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Controlling deforestation in the Brazilian Amazon: Regional economic impacts and land-use change

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ABSTRACT

Brazil confirmed targets for reducing greenhouse gas emissions in 2008, including an 80% reduction in deforestation in the Amazon by 2020. With this in mind, we investigated the trade-off between environmental conservation and economic growth in the Amazon. The aim of this study is to project the economic losses and land-use changes resulting from a policy to control deforestation and the rise in land productivity that is necessary to offset those losses. We developed a Dynamic Interregional Computable General Equilibrium Model for 30 Amazon regions with a land module allowing conversion between types of land. The results have shown that the most affected regions would be soybeans and cattle producers as well as regions dominated by family farms. To offset these impacts, it was estimated that an annual gain of land productivity of approximately 1.4% would be required.

1. Introduction and Background

Deforestation in the Brazilian Amazon has attracted the attention of researchers and public authorities toward methods and policies that involve both its measurement and control. In addition to the importance of conserving one of the largest biomes of ecological diversity (Peres et al., 2010) and harboring the largest area of primary forest in the world – 35% of the world's total primary forest (FAO, 2010) – the region has become the target of policies to reduce deforestation because it constitutes an important measure in the mitigation of emissions of greenhouse gases (GHG).

The Amazon region has already lost about of 15% of its total forest area. However, according to INPE (2013), there was a decline in deforestation rates from 2004 to 2012. This decline is related to economic factors, such as the reduction in international soybean and beef prices and the appreciation of the Brazilian currency, which discouraged exports. Another contributing factor is the increased surveillance of the Amazon, which has been made possible by the implementation of government programs, such as the Action Plan for the Prevention and Control of Deforestation in the Amazon (Soares-Filho et al., 2009; Assunção et al., 2012).

Arima and Veríssimo (2002) pointed out that the three major forms of deforestation in the Amazon are: (i) the conversion of forest into pasture for livestock; (ii) cutting and burning to convert forest into crops for family farming; and (iii) deployment of grain crops by agro-industry. Of these, the conversion of forests into pasture is predominant (Margulis, 2003). They have also argued that the drastic reduction in tax incentives for agricultural enterprises in the late 1980s lead to a reduction in the pace of deforestation, which, however, did not occur. In the 1990s, other factors than the government development projects[1] became more decisive in the maintenance of deforestation, primarily predatory logging, extensive livestock farming and agrarian reform settlements.[2]

Some projections suggest that deforestation, despite a reduction in its rates between 2004 and 2012, may expand in the coming decades. Soares Filho et al. (2005) estimated that the projected

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[1] The government development projects appear to affect deforestation, mainly in the decades of 1970 and 1980 (Pfaff, 1999).
[2] Land reform policies and violent conflict in the Amazon region can be seen in Alston et al. (2000).

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deforestation will eliminate 40% of the current 5.4 million km^2 of forests by 2040 if the occupancy patterns follow the trajectory of the last two decades. Moreover, an increase in deforestation implies a growth of GHG emissions associated with changes in land use. According to Gouvello (2010)'s estimates, the total emissions from land-use change and forests in Brazil may grow by 25% by 2030, reaching an annual rate of 916 thousand tons of CO_2 equivalent, which may compromise the target reductions of reducing GHG proposed by the Brazilian government.

The latest deforestation estimates in the Amazon published by INPE (2013) showed that from 2012 to 2013, there was an approximate 30% increase in the deforestation rate, which seems to confirm these previous projections. Although it is the second lowest rate recorded by INPE since the monitoring system began in 1988, it is an indication that deforestation could increase in the future. The prospect of increased deforestation in the Amazon has even more force when considering the adoption of some measures in the New Forest Code,[3] which was approved in May 2012. Included among the points of the New Code is a reduction of the limit of the legal reserve (RL) in the region[4] and a regularization of the smallholder farmers, excluding them from the obligation of recovering areas that were deforested in permanent preservation areas (APPs.) According to IPEA (2011), the recovery of deforested legal reserves would offset the emissions of 3.15 billion tons of carbon, which would be enough to meet the Brazilian government's four-year target to reduce emissions from deforestation.

This target assumed by the Brazilian government was presented in 2009 at COP15.[5] The proposal was a voluntary reduction in GHG emissions mainly through an 80% reduction in deforestation by 2020. Thus, combating deforestation in Brazil has become a priority for the government as well as for the international organizations that are concerned with global warming's effects. According to Fearnside (2005), an effective surveillance and the collection of taxes from those who do not have authorization from the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) should be accompanied by the necessary understanding of the social, economic and political aspects of the region. Bringing this concern to the economy of the regions in the Amazon, the question arises as to how the control of deforestation can restrict agricultural expansion, which represents an important economic activity in the region. Without alternatives for growth in agriculture and other sectors, which are indirectly affected, there may be a tradeoff between the goals of regional economic growth and the preservation of the forest.

Some options are indicated to reconcile the economic growth of the region with sustainable development and the reduction of deforestation. For example, the intensification of agriculture by increasing land productivity. This increase in productivity would allow the same area, which has been deforested, to produce a greater output amount without expanding the deforested area as crop or pasture land through additional deforestation.

In this context, it is relevant to investigate the aspects of a possible tradeoff between environmental conservation and economic growth in the region. Furthermore, it is important to understand the relationship among agricultural activities with the land occupation and use. The goals of this paper, therefore, are: (i) to evaluate the impacts of land-use policies on regional growth in Amazon[6]; (ii) to investigate the role of agricultural technical improvement in the region. We built an interregional dynamic computable general equilibrium model (CGE) for 30 regions in the Amazon and the rest of Brazil, called REGIA (Interregional General Equilibrium Model for the Brazilian Amazon).[7] REGIA has a module of land-use change that enables it to model the conversion of different categories of land use. The incorporation of the land module into REGIA is fundamental in the analysis of the effects of a policy that restricts land use and directly affects the agricultural activity in the region.

The development of economic models with land use change module has been started with Darwin et al. (1995). The advantage of CGE models with land use specification is the possibility to capture the economic effects of changes in the pattern of land. Thus, CGE models would incorporate the behavior of producers toward demand of land according to the different possibilities of use. Due to the optimizer behavior, the allocation of land would be directed to the productive uses that provide the highest return (Farias, 2012). Usually, CGE models with land use in the literature can be divided into two different approaches, the comparative static and the dynamic models. However, it is observed that the process of land use change is a highly dynamic process (Heistermann et al., 2006). Therefore, land use decisions do not depend only on the past and current uses, but on future expectations - especially in sectors such as forestry, where long-term planning is essential. The disadvantage of comparative statics models is the inability to describe trajectories and the future behavior of land use. This makes REGIA more appropriate for studies focusing on deforestation.

According to Heistermann et al. (2006), an important aspect of the land use treatment in the production process is its heterogeneity. The land productivity may vary between products, regions and time. The main reasons for the differences, as pointed out by the authors, are the biophysical characteristics of the land, such as climate and soil. One way to introduce this heterogeneity is to adopt the imperfect substitutability between the different sectors and uses. Another advantage of REGIA is to model this heterogeneity through a transition matrix which drives the movements of land between uses.

Therefore, REGIA was used to simulate a scenario considering the targeted deforestation reduction of 80% by 2020 in accordance with the National Plan on Climate Change – PNMC (2008), followed by a zero deforestation policy from 2021 to 2030 which is part of the most recent proposal of the Brazilian government. Moreover, a simulation was performed to estimate the land productivity gains needed to offset the adverse effects of the deforestation policy on the Amazon economy.

2. Methodology

2.1. REGIA model

REGIA is a Computable General Equilibrium model (CGE) with a recursive dynamic and land-use module for 30 regions of the Brazil-

[3] The Brazilian Forest Code was created by Law No. 4771 on September 15, 1965. The Code sets limits on property use, which must coincide with existing vegetation on the ground for the common good of all inhabitants of Brazil. The first Brazilian Forest Code was established by Decree No. 23,793, on January 23, 1934.

[4] The portion to be preserved in the current Forest Code is 80%, but is decreased to 50% in states that have 65% of their territory designated as protected areas or indigenous lands.

[5] COP15 (United Nations Conference on Climate Change), held from December 7–18, 2009, in Copenhagen brought together 193 member countries of the United Nations Framework Convention on Climate Change. Its proposal was to define a global action agenda to control global warming and ensure the survival of the human species.

[6] This paper is a contribution of the Brazilian Network on Global Climate Change Research funded by CNPq Grant Number 550022/2014-7 and FINEP Grant Number 01.13.0353.00. Edson P. Domingues also thanks CNPq (Produtividade em Pesquisa) and Fapemig (Programa Pesquisador Mineiro).

[7] REGIA refers to the aquatic lily pad that is typical of the Amazon region. It has a large leaf-shaped circle, which lies on the surface of the water, and can grow to be up to 2.5 meters in diameter and support up to 40 pounds if well distributed on its surface.

