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How commodities demand growth can affect the deforestation and the frontier expansion in the Brazilian Amazon region?[1]

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Resumo:
Um aumento substancial da demanda mundial de commodities é esperado entre 2015 e 2025, de acordo com as projeções da Organização das Nações Unidas para a Agricultura e Alimentação (FAO). Estima-se que a demanda de exportações brasileiras de soja aumentaria em 32% e a demanda de exportação de carne cresceria 40%. Historicamente, essas atividades são consideradas importantes vetores do desmatamento na Amazônia brasileira. Para atender a essa crescente demanda, a região poderia depender da expansão de sua fronteira agrícola. Com o objetivo de estudar as consequências desses cenários sobre a mudança do uso da terra e, consequentemente sobre o desmatamento, foi utilizado um modelo dinâmico inter-regional de equilíbrio geral computacional (EGC) para 30 regiões da Amazônia e do resto do Brasil. Em geral, os resultados sugerem que o desmatamento agregado aumentaria ao longo do tempo, o que significa uma redução adicional na área de floresta natural, projetada para ser de 1.610 km^2 em relação ao cenário base. Entretanto, o desmatamento adicional não seria muito grande na maioria das regiões, afetando apenas marginalmente suas taxas anuais. Por sua vez, a soja teria um efeito mais forte sobre a economia e o uso da terra da Amazônia e seu crescimento poderia levar a um deslocamento da pecuária para outras áreas florestais.
Palavras-chave: modelo de equilíbrio geral computável, região amazônica, Brasil, fronteira agrícola, desflorestamento

Abstract:
A substantial increase of the world demand of commodities is expected between 2015 and 2025, according to the Food and Agriculture Organization of the United Nations (2016) projections. It was estimated that Brazilian soybean exports demand would increase by 32% and the beef exports demand would grow 40%. Historically, those activities are considered important drivers of deforestation in the Brazilian Amazon. Then, to meet these increased demand, the region could depend on expanding its agriculture frontier. In order to study the consequences of these scenario over land use change and consequently over deforestation, we use an interregional dynamic computable general equilibrium model (CGE) for 30 regions in the Amazon and the rest of Brazil. In general, the results suggest that the aggregate deforestation would increase over time, which means an additional decrease in natural forest area, projected to be 1,610 km^2 relative to the baseline. However, the additional deforestation is not very large in most of the regions, only marginally impacting annual rates. By its turn, soybean would have a stronger effect on both the economy and land use of Amazon and its growth could lead to a shift of cattle towards other forest areas.
Key words: general equilibrium model, Amazon region, Brazil, agricultural frontier, deforestation

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1. Introduction

Encompassing one of the world's largest tropical rainforests, the Amazon region has already lost about 15% of its total forest area. 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 crucial 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). However, this pattern changed after 2013 and the deforestation went forward again. One of the reasons could be the New Forest Code[2], which was approved in May 2012. Included among the points of the New Code is a reduction of the limit of the legal reserve[3] 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[5].

Historically, a huge part of deforestation has occurred to increase the Brazilian agriculture frontier, mainly due to the large-scale agriculture and the slash and burn agriculture. The extensive livestock with low productivity has been pointed out by the literature as one of the main drivers of deforestation (MARGULIS, 2003; MERTENS et al., 2002). The increase in deforestation for the establishment of low productivity pastures is also motivated by land tenure and speculation. According to the Brazilian Institute of Geography and Statistics (IBGE[6]), from 1990 to 2008 the herd of the region increased from 21.1 million head (18% of the national total) to 73.9 million (43% of the national total) (IBGE, 2006). About 75% of the new cattle added to the national herd comes from the Amazon. However, this expansion presents very low productivity, less than one head per hectare (MMA, 2012; ALENCAR et al., 2004), which suggests its use also for speculative purposes.

The soybean growth has been also considered an important driver. According to Brandão et al. (2006), the agriculture growth in the 2000 decade was characterized by a strong expansion of the total planted area. In the soybean case, the influence on deforestation is mainly indirect. The crop expansion has occurred basically in pastures already formed, where the cost of implantation of the activity is smaller. However, the soybean, by occupying these existing pastures, ends up pushing the expansion of livestock to other areas of forests (ALENCAR et al., 2004). According to Domingues and Bermann (2012), the soybean expansion is causing deforestation through the dynamics of forest clearing, the implantation of livestock and the later transformation of the area into mechanized agriculture. At the same time, this process would lead to the expansion of the agriculture frontier, meeting the increasing consumption.

