCC, 2013).

If humanity doesn’t act, the rise in average temperature on planet Earth will continue and may vary between 1.4 and 5.8 degrees Celsius by the year 2100 (IPCC, 2014). The impacts of global warming are diverse and affect the entire set of life that inhabits the planet, especially human life. Among the most immediate impacts caused by global warming are the displacement of populations due to extreme climates such as hurricanes, droughts, flooding, disease proliferation, ecosystem change and food production.

Food production and consequently food security stand out as challenging issues, as the world’s population continues to grow demanding food production in an uncertain and changing environment. Valin et al. (2014) estimate that food demand will increase by 60-70% over the next 40 years, in an environment where droughts and precipitation will have a negative impact on food production.

The changes in rainfall and temperature responsible for climate change will impact the level of agricultural productivity in a heterogeneous way. The perverse effects will be concentrated in the regions located at low latitudes, while the middle latitudes will become more propitious to the agricultural production of diverse cultures, given its mild temperature. However, it is known that despite the increase in CO2 and temperature levels favoring the growth of some crops, this does not translate into greater production. Global warming brings with it negative factors that overlap with the positive, such as the proliferation of pests and scarcity of water sources for irrigation, as well as changes in rainfall levels (FAO, 2005; FAO, 2016).

In recent decades, numerous studies about the impacts of climate change on the Brazilian economy have emerged. The studies point out, that Brazilian agriculture is vulnerable to climatic conditions. The possible consequences involves reducing crop productivity in some regions (Assunção & Chein, 2016; Féres et al., 2009); change in land use and losses of agricultural areas (Evenson and Alves, 1998; Assad and Pinto, 2008; Féres et al., 2009); and devaluation of agricultural land (Massetti et al., 2013).

Regarding to land use in agriculture, climate change can cause a reduction in forests and increased pastures in Brazil. Evenson and Alves (1998) estimated the allocation of land use derived from climate change in Brazil. The results indicated a drop of 1.98% in the areas of natural forests and an increase of 3.54% of natural pasture areas in the scenario of uniform increase of 1 °C in temperature. Féres et al. (2009) also found similar results, their estimates indicated a significant reduction in forest and agricultural areas, mainly in the Amazon, and an increase in pasture areas.

Domingues et al., 2008 used the availability of land suitable for agriculture in the context of global warming as input (shocks) to feed the interregional CGE model with the aim of assessing the economic impact of climate change effects on states of northeastern Brazil. Simulation projections indicated a 13.1% drop in GDP and a reduction in employment of 5.95% in the Northeast region for the period 2010-2050.

Ferreira Filho and Moraes (2014) also evaluated the economic effects of climate change on agriculture with interregional EGC model for 27 federation units in Brazil. The simulations were based on the A2 and B2 climate scenarios of the IPCC (2007) for the year 2020 and 2070. The shocks applied were the decrease in agricultural productivity and reduction of the cultivated areas detailed by crops and by federation unit. Their results indicated that monetary losses on Brazilian agriculture will be relatively low in the long term due to the incidence of negative shocks on the less significant economic regions for agricultural activities. At the regional level, there was greater damage to poorer regions, especially in low-income families.

Margulis and Dubeux (2010) evaluated the impacts of climate change on the Brazilian economy using other factors than the effects on agriculture. Its methodology uses as core the CGE model integrated with other modules of energy, agriculture and demographics. Its projections were simulated with Brazilian economic and climatic scenarios (A2-BR and B2-BR), based on the climatic scenarios developed by the IPCC (2007). The results of the projections show that there would be GDP losses of R$ 719 billion in 2050 in the A2-BR scenario and R$ 3,6 billion in B2-BR. In regional terms, the worst economic losses will affect the North and Northeast regions, the poorest in Brazil.

Assunção and Chein (2016) estimated the impacts of climate change on municipal agricultural productivity in Brazil in the period between 2030 and 2049 using the IPCC (2000) scenario A1B. The results indicate great heterogeneity in the national territory. The concentration of negative effects on agricultural productivity is mainly in the Legal Amazon region, comprising the states of the North, Northeast and Mid-West. Féres et al. (2009), also, point out that in general the regions most affected by climate change would be North and Northeast, and in the South, there may even be an increase in productivity of some crops.

This brief literature review shows that climate change has great potential to trigger significant costs in the Brazilian economy especially in agriculture and the Northern region where it concentrates a larger portion of the Legal Amazon, as Fig. 1 illustrates. It is also evident that it is important to measure these impacts at the most disaggregated regional level possible, because the effects of climate change are heterogeneous regionally and among economic sectors. This work aims to fill this last gap in the literature.

The concentration of negative impacts on agricultural productivity due to climate change in the Legal Amazon region, also generates indirect effects on land use, which occur due to profit relocation between activities. The decrease on productivity makes the agricultural producers to increase the use of land rather to maintain the level of production. Crop areas tend to grow over pasture and native forests. This mechanism could increase deforestation, which is a relevant subject related to the maintenance of the biomes and climate regulation in Brazil and enhances the relevance of this study.

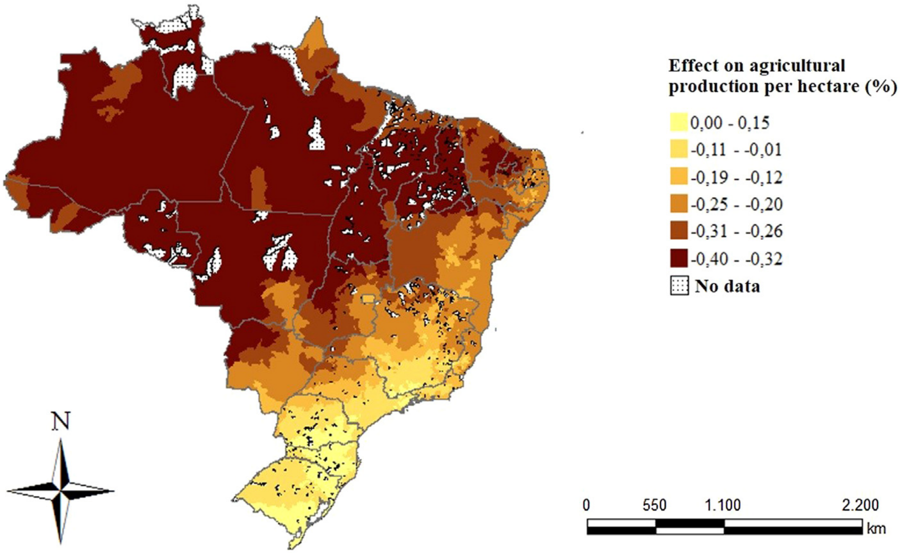

Fig. 1. Effect of climate change on Brazilian agricultural production per hectare at municipal level (2030 to 2049). Source: Elaborated by the authors based on Assunção and Chein (2016).

Thus, given the intensity of these effects on the Legal Amazon region, the need to understand and measure the economic impacts of the change in agricultural productivity in the region is reinforced. Understanding this is essential for the formulation of adaptation policies to climate change. The next section gives a brief characterization of the economic dynamics of the Legal Amazon.

3. Economic Aspects of the Legal Amazon

The definition of the Brazilian Legal Amazon area dates from 1953 and is associated with the creation of public agencies and the implementation of government policies. The Legal Amazon is a geopolitical construction aimed to define an area for the application of territorial and economic policies to incorporate the northern vastness of the Brazilian territory into the country's socioeconomic structure, thus guaranteeing sovereignty over the territory. The region comprises the federal states of Amapá, Amazonas, Acre, Rondônia, Roraima, Tocantins, Pará, Mato Grosso and the municipalities of Maranhão state situated west of 44th meridian (IBGE, 2014).