Table I
Sectors disaggregation of REGIA.

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: Elaborated by the authors.

ian Legal Amazon[8] and the rest of Brazil. It is a bottom-up model, that is, a multiregional model where the national results are aggregations of the regional results. Moreover, it is the first CGE model built for the Amazon economy with this very detailed regional disaggregation. The model consists of 27 sectors in each one of the 30 regions, including 18 agricultural commodities as shown in Table I.

REGIA has some improvements over other CGE models that also examined issues related to the Amazon and deforestation, such as Pattanayak et al. (2009) and Cattaneo (2001). The first improvement is the treatment of land use in a recursive dynamic model so we can analyze the impacts of different scenarios over time as well as the endogenous adjustment of land supply. The second improvement is the largest regional disaggregation – 30 regions of the Amazon and the rest of Brazil.

REGIA has a core theoretical structure similar to the Australian TERM, an acronym for The Enormous Regional Model (Horridge et al., 2005). TERM is a Johansen type bottom-up multi-regional CGE model that is derived from the continued development of the ORANI (Dixon et al., 1982) model and its generic version, the ORANI-G (Horridge, 2000). TERM was developed to address disaggregated regional data and also to allow for the generation of faster solutions for simulations relative to available models (Horridge et al., 2005).

REGIA is composed of blocks of equations that determine relationships between supply and demand, according to optimization assumptions and market-clearing conditions. In addition, several national aggregates are defined in these blocks as the aggregate employment, GDP, balance of trade and price indexes. The most productive sectors minimize production costs subject to a technology of constant returns to scale in which the combinations of intermediate inputs and primary factors (aggregated) are determined by fixed coefficients (Leontief). There is substitution via the prices of domestic and imported goods in the composition of inputs according to the function of the constant elasticity of substitution (CES). A CES specification also controls the allocation of a domestic compound among the various regions. In REGIA, substitution also takes place between capital, labor and land in the composition of the primary factors through CES functions; however, the land factor is allocated only in the agriculture and livestock sectors.

The goods of a given region that are directed to another are compounded by the basic values and the trade and transport margins. The share of each margin in the delivery price is a combination of origin, destination, goods and source (domestic or imported). Margins on goods from one region to another can be produced in different regions. It is expected that margins are distributed more or less equally between the origin and destination or between intermediate regions in the case of transport from more distant regions. In addition, there is substitution between suppliers of margins, according to a CES function.

In the model, there is a representative household for each region consuming domestic and imported goods. The choice between domestic and imported goods (from other countries) is held by a CES (Armington assumption[9]) specification. The treatment of household demand is based on a combined system of preferences, CES/Klein-Rubin. Thus, the utility derived from consumption is maximized according to this utility function. The specification gives the linear expenditure system (LES),[10] in which the share of expenditure above the subsistence level for each good represents a constant proportion of the total subsistence expenditure of each family.

The REGIA model has a recursive dynamic specification. Investment and capital stock follow mechanisms of accumulation and intersectoral shift from pre-established rules related to the depreciation and rates of return. Thus, one of the modifications to make REGIA a dynamic model was to connect the annual investment flows to the capital stocks.

The model does not include a process of temporal labor market adjustment. For the simulations in this paper, which has a time horizon of 25 years, a configuration was adopted where the national aggregated employment in the baseline is exogenous (from 2006 to 2011, adjusted with observed data, and from 2012 is determined by population growth). In the policy scenario, the aggregate national employment is fixed relative to the baseline scenario. This implies an endogenous response of the average wage with the fixed sectoral wage and regional wage differentials. Thus, there is intersectoral and regional labor mobility.

Government consumption is exogenous. The model operates with market equilibrium for all goods, both domestic and imported, as well as the market factors (capital, land and labor) in each region. The purchase prices for each user in each region (producers, investors, households, exporters, and government) are the sum of the basic values, sales taxes (direct and indirect) and margins (trade and transport). Sales taxes are treated as ad valorem taxes on basic flows. Demands for margins (trade and transport) are proportional to the flow of goods to which the margins are connected.

2.2. The land use module

One of the advantages of REGIA is the incorporation of a land-use module. Land is one of the primary factors in the model, in addition to capital and labor, and it is an important factor in the production of agricultural sectors. Land use is modeled separately for each region, keeping the total area fixed and divided into four types: (i) cropland, (ii) pasture, (iii) planted forest and (iv) natural forest and other areas. In the model, the agricultural sectors/goods, as well as land use, are specific to each region.

[8] Throughout the paper we use the word "Amazon" to refer to the "Brazilian Legal Amazon".

[9] Armington hypothesis – goods of different origins are treated as imperfect substitutes.

[10] The LES function is suitable for broad aggregates of goods where specific substitutions are not considered. That is, cross-price elasticities are equal to the income effect given in the Slutsky equation without any contribution from the cross-price effects. This implies that all goods have a weak complementarity. The linear expenditure system does not allow the inclusion of inferior goods (that is, negative income elasticities).

It is assumed that each agricultural sector of the model is connected to one of these types of land uses. The area of natural forest and other uses is defined as the total area of each region minus the cropland, pasture and planted forest. That is, it includes the whole areas that are not used in agro-forestry systems, such as natural forests, urban areas, mountains, roads and rivers. These latter areas are thought to change more slowly than natural forests, and therefore, the change (decline) in this type of land use is a proxy for measuring deforestation by the expansion of agriculture or livestock.

The land process is guide by two levels of substitution as shown in Fig. 1. At the first level, cropland and pasture may be allocated between different agricultural sectors according to the remuneration gap. Thus, the demand for land responds to changes in the land remuneration to each sector. At this level, each land use (cropland, pasture and planted forest) is distributed in year t according to a CET (constant elasticity of transformation) function[11] between different commodities for each region:

$$x_{ir} = x_r + \alpha_{ind}(p_{ir} - p_r) \quad (1)$$

where x_{ir} is the percentage change in the demand for land allocated to sector i[12] in region r; p_{ir} is the percentage change in the land remuneration to sector i in region r; x_r is the percentage change of the total land (cropland, pasture and planted forest) in region r; and p_r is the average remuneration to all sectors in region r. Thus, if in one region the remuneration to sector i is above the average remuneration in the region ($p_{ir} - p_r > 0$), then a positive change in the allocation of land will occur toward sector i.

The total change in the demand for each land use for each region is given by $x_r = \Sigma_k S_k x_k$, using the distribution of the remuneration S_k, with k representing the various lands uses. However, we should adopt a physical limit to the total area in region r, which will be $\sum_k H_k x_k = 0$, using the distribution of land in hectares H_k. Therefore, to maintain constant the total area, a physical variable in hectares, n_{kr}, was used for each land use type by region r and computed by:

$$n_{kr} = x_{kr} + \mu \quad (2)$$

in which μ is calculated so that $0 = \sum_k H_k n_k$ to guarantee that the total physical supply of land will be fixed. Thus, the demand for land, according to the different uses, is connected to the land supply in the model. The idea is that the demand for land, x_{kr}, influences the process of the conversion of land between the uses that is, the supply side, n_{kr}. In the REGIA model, this is operationalized upon determining that the variation of demand for land is equal to the variation of supply for land. This mechanism guarantees the equilibrium in the land market, fixing the total regional land available.

At the second level, supply side of land will allow the factor to move between different categories of land between year t and year $t+1$. A CET function could not capture the conversion process between the types of land uses. For this, the conversion process is controlled by a transition matrix representing the conversion possibilities of land between year t and year $t+1$. The matrix represents the mobility of land between uses, indicating the possibilities of the transformation of different types of land.

The transition matrix captures the fact that the most productive land is initially used in the production process, and at the same time, the use of marginal land that could be converted into productive use is limited. The economic process of land conversion is as follows: initially, forests would be converted into pasture, which ultimately could be converted into cropland (Ferreira Filho and Horridge, 2012; Cattaneo, 2002; Macedo et al., 2012; Barona et al., 2010). Therefore, the matrix shows that the conversion between uses, such as cropland from pasture, for example, is more easily performed than that for cropland directly from natural forests. If the difference between the amount of land used in agricultural production and the total area of the region is large, the rise in the demand for land will lead to a greater conversion of land for agricultural uses. This, in turn, will lead to an increase in the remuneration of land to offset the costs associated with this conversion.

The transition matrix was built based on the methodology developed by Ferreira Filho and Horridge (2014), and calibrated with satellite data from TerraClass[13] 2008 and 2010 (obtained from Prodes/INPE) along with data from the Agricultural Census for 1995 and 2006[14] (IBGE) for the 30 regions in the Brazilian Amazon. The calibrated matrix indicates how land use changes between different types (cropland, pasture, planted forest and natural forest) over time. The cropland area is used to produce all the commodities of agriculture sector, pasture area is used to produce goods of livestock sector and planted forest area to produce silviculture and forest management sector.