Arima et al. (2011) assert the expanding global demand for soybean and biofuels threatens the food security and the environment. An environmental impact that has become a serious concern

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[2] 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.

[3] Legal Reserve is the area located in the interior of a property or rural property with the purpose of ensuring the sustainable economic use of the natural resources of the rural property, assisting the conservation and rehabilitation of ecological processes and promoting the conservation of biodiversity, as well as the shelter and protection of wildlife and native flora.

[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] Areas of permanent preservation are forests and other forms of natural vegetation that are located along the rivers or from any watercourse from its highest level.

[6] From Portuguese *"Instituto Brasileiro de Geografia e Estatística"*.

is the loss of forest vegetation in Amazon through indirect land use change (ILUC) where the mechanized agriculture invades existing pastures and move them to new areas of forest.

This problem becomes important as the Food and Agriculture Organization of the United Nations – FAO (2016) projects a substantial increase of the world demand of commodities until 2025. According to these projections, Brazilian soybean exports will increase by 32% from 2015 to 2025 and the beef exports will grow 40%. With the recent policies of the Brazilian government to reduce and control deforestation, such as the "Intended Nationally Determined Contribution (INDC)[7]" and the world concern to mitigate the effects of global warming (GHG emissions), it is important to evaluate how commodities production expansion, especially beef and soybean, can affect the land use in the region. Under this scenario, what will be the effect on land use in Amazon?

In order to study these aspects of land use change in the Amazon region, a consistent economic model has to embrace both particular data about the region and a strong theoretical background. We use an interregional dynamic computable general equilibrium model (CGE) for 30 regions in the Amazon and the rest of Brazil, REGIA (Interregional General Equilibrium Model for the Brazilian Amazon). REGIA has a land-use change specification that enables the conversion of different categories of land use, a detailed regional database and dynamic general equilibrium framework. Besides this introduction, this paper contains more three sections. The next one explains the methodology including the theoretical structure of the CGE model REGIA, database, model closures and simulations. The third presents and discuss the model results. And the last section shows the final considerations.

2. Methodology

2.1. REGIA model

REGIA is a Regional Computable General Equilibrium model (CGE) with a recursive dynamic and land-use module for 30 regions of the Brazilian 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 15 agricultural commodities as shown in Table I.

According to Carvalho et al., (2017) REGIA has 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 one is the treatment of land use in a recursive dynamic model so it is possible to 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. Therefore, it is possible to analyze the impacts in a regional level.

[7] Brazil intends to commit to reduce greenhouse gas emissions by 37% below 2005 levels in 2025. One of the measures is to strengthening policies and measures with a view to achieve, in the Brazilian Amazonia, zero illegal deforestation by 2030 and compensating for greenhouse gas emissions from legal suppression of vegetation by 2030.
[8] Throughout the paper, we use the word "Amazon" to refer to the "Brazilian Legal Amazon".

Table I – Sectors Disaggregation of REGIA

Sector	Goods
Agriculture	1. Rice, 2. Corn, 3. Others of agriculture, 4. Sugarcane, 5. Soybean, 6. Other crops, 7. Cassava, 8. Citrus Fruits, 9. Coffee bean
Livestock	10. Cattle, 11. Milk and Cow, 12. Pigs, 13. Birds and Eggs, 14. Fishing
Silviculture and Forest Management	15. Silviculture and Forest Management
Industry	16. Mining Industry, 17. Food and Beverage, 18. Textile, leather and shoes, 19. Other Industries, 20. Fuels, 21. Appliances
Services	22. Energy and Water services, 23. Construction 24. Trade, 25. Transportation, 26. Services
Public Administration	27. Public Administration

Source: Elaborated by the authors

REGIA is composed of many 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. And the model has a land use change module which will be discussed on next section.

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 also 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 dynamic characteristics of REGIA is the connection between annual investment flows and capital stocks.

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[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).

The model does not include a process of temporal labor market adjustment. For the simulations in this paper, which has a time horizon of 20 years, a configuration was adopted where the national aggregated employment in the baseline is exogenous (from 2006 to 2014, adjusted with observed data, and from 2015 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 main 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 essential factor in the production of agricultural sectors and mainly for the Brazilian Amazon. 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.

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 area 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 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 (Carvalho et al., 2017).