The economy of the Legal Amazon is very heterogeneous and mirrors its environmental, social and cultural diversity. The most relevant economic sectors for the region are the agricultural, forestry, mineral, industrial and urban activities, which, because of their distinct dynamics, appear in specific regions within the region. For example, the mining complex of Carajás in the states of Pará and Maranhão, the industrial free zones in Amazonas and Amapá, and the agribusiness linked to the states of Mato Grosso, Rondônia, Tocantins, Pará and Maranhão.

According to the IBGE (2010), the GDP of the legal Amazon was R$136.7 billion in 2010, representing 8.1% of the national GDP, which is increasing, compared to 7.88% of national participation in 2005 and 6.57% in 1990. Within the Legal Amazon, the participation of the state of Pará is responsible for about 25% of the regional GDP. Amazonas and Mato Grosso have a similar share of 19.5% and 19.4%, respectively, and make up the most representative group of states in terms of GDP.

Among the states belonging to the Legal Amazon region, the composition of GDP is diversified. Agricultural sector participation is relevant in the state of Mato Grosso, responsible for 32% of the agricultural GDP of the Legal Amazon, followed by Maranhão with 19.4%, Pará with 13%, Rondônia 12% and Tocantins with 7%.

Until the end of the 1960s, agriculture was confined to the territories of Maranhão and eastern Pará, and then incorporated the Cerrado biome areas of Mato Grosso, Rondônia, Tocantins and southern Maranhão. (Brasil, 2008). From then on, Mato Grosso state has emerged as the main agricultural producer of the Legal Amazon region. According to IBGE (2019), Mato Grosso responds for 80% of soybean production, 94% of corn production (2nd crop season), 97% of cotton and 65% of beans production in the region.

Nationally, the Legal Amazon accounted for about 34% of the national soybean production, with 39 million tons, of which 31 million tons were produced by the state of Mato Grosso. The production of cotton seed represents about 67% of the national total, also concentrated in Mato Grosso. Thus, the Legal Amazon region is also responsible for 30% of maize production, 14% for rice and, to a lesser extent, 4% of total sugarcane production (IBGE, 2019).

In the transition areas between the Cerrado and the tropical forest there is a predominance of family production with manioc, corn, beans and rice, as well as perennial crops such as banana, cocoa and coffee. These activities occur in river floodplains and along the main roadways of the region, such as Transamazônica, BR-364 and PA-150 (Brasil, 2008).

Among the activities carried out by family agriculture, the highlight is the production of manioc which fulfills the dual role of supplying the national market and contributing to the food security of its producers. The main national producer is the state of Pará, with 5.08 million tons, and the Legal Amazon region accounts for about 41% of the national total, according to IBGE (2019).

Livestock activity in the Legal Amazon began to develop in the 1980s, when the activity was restricted to the Pantanal region of Mato Grosso and to the lower valleys of rivers at Maranhão state, Marajó Island and the middle courses of the Araguaia and Tocantins rivers. The stimulation given by the Superintendency of the Development of the Amazon (SUDAM) promoted the raising activity of cattle in the Cerrado biome areas and in the areas of the Amazon biome along the Transamazônica road and among the BR-364, BR-163, BR-319, PA-150, PA-279 and MT-138 (Brasil, 2008).

Between the years of 1990 and 2005, 70% of the national herd growth occurred in the region, specifically in the border areas between the Cerrado biome and the Amazon forest, involving part of both ecosystems. Currently the largest herds are in the state of Mato Grosso, Pará, Rondônia, Tocantins and Maranhão, and the activity is directed mainly to the production of meat. The milk production has a smaller dimension, being carried out with prominence in the north of Mato Grosso and the east part of Pará. Pig farms and poultry farms have flourished in Mato Grosso and Pará (Brasil, 2008).

The mineral sector has relevance for the eastern portion of the region, with emphasis on the extraction of iron, manganese and copper in Carajás; aluminum production in Pará; alumina in Maranhão; kaolin in Paragominas; bauxite in the Trombetas river region; cassiterita in Amazonas and Rondônia. These projects are large and have a potential multiplier effect for the region. According to studies of the Brazilian Geological Service, for every mining job created in the region, 13 others are created along the production chain (Brasil, 2008).

In relation to the industrial GDP of the region, the highest participation is in the state of Pará with 37%, followed by the Amazon with 28% (IBGE, 2010). The industrial sector in the Legal Amazon was stimulated with the creation of SUDAM[1] in 1966 and SUFRAMA[2] in 1967. Before that the sector was restricted to the food and beverage, textile, forestry and construction industry. It should be noted that about 75% of the regional industrial activity is concentrated in the four major urban centers, Manaus, Belém, São Luís and Cuiabá (Brasil, 2008).

According to IBGE (2010), the industrial GDP of the Legal Amazon totaled R$34.9 billion in 2010, representing 26% of the total GDP of the Legal Amazon and 8.6% of the national industrial GDP. The largest and most modern industrial center in the region is the Manaus Industrial Sector (PIM) in the state of Amazonas, employing around 100 thousand workers mainly concentrated in the electronics, computer and motorcycle sectors.

The public administration sector, in turn, plays a relevant economic role for half of the Legal Amazon region states. Considering the share of gross added value at current prices of public sector in the corresponding state's GDP, Roraima accounts with 49%, Amapá (48%), Acre (36%), Tocantins (30%), Rondônia (28%) and Maranhão (25%). Indicating dependence on the sector for income generation and formal occupations (IBGE, 2010).

In relation to the tertiary sector, a characteristic of the Legal Amazon region is that no municipality employed more than 50% of the economically active population. Public administration responds in large part to formalization of work, followed by commerce and services in large urban centers. The rest of the activities are composed of the popular economy of small commodity production and services (Brasil, 2008).

[1] *Superintendência do Desenvolvimento da Amazônia* (SUDAM) in English: Superintendency of Development for the Amazon. Was stabilised to promote the development of the region through tax and financial incentives.

[2] Manaus Free Trade Zone was conceived as a free import and export trade area with special tax incentives. It was set up with the object of creating an industrial, commercial and agricultural center in the hinterland of the Amazon Region, which would be equipped with economic conditions that would enable the region to be occupied and developed (Suframa, 2018).

Therefore, since the region of the Legal Amazon is an extensive area comprised of three biomes: Amazonas, Cerrado and Pantanal, its economic activities are distributed in a very heterogeneous way across the territory. In general terms, agriculture stands out in the Cerrado biome and borders with the tropical forest, with the states of Mato Grosso, Tocantins, Pará and Maranhão as the main areas responsible for regional production; the industry is concentrated in the great urban centers, mainly in the Manaus Free Trade Zone. The informality and the presence of the popular economy is striking in urban areas and mining plays a limited role in local development, especially in Pará (Brasil, 2008).

In this sense, just as economic activities are distributed in a heterogeneous way, the impacts of global warming on agricultural production will also occur in a disparate manner. This highlights the importance of evaluating the economic impacts of the decrease in agricultural productivity as a result of climate change. The next section presents the methodology used to verify the new economic dynamics of the Legal Amazon before the impacts of these changes.