Between two periods (years), the model allows land to move between cropland, pasture, planted forest, or natural forest and to be converted into one of the three. The transition matrix[15] are illustrated in Chart 1. The sum of the lines represents the land use in year 2008, and the sum of the columns represents the land use in year 2010. The matrix was built using a bi-proportional adjustment method, known as RAS,[16] of rows and columns scaling. The off-diagonal elements show the areas of land that have changed between the two periods.

Chart 1 shows in the first line and column that 5 of 5.9 million hectares, which was cropland in 2008, remained as cropland in 2010. The first column also shows that 2.3 of 44.5 million hectares, which was pasture in 2008, were converted to cropland in 2010. The last line shows the transformation of natural forest into other uses, which can be understood as deforestation. For example, 4.3 million of hectares, which were natural forest in 2008, were converted to pasture in 2010. And another 22.1 million of hectares were converted from natural forest in 2008 into planted forest in 2010.

The land supply in each category (cropland, pasture, planted forest and natural forest) for each region increases according to the

[11] Within each region, the area of "Cropland', for example, in the current year is predetermined. However, the model allows a given area of "Cropland" to be re-allocated among crops according to a CET rule where CET = 0.5 (Ferreira Filho and Horridge, 2014).

[12] i = 1 (rice), 2 (maize), 3 (wheat and cereals), 4 (sugar cane), 5 (soybeans), 6 (other crops), 7 (cassava), 8 (tobacco), 9 (upland cotton), 10 (citrus fruits), 11 (coffee beans), 12 (forestry and silviculture), 13 (cattle), 14 (milk and beef), 15 (pigs) 16 (birds) and 17 (eggs). Products 1 to 11 are linked in the model code to the cropland; good 12 is related to the use of planted forests and, finally, products 13 to 17 for pasture use.

[13] This article falls under the URBIS Amazonia project that discusses the influences of social and economic factors in the process of urbanization in the Amazon. This project was conducted by a multidisciplinary team led by the INPE, which provided the TerraClass data for the construction of the transition matrix to REGIA. See the following link to published papers of the URBIS Amazônia project: <http://www.dpi.inpe.br/urbisAmazonia/doku.php?id=urbis:producao>

[14] The data used to construct the transition matrix were given by TerraClass. However, because the data source for the sectoral output was from the IBGE, some adjustments had to be made using the Agricultural Census data because some sectors had production according to IBGE data, but did not have output according to data from TerraClass. This adjustment was minimal and represented less than 10% of the land-use data. The option for TerraClass data is explained by the quality of information from satellite data compared to Census data, which is based on farmers' responses.

[15] The transition matrix assumes that natural forests would be initially converted into areas for pasture and that after some time would be able to be converted into areas for crops. We built a transition matrix for the 30 regions in Amazon and for the rest of Brazil.

[16] The RAS method is an interactive mechanism that seeks to adjust the values of the rows and columns of a matrix, with its total considering the proportionality of the total values. This method calculates a new set of values for a matrix of cells from a previous structure, causing the sum of the rows and columns to be consistent with the expected total. More information about the RAS method can be found in Miller and Blair (2009).

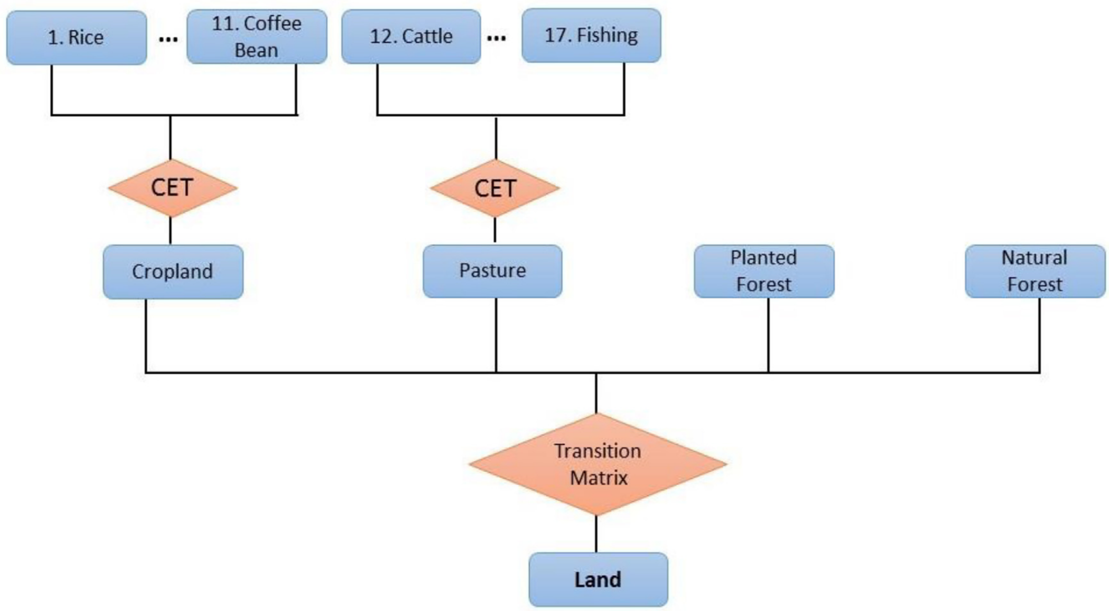


Fig. 1. Land allocation in REGIA.

Source: Elaborated by the authors.

Conversion Possibilities	Cropland	Pasture	Planted Forest	Natural Forest	Total in 2008
Cropland	5.0	0.2	0.2	0.5	5.9
Pasture	2.3	39.5	2.0	0.6	44.5
Planted Forest	0.2	0.9	13.7	0.2	15.0
Natural Forest	0.8	4.3	22.1	413.5	440.8
Total in 2010	8.3	44.9	38.1	414.9	506.2

Source: Elaborated by the authors according to INPE data

Chart 1. Brazilian Amazon transition matrix used in REGIA model (in millions of hectares).

Source: Elaborated by the authors according to INPE data.

annual percentage growth rate of each use given by the transition matrix:

$$N_{k,t+1} = 100 * \frac{\Delta N_{k,(t+1,t)}}{N_{k,t}} \quad (3)$$

In addition to this annual growth rate, to adjust the transition matrix for the next period, the current stock of land in year t is distributed for next year, $t+1$, responding to changes in the remuneration of land. The transition matrix can be expressed as a percentage share (that is, the total sum of lines is equal to 1) showing the Markov probabilities that a particular hectare of land used for pasture would be used the next year for cropland, for example. 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:

$$S_{pkr} = \mu_{pr} \cdot L_{pkr} \cdot P_{kr}^{\beta_{lnd}} \cdot M_{kr} \quad (4)$$

where the subscript r denotes the region. S_{pkr} is the participation of land of the p type that becomes k in region r. μ_{pr} is an adjustment variable to ensure that $\Sigma_k\, S_{pkr} = 1$. L_{pkr} is a constant of calibration that represents the initial value of S_{pkr} (given by the transition matrix). $P_{kr}^{\beta_{lnd}}$ is the average remuneration of land of the type k. β_{lnd} is a sensitivity parameter that measures the response of the supply of land in relation to changes in the remuneration. $M_{k,r}$ is a shift variable with an initial value equal to 1. Thus, the land supplies are summed to determine the total area of each type of land in each region and year.

The sensitivity parameter, β_{lnd} represents the elasticity of land supply and was calculated according to 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. We can see the elasticity by region in Table II.[17] A greater availability of land implies an easier process of land conversion in terms of costs. Thus, if the remuneration of cropland increases in relation to the remuneration of pasture in year t (demand side), the rate of conversion from pasture to cropland will increase, and thus, the amount of land devoted to cropland in $t+1$ also increases. To model the conversion rate of natural forests, it was necessary to consider a fictitious remuneration, which was the Final User Price Index. Thus, the transition matrix is adjusted annually as is the supply of land.

[17] To build this elasticity was removed from the available land all the areas of: Legal Reserve (RL – imposed by the Brazilian Forest Code) and Permanent Preservation Areas (APPs). So, this elasticity reduces the possibilities of conversion in regions with large areas of APPs and RL.

Table II
Elasticity of land supply by region in Amazon and the rest of Brazil.