The land process is guide by two levels of substitution. At the first level, cropland and pasture may be allocated between different agricultural sectors according to the land remuneration differential. Thus, the demand for land responds to changes in the remuneration of 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:

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

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*.

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[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.

The total change in the demand for each land use for each region is given by $x_r = \sum_k S_k x_k$, using the distribution of the remuneration S_k, with *k* representing the various land 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:

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

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 shows the mobility of land between uses, indicating the possibilities of the transformation between 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 instance, 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 2008 and 2010 (obtained from Prodes/INPE) along with data from the Agricultural Census for 1995 and 2006[13] (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[14] 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

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[13] 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.

[14] 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 one transition matrix for each of the 30 regions in the model.

adjustment method, known as RAS[15], of rows and columns scaling. The off-diagonal elements show the areas of land that have changed between the two periods.

Chart 1 – Brazilian Amazon Transition Matrix used in REGIA model (in millions of hectares)

Conversion Possibilities	Crops	Pasture	Planted Forest	Natural Forest	Total in 2008
Crops	5.00	0.20	0.20	0.50	5.90
Pasture	2.30	39.50	2.00	0.60	44.50
Plated Forest	0.20	0.90	13.70	0.20	15.00
Natural Forest	0.80	4.30	22.10	413.50	440.80
Total in 2010	8.30	44.90	38.10	414.90	506.20

Source: Elaborated by the authors according to INPE data.

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, was 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 was natural forest in 2008, was converted to pasture in 2010. And another 22.1 million of hectares was 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 annual percentage growth rate of each use given by the transition matrix:

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

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:

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

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 $\sum_k S_{pkr} = 1$. 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_{kr} 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.

[15] 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).

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[16]. 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 (Carvalho et al., 2017).

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: Carvalho et al., (2017)

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 database[17]. The procedure was based on the methodology developed by Horridge (2006) adapted for

[16] To build this elasticity was removed from the available land all the areas of: Legal Reserve (RL, from portugues "*Reserva Legal"* - imposed by the Brazilian Forest Code) and Permanent Preservation Areas (APPs, from portugues *"Áreas de Preservação Permanente"*). So, this elasticity reduces the possibilities of conversion in regions with large areas of APPs and RL.

[17] 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).

the Brazilian case. Basically, from the input-output data for 2005 and a large set of regional data[18], we estimated an interregional trade matrix using a distance matrix and a gravitational approach. The main hypothesis of the gravitational approach[19] 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)[20].

2.4. 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 recursive 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 2014 to update the database using observed macroeconomic variables according to IBGE data. In this case, the main national aggregates are considered 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 2014 according to INPE data.

At baseline from 2016 to 2025, the macroeconomic variables for the aggregate GDP, household consumption and government expenditure are still exogenous. 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 nominal exchange rate was chosen as a numeraire. "Natural

[18] 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.

[19] 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 applications can be found in Miller and Blair (2009).

[20] 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.

forests and other uses" is still exogenous representing a scenario of moderate growth of deforestation rates based on the recent years observed data.

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.

2.5. Simulations

The baseline shows a 3% per year growth of the national economy for the period from 2016 to 2025 and represents the projection that is compared to the policy scenario[21]. 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.

The main goal of the policy scenario is to evaluate the impacts in Amazon region of the world demand growth for agriculture commodities from 2016 to 2025, mainly on deforestation and land use through the projections by FAO (2016)[22]. It has been pointed out that the growth of global demand for commodities, mainly soybean and beef, threatens the forest maintenance. This could cause an important environmental impact in Amazon increasing the deforestation rates over the next years through indirect land use change (ILUC) where the mechanized agriculture invades existing pastures and move them to new areas of forest. Table III presents the annual FAO projections of exports demand growth of six agricultural commodities considered in this study.

FAO (2016) estimates that soybean exports demand will increase by 32% from 2016 to 2025 and the beef exports will grow 40%. We need to highlight this projection as the international market for these products is considered an important determinant of deforestation in the region. In general, if the growth of cattle and soybean production is based on land expansion this will lead to more conversion of natural forest areas into other productive uses, such as cropland and pasture.

From the REGIA model perspective, the first-round impact of the growth of international demand is to benefit the production of the agricultural sectors (Table III) and other sectors of the economy through input-output relations. To increase its production, sectors will use more primary factors (labor, capital and land). Then employment, investment and land use increases and also their prices as regional supply is fixed or costly. Additionally, household consumption is positively impacted by the increase in income.