4. Methodology

Computable general equilibrium (CGE) models are composed of a system of equations that describe the real economy as a whole and the interconnections between each of the economic sectors and agents. This is one of the aspects that puts this methodology in focus in relation to other methods and presents itself as the most appropriate to evaluate the economic impacts of climate change, since such climate phenomena have a direct and indirect effect on the economy on a large scale, both regionally and sectorally.

In addition, the effects of perceived temperature and weather conditions on historical data are small. In other words, absence of adequate data from the past, limits the estimation of the phenomenon through econometric or statistical models (Domingues et al., 2008). In this sense, the use of ex-ante models, such as CGE, has been the most advisable for projections of the impacts of climate change.

4.1. The REGIA Model

The REGIA model was constructed by Carvalho (2014) to study regional and sectoral economic impacts from land use and deforestation in the Legal Amazon region. The model follows the inter-regional CGE bottom-up structure of the Johansen type encompassing 30 mesoregions of the Legal Amazon plus the rest of Brazil. The main characteristics of this model are a) disaggregation at the regional level of the Legal Amazon; b) an CGE structure with recursive dynamics; and c) land use modeling.

The theoretical structure of REGIA is based on the TERM model (Horridge et al., 2005). The sets of equations that make up the relations of demand and supply follow the hypothesis of optimization and conditions of market equilibrium. The sector production follows the minimization of costs subject to production technology with constant returns of scale and its composition of intermediate inputs and primary factor follow the Leontief function (fixed ratio). For each sector, the allocation of intermediate inputs is determined by substitution between domestic and imported products, following the constant substitution elasticity function (CES). In addition, the CES function determines other allocations such as domestic composition between regions and the choice between capital, labor and land. The land factor is used in the model by the agricultural, livestock and forestry sectors (Carvalho, 2014).

Regarding the mechanism of composition of the demand for goods, there is a representative family for each region that makes a choice between domestic and imported goods oriented by the CES function, in which goods of different origins are treated as imperfect substitutes (Armington hypothesis). Moreover, in the choice of these domestic goods there is still the option between different regions, being again specified by a CES function. Household consumption preferences are determined by the CES / Klein-Rubin utility function combination. From this function a linear system of expenses (LES) is created in which the share of consumption above the level of subsistence of each good represents the fixed proportion of the total subsistence consumption of each family.

As mentioned previously, one of the differentials of the REGIA is the land use module, also known as indirect land use change (ILUC), being a fundamental characteristic for the objective of the present work, which focuses on the dynamics of the decrease of agricultural productivity due to climate change. This module is inserted in the factor of land located in the composition of the primary factors (labor, capital and land), in which the factor is determined for

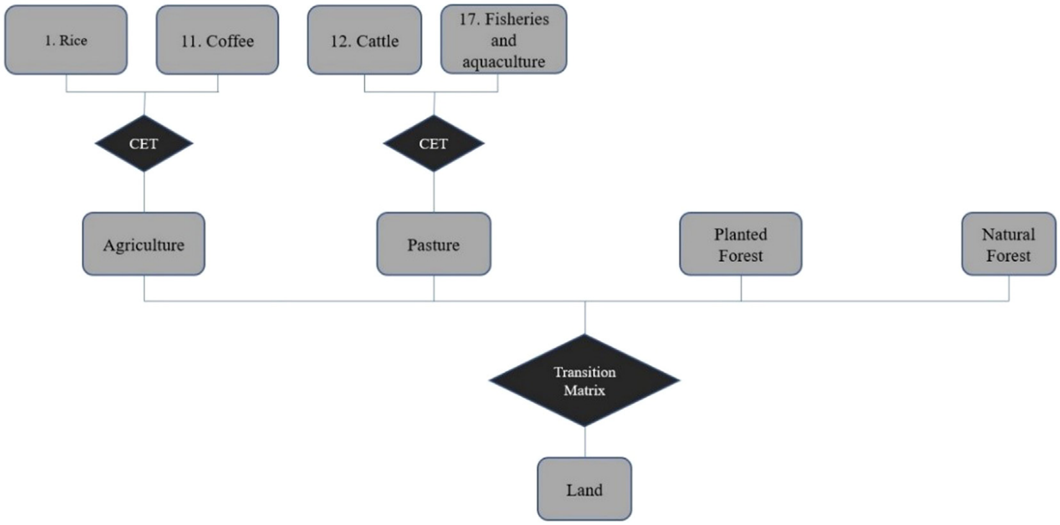

Fig. 2. Land Use in the REGIA Model. Source: CARVALHO et al., (2017).

each region so that the use of the total land area is fixed and without factor mobility between the regions, that is, the size of the territory of each region does not change.

Fig. 2 illustrates the structure of the land use module in the REGIA. At the first level there is the factor land that is disaggregated into three types of use in year t: a) Agriculture, used for tillage sector; b) pasture, used for livestock sector; and c) planted forest used for forestry. At this level, each land type can be allocated between different agricultural sectors according to the pay differential according to a CET (constant elasticity of transformation) function. At the second level, the land supply side allows conversion between different uses in years t and t + 1, controlled by a transition matrix[3] . This matrix represents the mobility of land between uses, indicating the possibilities of transformation (Carvalho et al., 2017).

Each sector of the model is assumed to be linked to one of these types of land use. The area of natural forest and other uses is defined as the total area of each mesoregion minus the areas of crop, pasture and planted forest. That is, it includes all areas that are not used in agroforestry systems, such as natural forests, urban areas, mountains, roads and rivers. These latter areas are considered to change more slowly than natural forests, and therefore the change (decrease) of this type of land use is a proxy for measuring deforestation for the expansion of agriculture or forestry. Besides that, to calculate the elasticity of land use supply all the areas of Legal Reserve (RL - imposed by the Brazilian Forest Code) and Permanent Preservation Areas (APPs) was removed from the available land. So, this elasticity reduces the possibilities of conversion in regions with large areas of APPs and RL.

In addition to the matrix, the conversion between uses also responds to the yield differential of land types and the magnitude of the response depends on the supply elasticity of the land. Elasticity varies according to the size of the available area, the larger the area, the greater the ease of conversion in terms of costs. Therefore, the dynamics of the land supply market is adjusted under the guidance of the transition matrix and the pay differential between uses. Finally, in the market equilibrium of the land, the variation of land demand is equal to the variation of the land supply, setting the total available supply for each region (Carvalho et al., 2017).

The REGIA database is generated by the IBGE input-output matrix for 2005, consisting of 110 products and 55 sectors, and complemented by deflated information from the 2006 Agricultural Census. Sources such as IBGE, RAIS, SECEX and POF implement regional information. Finally, the REGIA database presents a matrix structure of 31 regions[4] and 27 sectors[5] (Carvalho, 2014).

[3] The transition matrix and the elasticities are presented in Appendix B.
[4] See appendix C
[5] See appendix D

4.2. Shock building and simulation

In this work, the results of Assunção and Chein (2016) were used to calculate the shocks. The authors estimated the changes in the productivity of the Brazilian agricultural sector caused by climate change (precipitation and temperature) for each municipality in the period 2030 to 2049. The climatic scenario used in Assunção and Chein (2016) estimation was A1B from the 4th IPCC report. The A1B scenario describes a trajectory of the world with rapid economic growth with balanced use between fossil fuels and other energy sources (IPCC, 2007). Therefore, the results of the simulation of this work can be understood as the average effects of climate change, since the A1B scenario is an intermediate scenario between the most pessimistic (scenario A) and the most optimistic (scenario B).