Region	State	Elasticity of land supply	Region	State	Elasticity of land supply
Madeira Guapore	RO	1.05	Norte	AP	1.59
Leste de Rondonia	RO	0.55	Sul	AP	1.56
Vale do Jurua	AC	1.39	Ocidental	TO	0.50
Vale do Acre	AC	0.92	Oriental	TO	0.93
Norte	AM	1.65	Norte	MA	0.76
Sudoeste	AM	1.62	Oeste	MA	0.54
Centro	AM	1.52	Centro	MA	0.87
Sul	AM	1.58	Leste	MA	1.27
Norte	RR	1.55	Sul	MA	1.15
Sul	RR	1.52	Norte	MT	0.90
Baixo Amazonas	PA	1.37	Nordeste	MT	0.98
Marajo	PA	1.45	Sudoeste	MT	0.63
Metropolitana de Belem	PA	0.30	Centro-Sul	MT	1.32
Nordeste	PA	0.41	Sudeste	MT	0.70
Sudoeste	PA	1.37	Rest of Brazil	–	0.32
Sudeste	PA	0.56			

Source: Elaborated by the authors.

2.3. The database

According to Horridge (2012), the database of regional CGE models often assumes regional input-output matrices as a start point. Although, even when those matrices are available it could present some problems as: (i) few sectors disaggregation; (ii) inconsistent or incomplete regional data with different sources of data; and (iii) and it is not appropriate to use in a CGE model. Besides all these problems, there is no input–output matrices for the Amazon regions. Then, the database for the REGIA model was constructed through a process of regionalization of a national CGE model.[18] The procedure was based on the methodology developed by Horridge (2006) and was adapted for the Brazilian case. Basically, from the input-output data for 2005 and a large set of regional data,[19] we estimated an interregional trade matrix using a distance matrix and a gravitational approach. The main hypothesis of the gravitational approach[20] is that interregional trade is based on the distance between the regions and the interaction derived from the size of its economies.

Details of the procedure for building a database for REGIA are in Carvalho (2014). The result of this procedure is a consistency of the database with the official data of National Accounts, Input-Output Matrix, IBGE (*Brazilian Institute of Geography and Statistics*) information, International Trade (SECEX – *International Trade Secretary*), Industrial Production (IAP) and Employment (RAIS – *Annual List of Social Information*). One of the most important components of the database for the simulations is the remuneration of land by region. In the model, land remuneration was allocated to the agricultural and livestock sectors. The land remuneration was obtained from the data of the "Expenditure incurred by establishments – from Leasing" of the 2006 Agricultural Census (IBGE).[21]

Table III presents the shares of economic and population data for the 30 Amazon regions in the model and rest of Brazil.

3. Closure and simulations

3.1. Model closure

Model 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). REGIA is a dynamic model and allows for the accumulation of capital over time as well as adjustments to the land market. The three closures used for the simulations are: (i) historical closure, (ii) baseline closure and (iii) policy closure.

At first, there is a historical closure, from 2006 to 2011 to update the database using observed macroeconomic variables according to IBGE data. In this case, the main national aggregates are considered to be 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 2012 to 2030, 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

[18] The main database to build the regional data for REGIA was the BRIDGE model, a national CGE model for Brazil consisting of 110 products and 56 sectors which was made in Cedeplar/UFMG (Domingues et al., 2010).

[19] The regional data was built using: regional output shares (by sector and by region) – IBGE (Brazilian Institute of Geography and Statistics and RAIS, regional investment shares (by sector and by region) – RAIS (Annual List of Social Information), regional household consumption shares (by goods and by region) – POF (Household Budget Survey) and IBGE, regional exports shares (by goods and by region) – SECEX, regional government expenditure shares (by goods and by region) – IBGE, regional inventories shares (by goods and by region) – RAIS, regional imports shares (by goods and by region) – SECEX, regional population – IBGE.

[20] A widespread theoretical justification for the idea that bilateral trade flows are positively associated with regional incomes and negatively with the distance between them is based on a trade model developed by Krugman (1980). Further details about the method and some applications can be found in Miller and Blair (2009).

[21] The division of this information between livestock and agriculture was taken in accordance with the lease of land values by activity groups. For example, for agriculture, the rental values of the groups were combined, such as the temporary crop output, horticulture and floriculture, permanent crops output, seeds, seedlings and other forms of plant propagation and forestry production. For livestock, the rental values of the groups were also combined, such as livestock and keeping other animals, fisheries and aquaculture. Because the model's database comes from 2005, a deflator was applied to the monetary values of the Agricultural Census to be equal to the input-output matrix. Thus, we obtained the national land remuneration for agriculture and livestock. The last step was to divide the remuneration of land by region, given that the value of it is proportional to the production of agriculture and livestock in each region.

Table III
Shares of economic and population data for the 30 Amazon regions and the rest of Brazil.

Regions	State	Share in the Brazilian GDP (%)	Share in the Amazon GDP (%)	Share in the Brazilian Population (%)	Regions	State	Share in the Brazilian GDP (%)	Share in the Amazon GDP (%)	Share in the Brazilian Population (%)
Madeira Guapore	RO	0.21	2.78	0.30	Norte	AP	0.02	0.21	0.02
Leste de Rondonia	RO	0.34	4.40	0.53	Sul	AP	0.21	2.67	0.30
Vale Jurua	AC	0.04	0.53	0.11	Ocidental	TO	0.28	3.65	0.50
Vale Acre	AC	0.16	2.12	0.26	Oriental	TO	0.15	1.93	0.26
Norte	AM	0.02	0.20	0.06	Norte	MA	0.60	7.76	1.21
Sudoeste	AM	0.05	0.61	0.19	Oeste	MA	0.31	4.08	0.69
Centro	AM	1.54	20.03	1.37	Centro	MA	0.11	1.43	0.48
Sul	AM	0.05	0.60	0.13	Leste	MA	0.05	0.63	0.46
Norte	RR	0.13	1.70	0.17	Sul	MA	0.07	0.87	0.15
Sul	RR	0.02	0.30	0.04	Norte	MT	0.47	6.09	0.45
Baixo Amazonas	PA	0.14	1.85	0.37	Nordeste	MT	0.11	1.42	0.14
Marajo	PA	0.04	0.53	0.23	Sudoeste	MT	0.13	1.66	0.16
Metropolitana de Belem	PA	0.86	11.17	1.29	Centro-Sul	MT	0.46	5.96	0.55
Nordeste	PA	0.18	2.37	0.89	Sudeste	MT	0.32	4.09	0.22
Sudoeste	PA	0.07	0.97	0.26	**Legal Amazon**		**7.71**	**100.00**	**12.52**
Sudeste	PA	0.57	7.41	0.75	**Rest of Brazil**		**92.29**		**87.48**

Source: Elaborated by the authors.

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. "Natural forests and other uses" is exogenous only for regions in the model that do not comprise tropical forests and where the capacity for agricultural expansion through deforestation is small. In REGIA, this group is formed by Sudeste (MT), Centro-Sul (MT), Sul (MA), Leste (MA), Oriental (TO) and the rest of Brazil.

In the policy scenario, 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.

3.2. Simulations

The baseline shows a 3% per year growth of the national economy for the period from 2012 to 2030 and represents the projection that is compared to the policy scenario[22]. Thus, real GDP, household consumption and government expenditure are expected to grow at 3% per year, while population growth is set at 1% per year. In addition to these variables, projections of soybean and cattle exports demand were taken from Nassar (2011) consistent with FAO (2003)[23] projections. The reason for using projection of exports demand for soybeans and cattle is based on the fact that the export market for these products is considered an important determinant of deforestation in the region. Soybean and cattle exports demand were projected to increase by 4.25% and 2.01%, respectively, representing a total increase of 130% in soybean exports demand and 49% in cattle exports demand by 2030.

The aim of the policy scenario is to represent the deforestation control policy proposed in the PNMC (2008), projecting the impact of an 80% reduction in deforestation by 2020 and a 100% reduction from 2021 to 2030, which means achieving zero deforestation in regions of the Brazilian Amazon. In REGIA, the control of deforestation in the Amazon implies limiting the expansion of the land factor for productive uses in agriculture. In general, the restriction on land supply will reduce the possibility of converting natural forest areas into other productive uses, such as cropland, pasture and planted forest. The first round impact of the policy is an increase in the remuneration of land with negative economic impacts because of the rise in the production cost of agricultural goods. This will directly decrease the activity level in the agricultural sector and indirectly decrease the activity level in other sectors. Moreover, limiting deforestation tend to engender more intense impacts on regions where the economy is dependent on agricultural activities.

Another effect induced by the simulation is that a more expensive factor (land) encourages a shift toward other primary factors (capital and labor). Even with the replacement from land to labor and capital, there may be a reduction in employment and investment if the activity effect (declining output) is stronger than the substitution effect (between land, labor and capital). The increase in prices of all goods and the drop in employment levels may have the effect of reducing household consumption. Because the model is interregional, restricting deforestation also reallocates output toward least affected areas. These impacts are consistently designed by REGIA, which takes into account the regional interdependence. This spillover effect of policies is an important feature of regional economies in Brazil.