Another important expected result is on land use change. As land demand increases, the conversion of natural forests into productive uses also goes up. The simulation results can project the increase in deforestation, and therefore we can answer whether this increase in international demand for commodities could disrupt conservation goals in the region. In addition, we can understand the dynamics of this change in land use: will the increase in the agriculture area occur in existing pastures by driving the pasture areas to new areas of forest?

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[21] For more details on the baseline scenario, see Carvalho (2014).

[22] Brazil is modelled as a small open economy and the shock in the simulation was given in the variable “Export quantity shift”.

Table III – FAO projections on exports growth from 2016 to 2025 (in annual % change)

Goods	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Rice	1.34	12.54	-1.69	1.43	-1.13	0.18	-2.39	0.30	2.94	-0.43
Corn	14.36	-1.07	-2.27	2.57	0.78	2.92	1.27	1.75	3.82	0.29
Others of agriculture	-12.02	4.81	5.37	4.08	5.56	4.28	5.14	4.82	4.80	4.61
Soybean	2.30	3.37	4.68	1.29	2.11	3.61	2.32	3.72	2.12	3.29
Other crops	-9.95	26.19	-16.12	14.33	-9.15	18.85	-11.13	16.88	-8.03	-7.43
Cattle	-3.81	4.80	7.29	3.46	4.24	3.89	3.87	3.22	3.51	3.53
Pigs	-6.72	13.45	2.63	2.63	2.59	2.52	2.44	2.39	2.36	2.31
Birds and Eggs	-1.57	7.89	4.11	2.74	5.02	1.92	3.44	4.52	3.38	4.01

Source: Elaborated by the authors based on FAO (2016) projections

3. Results and discussion

3.1. Regional macroeconomic results

As explained in section 2.4 the policy scenario simulates a deviation from "business as usual" trajectory designed by baseline scenario. In the particular case analyzed in this paper, all deviations are a consequence of changes in commodities exports demand, especially soybean and beef, which are some very important products for Brazilian exports agenda and in particular for Amazon region. Therefore, an expansion in its demand is expected to generate positive macroeconomic regional effects.

Table IV show the results as accumulated deviations between 2016 to 2025 compared to baseline scenario. The most benefited regions in terms of regional GDP are located in Mato Grosso and Maranhao, which is explained by the large share of national soybean production concentrated in those states, and the positive effects on regional exports triggered by FAO's projections. To be more precise, only the Norte of Mato Grosso accounts for 20.83% of Brazilian soybean production while the whole state accounts for 30.63%. By its turn, despite Sul of Maranhao harvests only 2.09% of national soybean production, it represents 21.71% of the regional economy.

The least affected regions are in the states of Amazonas and Para, whose share in exports is lower compared to the other regions nearby. Notwithstanding, the changes in the regional composition of exports and the rise in prices, caused by the increase in demand for factors and exports, shall induce new investments through all areas. Table IV illustrates that investment growth is estimated to be higher in soybean producing regions, even though it is also significant in the other regions, due to the effects induced by interregional trade relations and between sectors. Consequently, the direct effect of the demand for exports of other products, combined with the regional spillover effects of soybean, allow positive deviations in employment, income and production for all Amazon regions.

Table IV – Simulated Impacts on Regional Macroeconomic Indicators of commodities demand growth from 2016 to 2025 - accumulated deviation relative to Baseline (in % change)