For shock calculations, changes in average agricultural productivity at the municipal level estimated by Assunção and Chein (2016) were aggregated according to the regions of the REGIA model (30 mesoregions of the Legal Amazon and the rest of Brazil) weighted by the size of the agricultural production of each region. Where missing data existed, spatial data interpolation was applied to fill the gaps. Finally, the rate of average change in agricultural productivity of 2030-2049 was divided into four composite rates representing 4 five-year periods: 2030-2034, 2035-2039, 2040-2044 and 2045-2049. The values of the shocks are found in Appendix A.

In the simulation, the shocks were applied in 4 five-year periods on the variable “alnd” that represents technological change of the primary factor “land”. That is, the shocks applied to represent the climate change scenario were the decrease in the land productivity among all agricultural sectors of the REGIA model. Pasture and Planted Forest land were not affected by shocks. Furthermore, the shocks were specific by geographical areas, for every 30 mesoregions of the Legal Amazon and one single region composed by the rest of Brazil.

The projection of this work does not incorporate other effects of climate change such as floods, storms, droughts, savanization, shocks over other sectors, advances in technology, among others. Therefore, the results of the simulation capture only a portion of the impact of climate change on the Legal Amazon. The effects considered here were only the variations in the average accumulated precipitation and average temperature, which alter the productivity of agriculture. This type of limitation is recurrent in economic studies on climate change due to the uncertainty inherent in the theme and lack of availability or compatibility (e.g. temporal and spatial clipping) of data with the CGE methodology.

In CGE models, the closure is the determination of sets of endogenous and exogenous variables in simulations. This closure represents hypotheses about the economy and its adjustments to shocks (policies). The two closures used for the simulations are: i) historical and baseline closure, and ii) policy closure. At first, there is a historical closure, from 2006 to 2015 to update the database using observed macroeconomic variables according to IBGE data. In this case, the main national aggregates are exogenous, such as real GDP, investment, household consumption, government expenditure, exports and aggregate employment. Thus, other variables, such as the national shifter of normal gross rate of return, the economy-wide government demand shift, the export quantity shift, national propensity to consume, as well as technological change variable are endogenous. In this case, the model calculates how these variables accommodate the national aggregates. Another assumption is that regional areas for “natural forests and other uses” are exogenous updating the deforestation rates from 2006 to 2011 according to INPE data. At baseline from 2016 to 2050, the macroeconomic variables for the aggregate GDP, household consumption and government expenditure are still exogenous and the regional deforestation rates become endogenous. It is assumed that regional consumption follows the regional income and the government expenditure follows the household income. Labor moves between regions and activities, driven by real wages changes. The model works with relative prices, and the Consumer Price Index was chosen as a numeraire.

In the policy scenario, which represents a productivity shock, each macroeconomic variable is endogenous, with the aggregate national employment set exogenously. That is, aggregate employment is fixed relative to baseline, and labor can move regionally. It is assumed that national consumption follows the GDP with endogenous national propensity to consume. And the national total is distributed between regions in proportion to labor income. The government expenditure follows the income of households regionally and nationally. A restriction is imposed on the national balance of trade that determines its exogenous participation in the national GDP, which does not restrict the possibilities of adjusting to the balance of trade for each region individually. The selected closures follow the pattern of a recursive dynamics model. The results should be read as accumulated deviations from the baseline scenario where climate change did not occur.

4.3. REGIA Causality Mechanisms

In the REGIA model, the initial impact of a negative shock of land productivity, is the increase of cost of production, which in turn increases the market price and decreases production. The producers incorporate more land rather to maintain the level of production. At the same time, some capital and labor are attracted by the agricultural sectors to compensate the need for more land as a primary factor, since the availability of land is restricted. Even with the replacement of the land factor by labor and capital, there may be a decrease in employment and investment if the activity effect (output reduction) is more intense than the substitution effect (substitution between land, labor and capital factors).

Rising product prices and falling employment levels can have a downward impact on household consumption. Also, rising product prices in the region make exported products relatively more expensive. Therefore, the regions most affected will be those with the economy focused mainly on agriculture-export activities (Carvalho, 2014).

Another relevant aspect for the dynamics of the results is the participation on the regional GDP of the sector impacted by the productivity shock. This characteristic reinforces the influence of the productive structure of the model, originated from the input product matrix, on the results performance. Production share acts to soften or enhance the effects of the applied productivity shocks.

Therefore, the net effect of these direct and indirect causalities will determine the impact on the level of activity of each mesoregion, and this effect is influenced by the characteristics and integration of regional trade, as well as the productive structure of the regions (Carvalho, 2014).

5. Results

This section presents the results of the simulation of the REGIA model. As noted, the results represent the difference between the baseline scenario and the scenario with the effects of climate change. Therefore, they should not be read, for example, as absolute falls in GDP, but relative variations, in contrast to a scenario where changes did not occur.

5.1. Land Use

The economic sectors most vulnerable to the effects of climate change are agriculture and livestock, due to their dependence on temperature and rainfall for production. One hypothesis is that the decline in land productivity due to climate change would probably lead to an expansion of the agricultural frontier in the region to compensate for the decrease in soil productivity in order to maintain the level of production.

Table 1 shows the effect of changes in agricultural productivity on the areas of agriculture, pasture, planted forest and natural forest. The land-use mechanism of the REGIA model projects the land use dynamics by considering the total available area of the regions, the productivity of each region and the relative profitability of the crops. As the total available area of the regions is fixed, an increase of the land use of a certain sector necessarily implies a reallocation between uses[6] .

As expected, the simulation results in Table 1 indicates that there would be growth patterns in land area used by agriculture in all regions. In contrast, the results suggest a decrease in the area for pasture (cattle raising) and / or forests. Negative variations of the natural forest are interpreted in the model as deforestation. In addition, despite this convergent pattern of shock effect, each mesoregion was affected with a distinct magnitude due to its productive structure and the intersectoral and interregional relations typical of each region.

Also, in the table, the regions that would tend to expand land use (in millions of hectares) destined for agriculture would be Norte Mato-grossense and Baixo Amazonas. Therefore, these are the regions most affected by deforestation in terms of area. However, when the same variable is evaluated in terms of accumulated percentage variation between 2030 and 2049, the region that stands out is the Norte Maranhense, with a deforestation rate of 0.81% in relation to the base scenario (Fig. 3).

[6] The REGIA model deducts from the available area the areas of environmental preservation for the calculation of the supply elasticity that guides the allocation of different types of land use.

Table 1
Effect of climate change on crop area, pasture, planted forest and natural forest (millions of hectares) - accumulated value 2030-2049.