The reduction in land supply also has an effect on exports. The increase in the domestic prices of goods in all regions makes the exported products relatively more attractive than imported goods. Hence, the most affected regions are those where the economy is primarily aimed at agro-exported activities. In summary, the net effect of the direct and indirect causalities will drive the impact on the activity level of each region, and this effect is determined by the characteristics, as the regional trade integration and production structures.

Finally, the last simulation aims to identify the gains in land productivity that would offset the adverse economic effects of the simulated policy of deforestation in the Amazon. The idea behind this simulation is that economic agents or related public policies may respond to deforestation control by modifying the agricultural techniques and livestock to mitigate the constraints imposed by controlling deforestation.

[22] For more details on the baseline scenario, see Carvalho (2014).
[23] Brazil is modeled as a small open economy and the shock in the simulation was given in the variable "Export quantity shift".

Table IV
Simulated Impacts of Controlling Deforestation from 2012 to 2030 – accumulated deviation relative to Baseline (in % change).

Regions	State	Regional GDP	Household consumption	Government expenditure	Investment	Employment	Exports	Imports
Madeira-Guapore	RO	−1.12	−1.08	−1.08	−1.82	−1.10	−0.19	−0.92
Leste de Rondonia	RO	−1.69	−1.58	−1.58	−2.71	−1.61	−0.23	−1.24
Vale do Jurua	AC	−1.25	−1.13	−1.13	−1.86	−1.16	−0.07	−1.13
Vale do Acre	AC	−1.37	−1.27	−1.27	−2.08	−1.29	−0.10	−1.25
Norte	AM	−1.66	−1.12	−1.12	−2.15	−1.14	0.01	−1.53
Sudoeste	AM	−1.46	−1.26	−1.26	−2.00	−1.28	0.04	−0.98
Centro	AM	−0.72	−0.73	−0.73	−1.26	−0.75	−0.25	−0.62
Sul	AM	−0.80	−0.73	−0.73	−1.26	−0.75	0.04	−0.42
Norte	RR	−1.02	−0.98	−0.98	−1.65	−1.01	−0.08	−1.04
Sul	RR	−0.61	−0.58	−0.58	−1.04	−0.60	−0.04	−0.57
Baixo Amazonas	PA	−1.66	−1.44	−1.44	−2.10	−1.46	−0.36	−1.16
Marajo	PA	−1.70	−1.22	−1.22	−1.90	−1.25	−0.01	−0.94
Metropolitana de Belem	PA	−0.66	−0.65	−0.65	−1.19	−0.67	−0.25	−0.65
Nordeste	PA	−0.86	−0.62	−0.62	−1.73	−0.64	−0.15	−0.81
Sudoeste	PA	−0.62	−0.52	−0.52	−1.12	−0.54	−0.12	−0.45
Sudeste	PA	−0.65	−0.58	−0.58	−1.06	−0.60	−0.25	−0.48
Norte	AP	−0.66	−0.58	−0.58	−1.10	−0.61	−0.06	−0.64
Sul	AP	−0.84	−0.83	−0.83	−1.38	−0.85	−0.11	−0.84
Ocidental	TO	−0.05	−0.04	−0.04	−0.11	−0.06	−0.09	−0.02
Oriental	TO	0.06	0.09	0.09	−0.06	0.06	−0.07	0.05
Norte	MA	−0.69	−0.65	−0.65	−1.11	−0.67	−0.26	−0.71
Oeste	MA	−1.09	−0.93	−0.93	−1.63	−0.95	−0.28	−0.80
Centro	MA	−1.38	−1.08	−1.08	−1.95	−1.10	−0.29	−0.96
Leste	MA	−0.23	−0.22	−0.22	−0.59	−0.24	−0.23	−0.29
Sul	MA	0.28	0.32	0.32	0.09	0.30	−0.15	0.11
Norte	MT	−3.56	−3.04	−3.04	−4.46	−3.06	−0.34	−2.30
Nordeste	MT	−2.96	−2.49	−2.49	−3.62	−2.51	−0.39	−2.08
Sudoeste	MT	−2.14	−1.94	−1.94	−3.26	−1.96	−0.33	−1.39
Centro-Sul	MT	−0.96	−1.00	−1.00	−1.66	−1.03	−0.21	−0.97
Sudeste	MT	0.14	0.17	0.17	−0.03	0.14	−0.15	0.15
Rest of Brazil	–	0.06	0.11	0.11	0.01	0.09	−0.11	0.05
Legal Amazon	–	−1.06	−0.91	−0.93	−1.55	−0.98	−0,20	−0.82

Source: Elaborated by the authors based on simulation results from the REGIA model.

4. Discussion and analysis of results

4.1. Regional macroeconomic results

The policy results presented here are reported as the cumulative percentage deviation (2012–2030) relative to the baseline scenario. Table IV presents the results for the major macroeconomic indicators by region. In general, the impact of the policy to control deforestation does not seem to be excessive. The most negative impacts would be in regions that are important producers of soybean and cattle and the regions where the family farm is the main activity. The six regions with major negative impacts on GDP were Norte (MT) (−3.6%), Nordeste (MT) (−3%), Sudoeste (MT) (−2.1%), Marajó, Baixo Amazonas and Leste Rondoniense (approximately −1.7% each). Considering the Norte (MT), for example, the interpretation of this result is that the region would attain a cumulative growth 3.6% lower than the one obtained in a scenario without the policy (the baseline scenario).

This greater impact on the Norte and Nordeste (MT) is explained in part because these regions have the highest shares of land remuneration on GDP of the entire Amazon. Moreover, agriculture accounts for over 50% of the total production in these regions[24]. The decline in GDP in Norte (MT) is a significant result because it is one of the largest regions in Amazon and is especially important in soybean and cattle production. The Sudeste (MT), Baixo Amazonas and Leste Rondoniense regions are economies based on agricultural activities, explaining the negative impact.

The silviculture and forestry activity accounts for more than 50% of all of the production in Marajo, with another 30% distributed among agriculture sectors. This high share of agricultural production and forestry makes this region one of the most affected by the policy. Also noteworthy is that the decline in investment and household consumption were major drivers of the decrease in GDP. Leste Rondoniense also has presented a large decline in GDP, which is a significant result because the region is an important producer of cattle, accounting for over 13% of cattle in Amazon.

As expected, the regions that would be less affected are those that do not have areas of natural forests to be converted into productive use. Some of these regions, such as Sul (MA), Sudeste (MT), Oriental (TO) and the rest of Brazil, even present a small gain in GDP (0.35%, 0.20%, 0.12% and 0.06%, respectively). This result can be explained mainly by the dynamics of the labor and capital market. Employment will increase in regions less affected by the policy, which will then lead to lower cost increases. Thus, these regions showed small gains in GDP due to the interregional migration which causes a drop in real wages that benefits the other regions. This result does not reflect a change in the location of deforestation for the rest of Brazil, because in the simulation there is a restriction of land expansion in all regions with different biomes of the Amazon, and land is a variable determined exogenously. The positive impact, almost negligible, is more related to movements in the market of primary factors such as capital and labor, and interregional trade.

[24] The shares of Agriculture, Livestock, Silviculture and Forest Management in the total production in each region and the shares of remuneration of land in the total of primary factors can be seen in Appendix I.

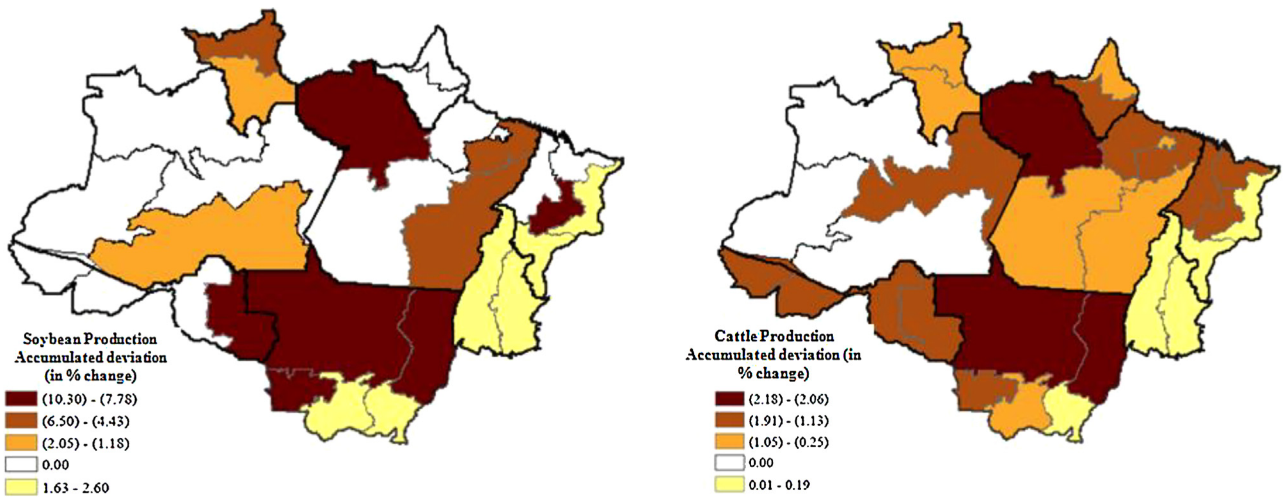


Fig. 2. Percent change in soybean and cattle production resulting from the policy to control deforestation (accumulated deviation from 2012 to 2030 relative to baseline). *Source*: Elaborated by the authors based on simulation results from the REGIA model.