Regions	State	GDP	Household Consumption	Government expenditure	Investment	Employment	Exports	Imports
Madeira-Guapore	RO	0.44	0.39	0.39	1.56	0.43	1.10	1.16
Leste de Rondonia	RO	0.52	0.46	0.46	1.66	0.51	3.28	1.23
Vale do Jurua	AC	0.40	0.33	0.33	1.54	0.37	-0.59	1.13
Vale do Acre	AC	0.43	0.35	0.35	1.43	0.40	-0.60	1.14
Norte	AM	0.33	0.29	0.29	1.13	0.34	-0.59	1.05
Sudoeste	AM	0.33	0.29	0.29	1.14	0.34	-0.61	1.04
Centro	AM	0.45	0.44	0.44	1.64	0.49	-0.66	0.86
Sul	AM	0.45	0.39	0.39	1.57	0.44	-0.51	1.15
Norte	RR	0.43	0.42	0.42	1.26	0.46	6.33	1.17
Sul	RR	0.48	0.46	0.46	1.68	0.51	3.87	1.15
Baixo Amazonas	PA	0.43	0.38	0.38	1.22	0.43	-0.58	1.04
Marajo	PA	0.32	0.29	0.29	0.94	0.34	-0.14	1.02
Metropolitana de Belem	PA	0.37	0.33	0.33	1.54	0.38	-0.65	1.01
Nordeste	PA	0.32	0.29	0.29	1.23	0.33	-0.36	1.01
Sudoeste	PA	0.45	0.41	0.41	1.42	0.46	-0.16	1.17
Sudeste	PA	0.46	0.45	0.45	1.33	0.50	-0.50	1.02
Norte	AP	0.53	0.42	0.42	1.74	0.47	-0.69	1.25
Sul	AP	0.29	0.25	0.25	1.09	0.30	-0.67	0.91
Ocidental	TO	0.68	0.55	0.55	1.89	0.59	17.47	1.42
Oriental	TO	0.96	0.79	0.79	1.78	0.84	23.17	1.63
Norte	MA	0.44	0.36	0.36	1.44	0.41	0.94	1.14
Oeste	MA	0.39	0.34	0.34	1.52	0.39	0.72	0.90
Centro	MA	0.40	0.35	0.35	1.48	0.40	4.01	0.75
Leste	MA	0.39	0.33	0.33	1.36	0.38	0.45	1.09
Sul	MA	2.37	2.11	2.11	4.77	2.17	5.01	2.90
Norte	MT	4.64	4.44	4.44	9.00	4.50	10.33	5.36
Nordeste	MT	3.77	3.40	3.40	7.57	3.46	8.79	4.18
Sudoeste	MT	0.76	0.76	0.76	1.74	0.81	3.53	1.37
Centro-Sul	MT	1.18	1.09	1.09	3.18	1.14	8.48	1.84
Sudeste	MT	2.49	2.44	2.44	5.33	2.50	11.32	2.96
Rest of Brazil	-	0.27	0.26	0.26	0.95	0.30	-0.24	0.88
Legal Amazon	-	0.90	0.76	0.69	2.17	0.84	2.74	1.14

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

3.2. Sectoral results

As expected, agriculture would be directly affected by the rise in commodities exports. The soybean sector stands out with an estimated accumulated deviation of 13.35% compared to baseline (Table V). The commodities rice, corn, cattle and pigs are also benefited directly from FAO's projections, while other products in agriculture and livestock, like cassava, other crops and citrus fruits are indirectly affected through intermediate and final demand changes. Apart from those activities, construction and trade would be positively impacted as well. While the rise in construction is deeply related to rise in investment, trade sector is mostly influenced by the rise economic activity in general, and the overall income effect.

Table V – Simulated impacts on Amazon production by sector between 2016 to 2025 – accumulated deviation relative to baseline (in % change).

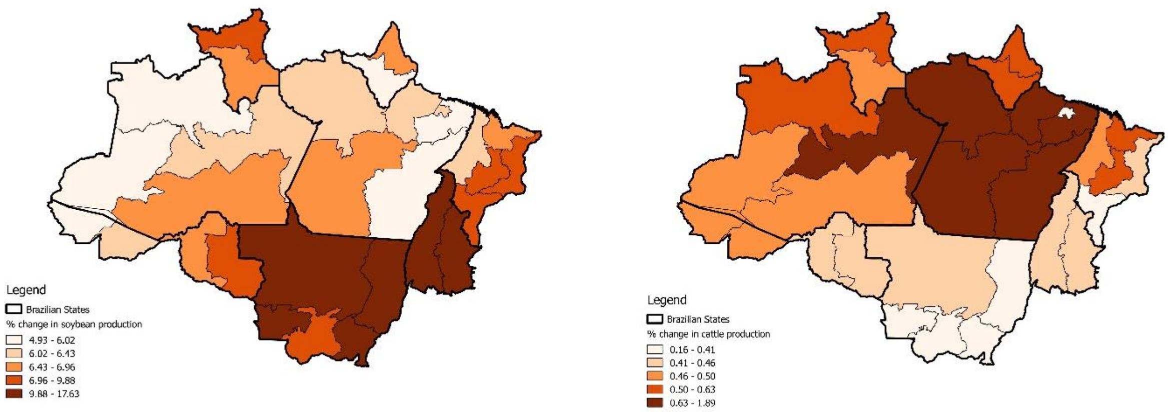
Sector	% change	Sector	% change
Rice	0.51	Silviculture and Forest Management	0.19
Corn	1.18	Mining Industry	-0.25
Others of agriculture	-0.11	Food and Beverage	0.18
Sugarcane	0.08	Textile, leather and shoes	0.34
Soybean	13.35	Other Industries	0.38
Other crops	0.85	Fuels	0.19
Cassava	1.02	Appliances	0.55
Citrus Fruits	0.28	Energy and Water services	0.42
Coffee bean	-0.02	Construction	1.44
Cattle	0.59	Trade	1.55
Milk and Cow	0.51	Transportation	0.66
Pigs	0.15	Services	0.49
Birds and Eggs	0.23	Public Administration	0.44
Fishing	0.34		