Mesoregion	**State**	**Agriculture**	**Pasture**	**Planted Forest**	**Natural Forest**
Madeira-Guaporé	RO	0,03	−0,02	0,00	−0,01
Leste Rondoniense	RO	0,06	−0,05	0,00	−0,01
Vale do Juruá	AC	0,05	−0,01	0,00	−0,04
Vale do Acre	AC	0,09	−0,05	0,00	−0,04
Norte Amazonense	AM	0,02	0,00	0,00	−0,02
Sudoeste Amazonense	AM	0,06	0,00	0,00	−0,05
Centro Amazonense	AM	0,13	−0,02	−0,01	−0,10
Sul Amazonense	AM	0,05	−0,01	0,00	−0,04
Norte de Roraima	RR	0,03	−0,01	0,00	−0,02
Sul de Roraima	RR	0,02	−0,01	0,00	−0,01
Baixo Amazonas	PA	0,21	−0,05	−0,02	−0,14
Marajó	PA	0,06	0,00	−0,01	−0,05
Metropolitana de Belém	PA	0,01	0,00	0,00	0,00
Nordeste Paraense	PA	0,08	−0,05	−0,01	−0,02
Sudoeste Paraense	PA	0,08	−0,03	−0,01	−0,04
Sudeste Paraense	PA	0,06	−0,04	−0,01	−0,01
Norte do Amapá	AP	0,00	0,00	0,00	0,00
Sul do Amapá	AP	0,01	0,00	0,00	−0,01
Ocidental do Tocantins	TO	0,13	−0,12	−0,01	0,00
Oriental do Tocantins	TO	0,04	−0,04	0,00	0,00
Norte Maranhense	MA	0,05	−0,03	0,00	−0,02
Oeste Maranhense	MA	0,04	−0,03	0,00	−0,01
Centro Maranhense	MA	0,04	−0,02	0,00	−0,01
Leste Maranhense	MA	0,01	0,00	0,00	0,00
Sul Maranhense	MA	0,01	−0,01	0,00	0,00
Norte Mato-grossense	MT	0,49	−0,29	−0,02	−0,19
Nordeste Mato-grossense	MT	0,13	−0,07	0,00	−0,05
Sudoeste Mato-grossense	MT	0,04	−0,03	0,00	−0,01
Centro-Sul Mato-grossense	MT	0,03	−0,03	0,00	0,00
Sudeste Mato-grossense	MT	0,04	−0,04	0,00	0,00
Amazônia Legal	-	2,10	−1,06	−0,10	−0,90

Source: Elaborated by the authors.

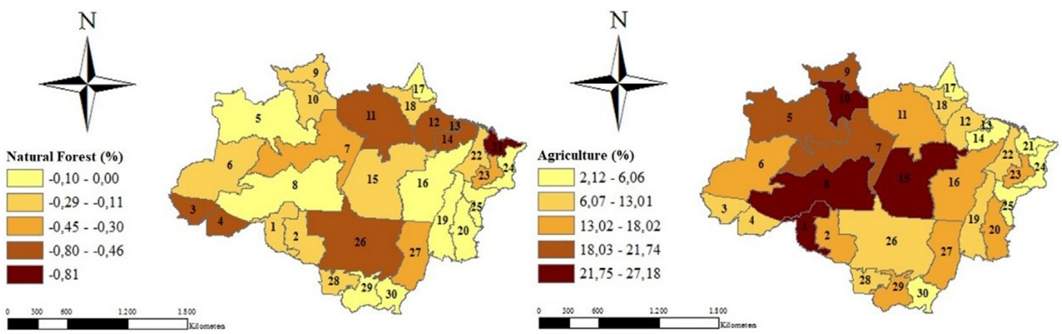

Fig. 3. Effects of climate change on natural forest (deforestation) and cropping areas in terms of accumulated percentage variation 2030 - 2049 in relation to the baseline scenario[a].

[a]Regions: 1- Madeira-Guaporé, 2- Leste Rondoniense, 3- Vale do Juruá, 4- Vale do Acre, 5- Norte Amazonense, 6- Sudoeste Amazonense, 7- Centro Amazonense, 8- Sul Amazonense, 9- Norte de Roraima, 10- Sul de Roraima, 11- Baixo Amazonas, 12- Marajó, 13- Metropolitana de Belém, 14- Nordeste Paraense, 15- Sudoeste Paraense, 16- Sudeste Paraense, 17- Norte do Amapá, 18- Sul do Amapá, 19- Ocidental do Tocantins, 20- Oriental do Tocantins, 21- Norte Maranhense, 22- Oeste Maranhense, 23- Centro Maranhense, 24- Leste Maranhense, 25- Sul Maranhense, 26- Norte Mato-grossense, 27- Nordeste Mato-grossense, 28- Sudoeste Mato-grossense, 29- Centro-Sul Mato-grossense, 30- Sudeste Mato-grossense.
Source: Elaborated by the authors.

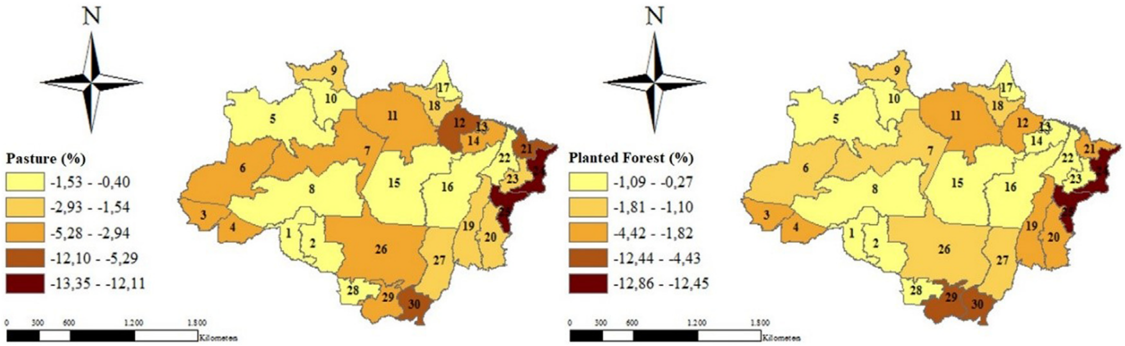

Fig. 4. Effects of climate change on pasture and planted forest in terms of accumulated percentage variation 2030 - 2049 in relation to baseline scenario. Source: Elaborated by the authors.

The mesoregions with the greatest increase in crop area as a result of a decrease in agricultural productivity would be Madeira-Guaporé, Sul Amazonense, Sul de Roraima and Sudoeste Paraense. The pasture areas, in turn, would present larger area reductions as a result of the expansion of the crop areas, as shown in Table 1. This effect is due to the greater ease of conversion of pasture to crop compared to other land use and to the fact that in the region of the Legal Amazon the activity of cattle raising has been developed extensively. Fig. 4 (left) illustrates the rate of reduction of pasture areas. The most impacted mesoregions would be Leste Maranhense and Sul Maranhense, with a fall, respectively, of 13.35% and 12.11% relative to the base scenario.

Fig. 4 (right) illustrates the rate of reduction of planted forest areas. The most impacted mesoregions would be Leste Maranhense and Sul Maranhense, with a decrease of 12.45% and 12.86%, respectively. However, observing Table 1 in terms of area (in millions of hectares) it is perceived that the effect on this land use is less intense when compared to the other uses. This indicates that there has been a greater shift of pasture areas to croplands than areas of natural forest (deforestation) to farming.

5.2. *Agricultural production*

Agricultural production will be highly affected by changes in rainfall and temperature as a result of climate change. Its effects, however, may be heterogeneous throughout the territory. In general, crops will be negatively impacted. Table 2 shows the percentage variation of production between the years 2030 and 2049, by mesoregion and by culture.

Table 3

The increase in the crop areas destined to suppress the decrease in the agricultural productivity would be insufficient. On average, there would be a decrease in the production of all crops in the Legal Amazon region. The greater impact would be verified in the production of sugar cane, with a drop of 11.34% in production.