This simulated policy represents a direct increase in the costs of agricultural production – the main economic activity in the Amazon – and has negative impacts on exports. The increase on production costs represents an increase in the final prices of goods and makes domestic production relatively more expensive than the imported goods, discouraging exports. Likewise, the effect of the drop in activity also reduces imports. As the regions cannot convert more land into productive use, they seek to replace the land factor for labor and capital. This suppresses the investment/capital ratio, promoting a decline in investment due to low rates of return. Employment also decreases, which suggests that the activity effect (decrease in GDP) is greater than the substitution effect (among the primary factors). The fall in employment leads to a consequent reduction in household income and consumption, which is an indication that the policy causes a loss of welfare.

4.2. Sectoral results

The policy has a negative impact mainly on the agricultural sectors. Soybean production is an important sector in Amazon and accounts for approximately 35% of the national production. Of the whole soybeans produced in the Amazon, nearly 60% are from the Norte (MT), followed by Sudeste (MT) and Nordeste (MT), which together produce over 25% of the total soybeans. Soybean production is considered to be one of the main drivers of deforestation, so the negative impact was expected. Fig. 2 shows the impact of the policy on the soybean and cattle sectors.

In Fig. 1 we have represented in white the regions in the database that the soybean and cattle production is virtually zero. Both the Norte and Nordeste (MT) are among the regions most affected by the policy. In general, production costs increase more in regions that are targets of the policy to control deforestation. This implies that in regions where there are greater production costs impacts,[25] the drop in activity level will be greater as well. In particular, soybean production is the sector with the greatest variations in production costs (one of the most modern agriculture production in Brazil).

Cattle production is also an important sector in Amazon and accounts for almost 30% of the national production. Its production is concentrated in Leste (RO), Sudeste (PA), Norte (MT) and Sudoeste (MT). We can observe from Fig. 2 that the regions where cattle production is concentrated are among the most adversely affected by the policy. Cattle activity is also considered to be an important driver of deforestation in the region but shows lower cost increases than soybeans. This is because of the lower remuneration of land in pasture areas than in croplands in the Amazon.

Table V presents the sectoral results with an aggregation of the 27 sectors into 6 major industries. Because of the free movement of goods and factors within the Brazilian economy, the region "rest of Brazil" shows a positive impact in all industries. However, regions as Centro-Sul (MT), Sul (MA) and Leste (MA), Oriental (TO) and Ocidental (TO), even if they do not have areas of natural forests to be converted into productive use, presented a decline in production of many industries. This is because of the strong commercial relationship between regions inside Amazon. And because of the linkage between the sectors, Industries, Services and Public Administration Sectors, present also a decline in its production, even if they are not affected directly by the restriction of land. In general, the results suggest that the largest sectoral negative impact occurs mainly on important agricultural regions such as Norte (MT), Nordeste (MT) and Sudeste(MT), and Leste (RO) and on regions dominated by small family farms such as Vale Acre and Baixo Amazonas.

4.3. Land-use results

Fig. 3 shows the projection of land use in Amazon in the policy scenario. Given the reduction goal, aggregate deforestation in the Amazon would decline over time which means an avoided deforestation relative to the baseline. This can be seen in the upward trend in the natural forest area, which is projected to increase to 14.56 million hectares in 2030 relative to the baseline scenario. Because the total area of the region is fixed, the growth of a particular land use must be accompanied by a reduction in another land use. Thus, we note that reducing deforestation is only possible by the reduction of cropland, pasture and planted forest relative to the baseline. In this instance, a reduction in these areas means that in the economic growth scenario (baseline) there would be less conversion of natural forests (deforestation) into these areas.

Because land conversion, as established in the REGIA, assumes that areas of natural forest are first converted into pasture, pasture areas would suffer the greatest reductions because of the policy. Therefore, these areas would decrease by approximately nine million hectares compared to the baseline. Then, the crop areas and planted forest areas would present a decline in response to the

[25] A table with the costs variation for soybean and cattle can be seen at the Appendix.

Table V
Percent change in production by sector resulting from the policy to control deforestation (accumulated deviation from 2012 to 2030 relative to baseline).

Region	State	Agriculture	Livestock	Silviculture	Industries	Services	Public
Madeira Guapore	RO	−1.12	−0.90	−2.12	−0.49	−1.21	−1.10
Leste Rondoniense	RO	−2.95	−1.23	−2.69	−0.68	−1.60	−1.53
Vale Jurua	AC	−1.42	−1.11	−2.56	−0.75	−1.15	−1.14
Vale Acre	AC	−1.61	−1.29	−3.78	−0.72	−1.18	−1.21
Norte	AM	−1.28	−0.46	−2.56	0.00	0.00	−0.82
Sudoeste	AM	−1.37	−0.56	−3.01	−0.86	−1.20	−1.19
Centro	AM	−1.58	−0.44	−2.62	−0.55	−0.81	−0.76
Sul	AM	−0.74	−0.36	−0.82	−0.28	−1.00	−0.98
Norte	RR	−1.89	−0.90	−1.46	−0.49	−0.84	−0.98
Sul	RR	−0.51	−0.56	−0.64	−0.43	−0.64	−0.92
Baixo Amazonas	PA	−2.41	−1.39	−2.57	−0.59	−1.18	−1.17
Marajo	PA	−1.36	−0.95	−2.43	−0.34	−1.12	−0.90
Metropolitana de Belem	PA	−0.80	−0.53	0.25	−0.44	−0.67	−0.65
Nordeste	PA	−1.09	−0.90	−0.17	−0.53	−0.82	−0.64
Sudoeste	PA	−0.69	−0.47	−0.55	−0.58	−0.83	−0.71
Sudeste	PA	−1.83	−0.61	−0.49	−0.46	−0.59	−0.60
Norte	AP	−0.93	−0.88	−1.43	−0.32	−0.49	−0.77
Sul	AP	−1.22	−1.22	−2.39	−0.47	−0.80	−0.83
Ocidental	TO	0.28	0.00	0.84	−0.13	−0.27	−0.17
Oriental	TO	1.28	0.05	0.96	0.02	−0.14	−0.05
Norte	MA	−0.84	−0.91	−4.67	−0.51	−0.60	−0.66
Oeste	MA	−1.91	−0.81	−2.95	−0.56	−0.82	−0.82
Centro	MA	−3.10	−0.77	−2.64	−0.62	−0.79	−0.79
Leste	MA	0.48	−0.14	0.50	−0.44	−0.57	−0.43
Sul	MA	0.97	−0.12	0.52	−0.15	−0.07	−0.49
Norte	MT	−3.75	−1.76	−3.77	−1.42	−2.45	−2.30
Nordeste	MT	−3.17	−1.73	−3.94	−1.55	−1.62	−1.44
Sudoeste	MT	−5.34	−1.45	−4.21	−1.53	−2.05	−1.73
Centro-Sul	MT	0.22	−0.35	0.70	−0.70	−1.08	−1.15
Sudeste	MT	0.35	0.01	0.97	−0.28	−0.33	−0.58
Rest of Brazil	–	0.19	0.10	0.95	0.02	0.02	0.09
Legal Amazon	–	−1.59	−0.81	−1.49	−0.61	−0.82	−0.91

Source: Elaborated by the authors based on simulation results from the REGIA model.