The mesoregion Metropolitana de Belém would be the most affected if we analyze all the crops presented, mainly due to their small territorial extension and the unavailability of lands for the conversion, which would partially compensate the decrease in crop productivity. On average, the expected production decrease of soybeans, maize, sugar cane and rice in the mesoregion would be 20.2% in relation to the reference scenario. As for the small forest area still available for conversion, the mesoregions present in the states of Tocantins and Mato Grosso would also show significant reductions by these crops, with a decrease of 12.7% and 9.1%, respectively. However, such activities are more representative in terms of state GDP, indicating higher economic impacts.

The Norte Mato-grossense and Nordeste Mato-grossense mesoregions represents a large share of soybean and cotton production in GDP. The results indicate decreases in 6.2% of soybean production in Norte Mato-grossense and 5.4% in Nordeste Mato-grossense, also a decrease of 1.3% and 1.07% respectively for cotton production. Those impacts are significant for the economies of these mesoregions.

Cassava, whose share of agricultural GDP in the Legal Amazon is around 10%, will decline by 1.14% in the region, a small decrease compared to other crops. However, cassava consumption is important for the food security of a large part of the population and is mainly produced by relatively vulnerable family farmers. The mesoregions located in the states of Maranhão, Tocantins, Pará and Mato Grosso would be among the most affected by the decrease in production.

Table 2
Impact on agricultural production by mesoregion and crop (cumulative percentage deviation between 2030-2049 in relation to base scenario.

Mesoregion	State	Rice	Corn	Soybean	Sugarcane	Cotton	Manioc	Other crops
Madeira Guaporé	RO	−0,92	−1,92	−1,97	−4,43	−0,38	−0,47	−0,4
Leste Rondoniense	RO	−11,93	−12,05	−11,78	−14,82	−2,72	−1,64	−2,26
Vale do Juruá	AC	−4,55	−4,9	−5	−7,45	−0,93	−0,73	−0,94
Vale do Acre	AC	−10,58	−10,56	−10,32	−13,34	−2,14	−1,33	−1,92
Norte Amazonense	AM	2,1	1,38	0,78	−0,78	0,12	−0,21	0,01
Sudoeste Amazonense	AM	0,54	−0,23	−0,76	−2,6	−0,03	−0,24	−0,19
Centro Amazonense	AM	−1,72	−2,24	−2,48	−4,98	−0,42	−0,48	−0,41
Sul Amazonense	AM	3,57	2,22	1,93	0,12	0,29	−0,1	0,16
Norte de Roraima	RR	−1,07	−1,94	−1,52	−3,98	−0,29	−0,44	−0,47
Sul de Roraima	RR	2,74	1,51	1,49	−0,42	0,22	−0,14	0,02
Baixo Amazonas	PA	−6,03	−6,37	−5,92	−9,35	−1,32	−0,93	−1,13
Marajó	PA	−2,71	−3,3	−3,22	−6,19	−0,56	−0,43	−0,39
Metropolitana de Belém	PA	−19,86	−19,73	−19,16	−22,09	−5,14	−2,77	−4,15
Nordeste Paraense	PA	−16,28	−16,14	−15,61	−18,98	−3,69	−2,01	−2,91
Sudoeste Paraense	PA	2,11	1,4	1,35	−0,8	0,19	−0,16	0,09
Sudeste Paraense	PA	−7,29	−8,12	−7,85	−10,89	−1,82	−1,14	−1,41
Norte do Amapá	AP	6,83	4,84	4,36	3,39	0,6	0,03	0,41
Sul do Amapá	AP	4,07	2,32	2,22	0,36	0,29	−0,23	0,15
Ocidental do Tocantins	TO	−14,27	−14,5	−13,7	−17,43	−3,34	−2,04	−2,58
Oriental do Tocantins	TO	−9,46	−10,06	−9,69	−12,51	−2,52	−1,67	−1,95
Norte Maranhense	MA	−5,72	−6,48	−6,14	−9,44	−1,13	−0,78	−0,99
Oeste Maranhense	MA	−9,51	−10,25	−10,15	−13,02	−2,5	−1,49	−1,94
Centro Maranhense	MA	−7,83	−8,28	−8,24	−11,19	−1,88	−1,12	−1,5
Leste Maranhense	MA	−15,97	−15,86	−15,34	−18,94	−3,62	−2,13	−2,84
Sul Maranhense	MA	−12,4	−12,56	−12,22	−15,77	−2,95	−1,84	−2,06
Norte Mato-grossense	MT	−6,41	−6,33	−6,82	−9,75	−1,32	−1,03	−1,1
Nordeste Mato-grossense	MT	−4,75	−5,23	−5,4	−8,17	−1,07	−0,83	−0,94
Sudoeste Mato-grossense	MT	−9,55	−9,64	−9,62	−12,52	−2,1	−1,38	−1,68
Centro-Sul Mato-grossense	MT	−9,72	−9,77	−9,81	−12,6	−2,05	−1,22	−1,55
Sudeste Mato-grossense	MT	−10,52	−10,11	−9,98	−13,48	−2,36	−1,59	−1,67
Amazônia Legal	-	−7,55	−7,9	−7,87	−11,34	−1,89	−1,14	−2,21

Source: Elaborated by the authors

Table 3
Macroeconomic variables by state and Legal Amazon Region (cumulative percentage deviation between 2030 and 2049 related to the base scenario).

State	Family Consumption	Investment	Government Consumption	Exports	Imports	GDP
Rondônia	−0,87	−2,85	−0,84	−0,26	−0,65	−0,94
Acre	−0,76	−2,57	−0,72	−0,13	−0,81	−0,78
Amazonas	−0,38	−1,15	−0,36	−0,23	−0,31	−0,32
Pará	−1,49	−3,95	−1,32	−0,25	−1,08	−1,18
Roraima	0,06	−0,20	0,07	−0,08	−0,06	−0,08
Amapá	−0,80	−2,35	−0,83	−0,14	−0,94	−0,75
Tocantins	−1,65	−5,44	−1,66	−0,34	−1,94	−1,69
Maranhão	−1,07	−3,24	−0,86	−0,36	−0,97	−1,05
Mato Grosso	−1,68	−4,56	−1,62	−0,21	−1,32	−2,00
Amazônia Legal	−1,03	−3,34	−1,03	−0,23	−0,94	−1,18

Source: Elaborated by the authors

Some crops in specific regions can benefit from climate change. According to projections, the state of Amapá and the mesoregions of Norte Amazonense, Sul Amazonense, and Sul de Roraima are the only ones whose production of some commodities, such rice, corn and soybeans, would be benefited.

The simulations also pointed to the reduction of the livestock production, mainly of cattle, and in smaller part in the production of milk, pork and poultry. The largest reduction in beef cattle ranching is related to the loss of pasture area

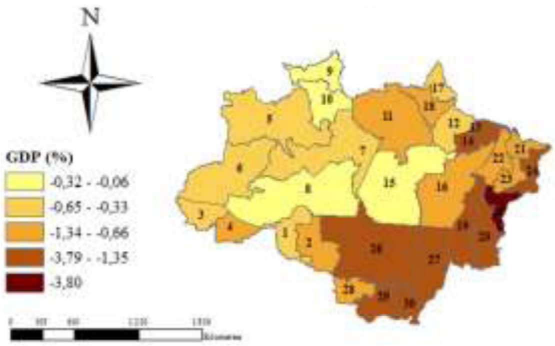

Fig. 5. Impact of climate change on real GDP - accumulated percentage deviation from 2030 to 2049. Source: Elaborated by the authors.

that is now destined for agriculture. Extensive and low productivity systems of cattle production are a characteristic of the legal Amazon region, indicating an easier replacement of land use.

It is emphasized that the impacts on livestock and forest production are indirect in the model. The agricultural sectors, due to the negative productivity shock, attract labor, capital and land from other sectors, changing their production costs. The magnitude of allocation depends above all on the remuneration differential from agricultural, livestock and forestry activities, given the factor costs between the model regions. In regions where livestock and forestry activities have a more competitive return, there will be less allocation of production factors with the agricultural sector, and therefore less expansion of cropland over pasture and planted forest areas.

5.3. Macroeconomic results for the region of the Legal Amazon

The macroeconomic effects of changes in rainfall and temperature show that climate change will be prejudicial to the economy of the Legal Amazon. The projected results indicate a decrease in the main macroeconomic variables of the region, in terms of household consumption, government, investment, exports, imports, GDP, employment and real wages.

The most affected states would be Mato Grosso, Tocantins and Pará, showing higher decreases in the macroeconomic aggregates than the average of the Legal Amazon. While the GDP of the Legal Amazon would be negatively impacted by 1.18% in relation to the base scenario, the reduction for these three states will be 2%, 1.69% and 1.18% respectively. This performance is due to the greater participation of agricultural activities in the economy of these states.

Fig. 5 illustrates at the meso-regional level the cumulative percentage deviation of real GDP in the period between 2030 and 2049 in relation to the base scenario. The effect of climate change is heterogeneous. The mesoregions that would suffer the greatest effects are located in the eastern and southern regions of the Legal Amazon, while the least affected regions are concentrated in the northern and western portions.

The states of Mato Grosso and Tocantins due to their greater dependence on agricultural activities would be the most affected states in terms of economic activity. The respective average accumulated decrease in GDP for these states is 2.00% and 1.69% between 2030 and 2049 in relation to the base scenario (the average decrease for the Legal Amazon would be 1.18%). This result indicates how negatively the phenomenon of climate change can affect food security, since the greatest impact would be located mainly in the regions that are big producers of soy and cattle, and part of this production is directed to supply the international demand of commodities.

6. Conclusion Remarks

The objective of the article was to simulate the effects of the productivity decrease due to climatic changes on the main agricultural crops in the region of the Brazilian Legal Amazon considering the period from 2030 to 2049, in order to project the possible impacts on land use and on the main economic indicators of the region.

The simulations indicate that during the period 2030 to 2049, climate change will bring negative impacts to the economy of the Legal Amazon. However, the effects are heterogeneous over the territory. The results suggest a gradual replacement of pasture areas (-0.3%) and natural forest (-0.3%) for cropping areas (0.6%), indicating that the decrease in agricultural productivity should be partially offset by territorial gain by the sector and with negative impacts on livestock and on deforestation. The GDP of the Legal Amazon will show a cumulative decrease of 1.2% in 2049 (in relation to the base scenario), as well as in household consumption (-1.03%), investments (-3.34%), government consumption (-1.03%), exports (-0.23%) and imports (-0.94%).

Since the agricultural sector is directly affected by climate change, the most dependent states on this activity, such as Mato Grosso, Tocantins and Pará, will have more significant impacts in terms of GDP decrease, with a cumulative reduction of 2%, 1.69% and 1.18% respectively, during the period analyzed. The most impacted crops in these states are corn (-9.06%), rice (-8.82%), soybean (-8.87%) and sugarcane (-11.9%).

Therefore, climate change can potentially have adverse effects on the economic and social dynamics of the Legal Amazon region. The impacts and their effects will be heterogeneous regionally and sectorally, causing imbalances, already quite present, in the region. In this way, climate change mitigation and adaptation policies become necessary to mitigate the probable economic, social and environmental damages.

Appendix A. Land productivity shocks

Table A.1

Table A.1
Land productivity shocks by region (2030-2049) (in five-year rates).

Mesoregion	State	Shocks
Madeira Guaporé	RO	−6,66
Leste Rondoniense	RO	−9,24
Vale do Juruá	AC	−9,21
Vale do Acre	AC	−10,35
Norte Amazonense	AM	−9,75
Sudoeste Amazonense	AM	−9,51
Centro Amazonense	AM	−11,01
Sul Amazonense	AM	−10,65
Norte de Roraima	RR	−5,89
Sul de Roraima	RR	−4,33
Baixo Amazonas	PA	−7,67
Marajó	PA	−9,84
Metropolitana de Belém	PA	−8,23
Nordeste Paraense	PA	−8,55
Sudoeste Paraense	PA	−9,88
Sudeste Paraense	PA	−7,55
Norte do Amapá	AP	−2,54
Sul do Amapá	AP	−4,69
Ocidental de Tocantins	TO	−9,8
Oriental de Tocantins	TO	−9,9
Norte Maranhense	MA	−7,21
Oeste Maranhense	MA	−3,72
Centro Maranhense	MA	−7,58
Leste Maranhense	MA	−8,13
Sul Maranhense	MA	−8,87
Norte Matogrossense	MT	−6,94
Nordeste Matogrossense	MT	−9,33
Sudoeste Matogrossense	MT	−10,22
Centro-Sul Matogrossense	MT	−10,32
Sudeste Matogrossense	MT	−7,42
Rest of Brazil	-	−4,36

Source: Prepared by the authors

Table B.1
Transition Matrices - million hectares (Database - TerraClass and Agricultural Census).

Brazil	Agriculture	Pasture	Planted Forest	Natural Forest and other	Total
Agriculture	85.81	1.19	0.11	5.62	92.74
Pasture	10.75	157.82	1.49	7.3	177.36
Planted Forest	0.12	1.78	16.37	0.76	19.03
Natural Forest and other	0.1	1.53	1.36	559.37	562.36
Total	96.78	162.32	19.33	573.06	851.49
Sudeste do Pará	Agriculture	Pasture	Planted Forest	Natural Forest and other	Total
Agriculture	0.25	0.03	0.01	0.03	0.32
Pasture	0.07	9.43	0.2	0.08	9.78
Planted Forest	0	0.11	2.37	0.01	2.49
Natural Forest and other	0	0.19	0.4	16.61	17.2
Total	0.32	9.76	2.98	16.73	29.8

Source: Carvalho (2014)

Appendix B. Transition Matrix

In REGIA model the transition matrix was built based on the methodology of Ferreira Filho and Horridge (2014), and calibrated with TerraClass satellite data from 2008 and 2010 (obtained from PRODES / INPE), and data from the 1995 and 2006 Agricultural Census (IIBGE, 2006) for the 30 mesoregions of the Brazilian Legal Amazon. The calibrated matrix indicates how land use changes between different types (agriculture, pasture, planted forest, and unused land) over time. Between two periods (years), the model allows land to move between agriculture, pasture and planted forest, and the unused land to become one of three (Carvalho, 2014).

The conversion[7] possibilities used in the transition matrix are illustrated in Chart B1. The transition matrix can be expressed as a percentage share (that is, the total sum of lines is equal to 100) showing the Markov probabilities that a particular hectare of land used for pasture would be used the next year for agriculture, for example.