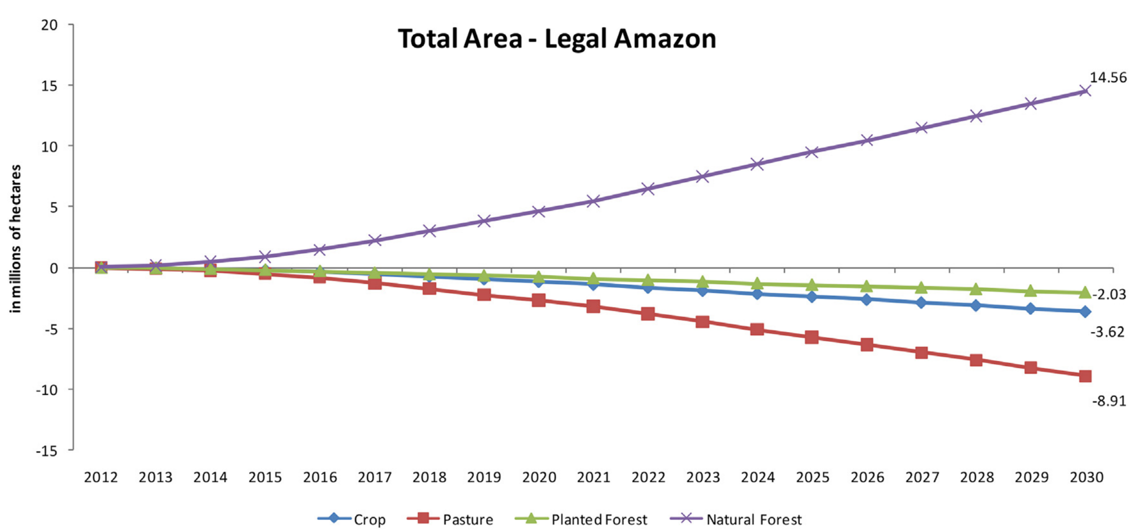


Fig. 3. Land-use projection as a result of the policy to control deforestation in the Amazon (deviation relative to the Baseline Scenario).
Source: Elaborated by the authors based on simulation results from the REGIA model.

deforestation control policy. The first would have a reduction in its area of about four million hectares, while the planted forest areas would be reduced by about two million hectares in 2012-2030 relative to the baseline scenario.

Table VI presents the results for different types of land use (in millions of hectares) by region. The policy increases the amount of land allocated for natural forest. Furthermore, we can note that the Norte (MT) and Sudeste (PA) would be the regions with the largest preserved areas (in hectares). Regarding the crop area, the regions with the greatest reductions in hectares would be Nordeste (MT), Nordeste (PA), Baixo Amazonas and Vale do Acre. These regions have agricultural goods/sectors as the most important activities in their production structures. In these regions, the policy to con-

Table VI
Change in cropland, pasture, planted Forest and Natural Forest Areas (in millions of hectares) in the Policy Scenario–accumulated from 2012 to 2030.

Regions	State	Crops	Pasture	Planted forest	Natural forest	Regions	State	Crops	Pasture	Planted forest	Natural forest
			in millions of hectares						in millions of hectares		
Madeira-Guapore	RO	−0.03	−0.52	−0.06	0.61	Norte	AP	−0.02	−0.01	0.00	0.03
Leste Rondoniense	RO	−0.08	−0.77	−0.07	0.92	Sul	AP	−0.04	−0.02	−0.01	0.07
Vale do Jurua	AC	−0.11	−0.06	−0.03	0.20	Ocidental	TO	0.01	−0.01	0.00	0.00
Vale do Acre	AC	−0.20	−0.34	−0.03	0.57	Oriental	TO	0.00	0.00	0.00	0.00
Norte	AM	−0.02	0.00	−0.02	0.04	Norte	MA	−0.18	−0.10	−0.04	0.33
Sudoeste	AM	−0.09	−0.02	−0.03	0.15	Oeste	MA	−0.06	−0.50	−0.07	0.62
Centro	AM	−0.19	−0.12	−0.13	0.44	Centro	MA	−0.07	−0.31	−0.07	0.45
Sul	AM	−0.03	−0.16	−0.04	0.24	Leste	MA	0.00	0.00	0.00	0.00
						Sul	MA	0.00	0.00	0.00	0.00
Norte	RR	−0.03	−0.05	−0.01	0.09						
Sul	RR	−0.01	−0.08	−0.02	0.11						
Baixo Amazonas	PA	−0.38	−0.32	−0.22	0.92	Norte	MT	−1.27	−2.10	−0.21	3.58
Marajo	PA	−0.12	−0.02	−0.06	0.20	Nordeste	MT	−0.27	−0.79	−0.06	1.12
Metropolitana de Belem	PA	−0.01	−0.01	−0.01	0.03	Sudoeste	MT	−0.08	−0.40	−0.03	0.51
Nordeste	PA	−0.21	−0.18	−0.16	0.55	Centro−Sul	MT	0.00	0.00	0.00	0.00
Sudoeste	PA	−0.06	−0.58	−0.20	0.84	Sudeste	MT	0.00	0.00	0.00	0.00
Sudeste	PA	−0.06	−1.44	−0.46	1.96						

Source: Elaborated by the authors based on simulation results from the REGIA model.

Table VII
Results pertaining to the increase in land productivity – accumulated deviation relative to the Baseline Scenario from 2012 to 2030 (in annual % change).

Region	State	Soybean	Cassava	Corn	Silviculture and forestry	Cattle
Madeira Guapore	RO	–	1.14	1.20	1.13	0.95
Leste de Rondonia	RO	0.93	0.92	0.93	0.95	0.66
Vale Jurua	AC	–	1.24	1.27	1.30	1.28
Vale Acre	AC	–	1.14	1.16	1.30	1.12
Norte	AM	–	1.27	–	1.28	–
Sudoeste	AM	–	1.35	1.39	1.38	–
Centro	AM	–	1.29	1.32	1.25	1.28
Sul	AM	1.05	1.00	1.05	0.95	–
Norte	RR	1.13	1.11	1.13	1.09	0.99
Sul	RR	0.89	0.83	0.89	0.83	0.75
Baixo Amazonas	PA	1.29	1.27	1.29	1.25	1.26
Marajo	PA	–	1.12	–	1.26	1.26
Metropolitana de Belem	PA	–	0.24	–	0.36	0.32
Nordeste	PA	0.51	0.50	0.51	0.61	0.54
Sudoeste	PA	–	0.91	0.96	0.84	0.78
Sudeste	PA	0.90	0.89	0.90	0.70	0.56
Norte	AP	–	0.97	–	1.05	1.03
Sul	AP	–	1.15	–	1.17	1.17
Ocidental	TO	0.00	−0.01	0.00	0.00	0.00
Oriental	TO	0.00	−0.01	0.00	0.00	0.00
Norte	MA	–	0.80	0.85	1.17	1.02
Oeste	MA	–	0.92	0.93	0.88	0.65
Centro	MA	1.25	1.24	1.25	1.18	1.01
Leste	MA	0.01	−0.01	0.01	−0.01	−0.02
Sul	MA	0.00	−0.01	0.00	0.00	−0.01
Norte	MT	1.11	1.09	1.11	1.30	1.10
Nordeste	MT	1.21	1.19	1.21	1.27	1.10
Sudoeste	MT	0.97	0.96	0.97	1.04	0.76
Centro-Sul	MT	0.00	−0.01	0.00	0.00	0.00
Sudeste	MT	0.00	−0.01	0.00	0.00	0.00

Source: Elaborated by the authors based on simulations results from the REGIA model.

trol deforestation would cause a more severe drop in agricultural production, explaining the greatest reduction in cropland area.

The pasture area in millions of hectares would be reduced more than the cropland area in most of the Amazon regions. The Sudeste and Sudoeste (PA), Norte (MT) and Nordeste (MT), and Leste (RO) would have the largest reductions in pasture area. This result is explained by the productive structure of these regions, which are important producers of cattle in the Amazon. In general, we observe that regions with more natural forest areas would be most affected by the policy to control deforestation and would show greater variation (decline) in its areas for productive use as well as a greater increase in production costs.

In terms of planted forest areas, it can be seen in Table IV that the reduction in these areas is of less magnitude than it is for other uses. This result indicates that the increase in production costs for this type of land is relatively smaller than for the others. However, we can highlight the reduction in planted forest area in Sudeste (PA) and Baixo Amazonas. The Sudeste (PA) is the largest forestry producer in the Amazon, and Baixo Amazonas also has a concentrated production in this sector.

4.4. Land productivity response to policy

In the simulations with REGIA, we have assumed that the policy to control deforestation occurs during the period from 2012 to 2030. Thus, this section aims to show how land productivity would have to increase in the same period to offset the impacts on regional outputs caused by the limited supply of land. In the baseline scenario, it is assumed that the productivity of land increases by 1% per year from 2012 to 2030. There is also an increase in the overall productivity of the primary factors of 0.7% per year in the same period. Therefore, the results reported in this section should be understood as an additional increase in productivity considering the baseline scenario. Table VII presents the regional results of the rise in productivity for the main agricultural sectors in the REGIA model that would offset the negative impacts in the regions due to the deforestation policy.

We notice, on average, that the annual productivity of land should grow at approximately 1% per year so that the policy to control deforestation would not cause any negative impact on production. According Gasques et al. (2008), the productivity of land in Brazil grew by 3.26% per year from 2000 to 2005, which suggests that this rate would be possible even in the Amazon. For example, to achieve the given results, the land productivity gains would have to be 0.5% to 1.4% per year compared to the baseline scenario. This would correspond to an increase in productivity of approximately 2.2% to 3.1% per year, including the increased productivity per year in the baseline scenario.