Chart B1 illustrates that in one region, 90% of the total land at period t remains the same usage at $t+1$ (sum of main diagonal). The first column shows that 2.25% of what would be Pasture on t will become Agriculture in $t+1$, and 0.23% of what would be Planted Forest and 0.23% of what would be Natural Forest will become agriculture in $t+1$. It is noted that 2.25% of what would be Planted Forest, and 2.25% of what would be Natural Forest will become Pasture at $t+1$. The transition matrix for Brazil and Sudeste do Pará are illustrated in Table B.1.

In Table B.1, the sums of rows and columns reflect current land use in the base year (2005) and the potential change in land use in the following year. The numbers inside the off-diagonal table shows that approximately 10 million hectares of pasture have been converted to agriculture land in Brazil. For the Sudeste do Pará region, the table shows that approximately 70 thousand hectares of pasture have been converted to agriculture.

The supply of land in each category (crop, pasture, planted forest and natural forest) for each region increases according to the annual percentage growth rate of each use given by the transition matrix. In addition to this annual growth rate, the transition matrix is adjusted for the next period distributing the current stock of land in year t for next year, t + 1, in response to changes in the remuneration of land according to a CET function. That means that even if the transition matrix is calibrated from observed data, the matrix is subsequently modified endogenously according to changes in the average remuneration of each type of land in each region (Ferreira Filho et al., 2015). Then in REGIA, these probabilities or proportions are modeled as a function of the variation in the remuneration of each type of land according to the land supply elasticity (Carvalho et al., 2017).

The elasticity of land supply is a sensitivity parameter that measures the response of land supply to remuneration variations and was calculated according to the methodology used in Van Meijl et al., 2006 and Farias (2012). The elasticity of land supply with respect to land price changes should reflect the notion that greater land availability is related to higher values of elasticity. A greater availability of land implies an easier process of land conversion in terms

[7] The conversion possibilities from Chart B.1, used to calculate the transition matrix, are hypothetical values and were based on the land use conversion direction which assumes that forests would initially be converted to pasture areas that would eventually be able to be converted into crop areas (Ferreira Filho and Horridge, 2012; Macedo et al., 2012; Barona et al., 2010; Cattaneo, 2002).

Table B.2
Land Supply Elasticities.

Region	Elasticity	Region	Elasticity	Region	Elasticity
Madeira Guaporé	1,05	Marajó	1,45	Centro Maranhense	0,87
Leste Rondoniense	0,55	Metropolitana de Belém	0,3	Leste Maranhense	1,27
Vale Juruá	1,39	Nordeste Paraense	0,41	Sul Maranhense	1,15
Vale Acre	0,92	Sudoeste Paraense	1,37	Norte Matogrossense	0,9
Norte Amazonense	1,65	Sudeste Paraense	0,56	Nordeste Matogrossense	0,98
Sudoeste Amazonense	1,62	Norte do Amapá	1,59	Sudoeste Matogrossense	0,63
Centro Amazonense	1,52	Sul do Amapá	1,56	Centro-Sul Matogrossense	1,32
Sul Amazonense	1,58	Ocidental de Tocantins	0,5	Sudeste Matogrossense	0,7
Norte de Roraima	1,55	Oriental de Tocantins	0,93	Restante do Brasil	0,32
Sul de Roraima	1,52	Norte Maranhense	0,76		
Baixo Amazonas	1,37	Oeste Maranhense	0,54		

Source: Carvalho (2014)

of costs. Thus, if the remuneration of agriculture increases in relation to the remuneration of pasture in year t (demand side), the rate of conversion from pasture to agriculture will increase, and thus, the amount of land devoted to cropland in t + 1 also increases. Thus, the transition matrix is adjusted annually as is the supply of land (Carvalho et al., 2017). Table B.2 presents the land supply elasticities.

Appendix C. Regions of REGIA model

Table C.1

Table C.1
Regions of the REGIA model.

Region		UF	Region		UF
1	Madeira Guaporé	RO	17	Norte do Amapá	AP
2	Leste Rondoniense	RO	18	Sul do Amapá	AP
3	Vale Juruá	AC	19	Ocidental de Tocantins	TO
4	Vale Acre	AC	20	Oriental de Tocantins	TO
5	Norte Amazonense	AM	21	Norte Maranhense	MA
6	Sudoeste Amazonense	AM	22	Oeste Maranhense	MA
7	Centro Amazonense	AM	23	Centro Maranhense	MA
8	Sul Amazonense	AM	24	Leste Maranhense	MA
9	Norte de Roraima	RR	25	Sul Maranhense	MA
10	Sul de Roraima	RR	26	Norte Matogrossense	MT
11	Baixo Amazonas	PA	27	Nordeste Matogrossense	MT
12	Marajó	PA	28	Sudoeste Matogrossense	MT
13	Metropolitana de Belém	PA	29	Centro-Sul Matogrossense	MT
14	Nordeste Paraense	PA	30	Sudeste Matogrossense	MT
15	Sudoeste Paraense	PA			
16	Sudeste Paraense	PA			

Source: Carvalho (2014)

Appendix D. Sectors of REGIA model

Table D.1

Table D.1
Sectors of the REGIA model.

Sector	Goods
Agriculture	1. Rice, 2. Corn, 3. Wheat and cereals, 4. Sugarcane, 5. Soybean, 6. Other crops, 7. Cassava, 8. Tobacco, 9. Cotton, 10. Citrus Fruits, 11. Coffee bean
Livestock	12. Cattle, 13. Milk and Cow, 14. Pigs, 15. Birds, 16. Eggs, 17. Fishing
Silviculture and Forest Management	18. Silviculture and Forest Management
Industry	19. Mining Industry, 20. Food and Beverage, 21. Other Industries, 22. Electronics, appliances and electric goods
Services	23. Trade, 24. Transportation, 25. Construction, 26. Services
Public Administration	27. Public Administration

Source: Carvalho (2014)

Appendix E. Sensibility test

The systematic sensitivity analysis employed in this work follows the Gaussian quadrature methodology proposed by Devuyst and Preckel, 1997. In this approach, the EGC model is treated as a numerical integration problem in which the solution of the model (result of endogenous variables) can be obtained simultaneously. Through this problem, we obtain two first moments (mean and variance), given a distribution of exogenous variables (parameters or shocks). Thus, the estimates of mean, standard deviation and confidence intervals for the model results are obtained. This information represents qualitative data regarding the sensitivity of the model's results to specific parameters and may suggest the elements to which the researcher's attention should be focused. The sensitivity test established a 50% interval for these parameters, with uniform distribution.

The sensitivity tests showed that the aggregate results for the regions, such as GDP, investment and household consumption are robust, being very little sensitive to the variation of the elasticities. In the early years, the results are very robust, slightly increasing the coefficient of variation - measured by dividing the average by the standard deviation - only at the end of the simulated period (2040 to 2050), mainly for investment results.

As for the sectoral impacts on agriculture production, the results of some regions were sensitive to parameterization. In the case of the elasticity of land supply, six regions were sensitive to parameterization, mainly of rice, corn, sugar and soy products. The regions are: Madeira Guapore, Vale do Jurua, Sul do Amazonas, Sudoeste do Pará, Oeste do Maranhão e Centro do Maranhão. Two other regions showed moderate sensitivity: Norte de Roraima and Baixo Amazonas. In the case of the elasticity of substitution of primary factors, the sectorial results for the Madeira Guaporé, Vale Jurua and Western Maranhão regions were slightly sensitive. The sensitivity analysis shows that the specification of these parameters for smaller regions, such as those reported, deserves further investigation. On the other hand, for the other elasticities, the sectorial results were, in general, robust.

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