5. Conclusions

The main goal of this paper was to analyze the dynamics of land use and impacts of a policy to control deforestation, seeking to contribute to an analysis of different scenarios in the Amazon. For this, we built an interregional dynamic Computable General Equilibrium (CGE) model called REGIA, which incorporates a land use module.

First, a baseline scenario was built to project economic growth by region in a business-as-usual situation without the policy to control deforestation. In this scenario, the Amazon regions are stimulated by the growth of the national economy and the increasing demand of soybeans and cattle exports. Related to this scenario, we simulated a policy to control deforestation that aims to reduce deforestation by 80% by 2020, followed by a reduction of 100% for the period from 2021 to 2030 according to the recent Brazilian government proposals. The increase in land productivity required to offset the negative impacts of the deforestation control policy was also projected.

Overall, the results indicated that the regions most affected by the policy follow two distinct patterns: (i) regions in the deforestation arc in Mato Grosso and Rondonia and (ii) regions outside the arc that have a smaller share in the total GDP of Amazon, in Amazonas and Para. According to the data and mechanisms of the model, the former are more negatively affected by having a higher remuneration of land and because are more productive. Thus restricting the supply of land would generate higher losses of production per hectare. The regions outside the arc have lower productivity, and often the growth of their production is linked to the expansion of land (low remuneration), which then leads to the greater negative impact in these regions.

However, in general, the results showed that the costs of the policy to control deforestation in Amazon are relatively small, although it is important to note that the distribution is heterogeneous between regions, particularly affecting the regions that are most dependent on agriculture and have low productivity. It was also noticeable that the agriculture intensification in the Amazon can be considered to be a viable alternative for the maintenance of the production, employment, income and consumption in the region.

According to other studies on this theme, the increased land productivity alone does not seem to hold the expansion of crop areas. The increase in productivity can generate an incentive for producers to add cultivated areas for further expansion of production. Thus, there must be a policy to control deforestation coupled with increasing land productivity. Thus, the government should exercise greater surveillance to curb illegal deforestation and, at the same time, promote economic incentives toward forest conservation. These incentives can be provided with forest concessions for sustainable forest management, payment for environmental services that highlight the payments of REDDs or even the promotion of programs aimed to increase the productivity of deforested land in the Amazon.

A limitation of the methodology employed in this paper is that the issue of proximity between regions has no role in the expansion of agricultural crops or livestock. The model only allows for the expansion of crops in regions where this production already exists in the database, and largely, only the economic conditions of the region influence its expansion. That is, the model does not work properly with the issue of expansion of the agricultural frontier, but with the local expansion of activities influenced by competitive market mechanisms.

Appendix I.

Table VIII
Shares of agriculture, livestock, silviculture and forest management of the total production in each region and shares of the land remuneration of total primary factors.

Region	State	Agriculture share	Livestock share	Silviculture and forest management share	Land share in the production costs
Madeira Guapore	RO	14.96	30.70	11.63	0.22
Leste Rondoniense	RO	13.68	48.94	4.71	0.34
Vale Jurua	AC	41.70	22.78	3.50	0.26
Vale Acre	AC	19.95	31.62	6.13	0.19
Norte	AM	28.82	51.63	49.47	0.87
Sudoeste	AM	27.80	35.41	16.62	0.40
Centro	AM	2.97	10.96	0.31	0.03
Sul	AM	40.89	39.65	17.47	0.59
Norte	RR	14.56	14.56	3.95	0.15
Sul	RR	40.96	32.23	19.50	0.39
Baixo Amazonas	PA	28.64	32.23	10.53	0.48
Marajo	PA	2.81	80.36	54.46	0.98
Metropolitana de Belem	PA	8.91	5.45	0.38	0.07
Nordeste	PA	52.70	30.95	22.17	0.83
Sudoeste	PA	22.97	51.53	15.04	0.59
Sudeste	PA	6.43	41.20	13.28	0.32
Norte	AP	32.44	14.94	1.36	0.16
Sul	AP	11.59	3.52	1.20	0.04
Ocidental	TO	29.28	26.66	1.01	0.40
Oriental	TO	9.47	28.22	1.19	0.31
Norte	MA	7.80	10.00	2.51	0.08
Oeste	MA	12.22	51.10	9.16	0.33
Centro	MA	12.04	67.15	18.88	0.55
Leste	MA	10.25	36.47	10.85	0.35
Sul	MA	27.93	31.92	4.82	0.99
Norte	MT	53.59	22.29	4.80	1.05
Nordeste	MT	58.31	27.19	1.22	0.52
Sudoeste	MT	7.40	55.63	1.57	0.10
Centro-Sul	MT	7.06	12.61	0.36	0.80
Sudeste	MT	61.01	18.51	0.37	0.39
Legal Amazon		21.85	26.19	5.81	0.13

Source: Elaborated by the authors.

Appendix II.

Table IX
Percent change in soybean and cattle production cost resulting from the policy to control deforestation (accumulated deviation from 2012 to 2030 relative to baseline).

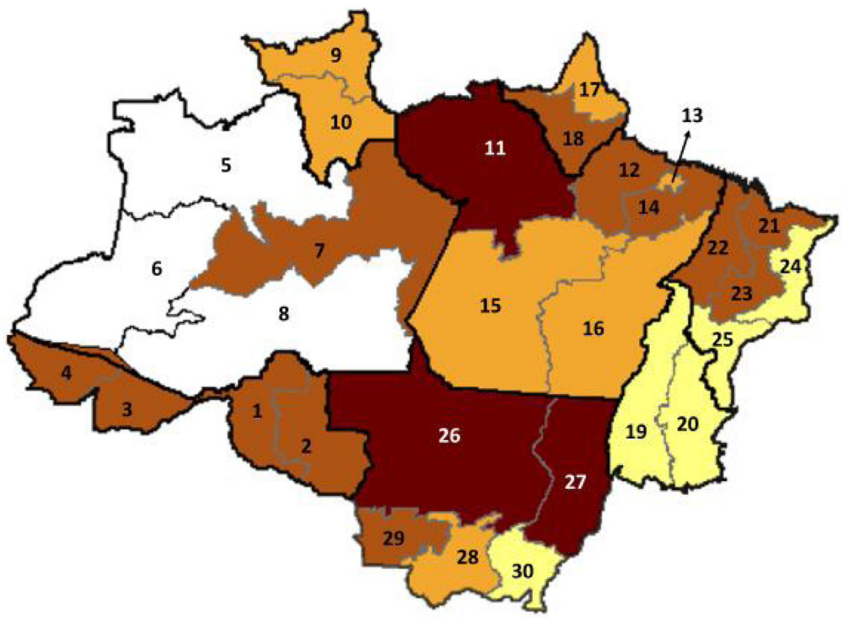
Region	UF	Soybean	Cattle
Madeira Guapore	RO	–	0.51
Leste Rondoniense	RO	3.98	0.69
Vale Jurua	AC	–	0.68
Vale Acre	AC	–	0.78
Norte	AM	–	–
Sudoeste	AM	–	–
Centro	AM	–	0.68
Sul	AM	2.09	–
Norte	RR	3.45	0.50
Sul	RR	1.89	0.37
Baixo Amazonas	PA	4.94	0.84
Marajo	PA	–	0.63
Metropolitana de Belem	PA	–	0.40
Nordeste	PA	2.76	0.67
Sudoeste	PA	–	0.38
Sudeste	PA	3.33	0.48
Norte	AP	–	0.52
Sul	AP	–	0.62
Ocidental	TO	0.38	0.15
Oriental	TO	0.32	0.13

Table IX (*Continued*)

Region	UF	Soybean	Cattle
Norte	MA	–	0.68
Oeste	MA	–	0.56
Centro	MA	4.73	0.50
Leste	MA	0.55	0.20
Sul	MA	0.54	0.18
Norte	MT	3.88	0.83
Nordeste	MT	4.45	0.84
Sudoeste	MT	4.04	0.78
Centro-Sul	MT	0.37	0.20
Sudeste	MT	0.46	0.18
Legal Amazon	–	0.20	0.10

Source: Elaborated by the authors based on simulations results from the REGIA model.

Appendix III. Regions of the model



1. Madeira Guapore
2. Leste RO
3. Vale Acre
4. Vale Jurua
5. Norte AM
6. Sudoeste AM
7. Centro AM
8. Sul AM
9. Norte RR
10. Sul RR
11. Baixo Amazonas
12. Marajo
13. Metropolitana de Belem
14. Nordeste PA
15. Sudoeste PA
16. Sudeste PA
17. Norte AP
18. Sul AP
19. Ocidental TO
20. Oriental
21. Norte MA
22. Oeste MA
23. Centro MA
24. Leste MA
25. Sul MA
26. Norte MT
27. Nordeste MT
28. Centro-Sul MT
29. Sudoeste MT
30. Sudeste MT

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