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

At the regional level, sectoral results change according to regional specialization in different types of crops, and the economic structure as a whole. In terms of land use changes, the most important results are shaped according to soybean and cattle production, which are both concentrated in specific areas. As Figure 2 shows, the changes in soybean production should be more intense in the South of Amazon, especially in Mato Grosso and Maranhao states, where soybean production is already a very import economic activity, directed to the external market. For instance, the estimated deviation for 17.63% in the Nordeste of Mato Grosso, 15.58% for Sudeste and 13.22% for Norte, all above the average for Amazon region.

On the other hand, cattle production would be concentrated in the north of Amazon, mostly in the state of Pará. The general impact is smaller compared to soybean, nevertheless it would be an important driver for land use changes discussed in the next section. The region of Marajo stands out with a growth 1.89% above baseline, while for the rest of the state (expect metropolitan region) the growth ranges between 0.79 and 0.69%.

Figure 2 - Percent Change in Soybean and Cattle Production (accumulated deviation from 2016 to 2025 relative to baseline)

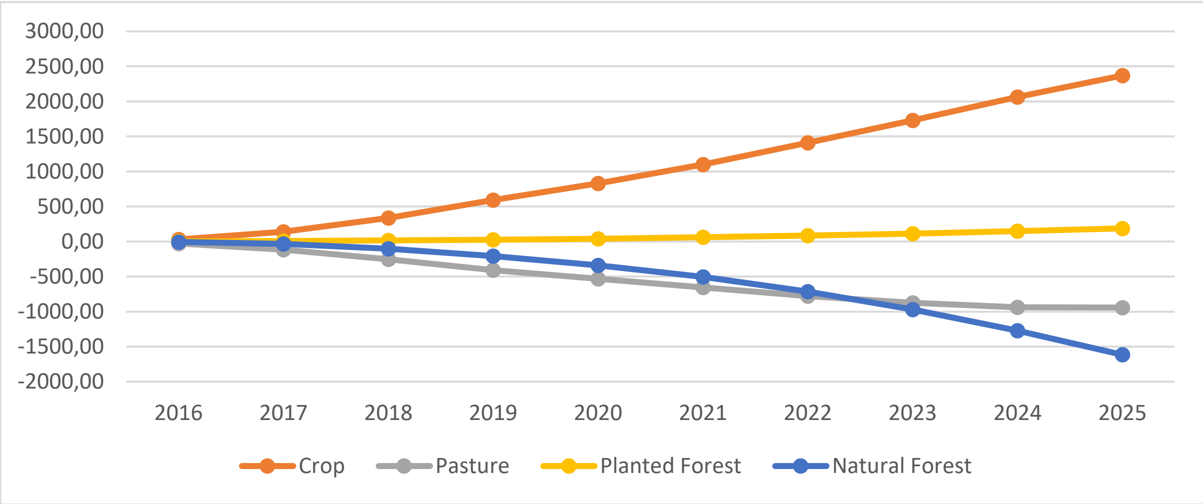


Source: Elaborated by the authors based on simulation results from the REGIA model

3.3. Land Use Results

Given the policy scenario, aggregate deforestation would increase over time which means an additional deforestation relative to baseline scenario. This can be seen in Figure 2 in the downward trend in natural forest area, which is projected to decrease to 1,610 km^2 relative to the baseline. As the total area of the region is fixed, the reduction of a particular type of land must be accompanied by an increase in another land use. Sectoral results discussed in the last section have showed the soybean sector presented the largest growth of Amazon agricultural activities followed by Cassava and Silviculture and Forest Management. Then, we can observe in Figure 2 the increase of cropland area by 2,370 km^2. Note the pasture area has also presented a decrease of almost 1,000 km^2.

Figure 2 – Total area: Legal Amazon (in Km^2)



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

The results of the simulation indicate that a large part of the increase in crop area occurred mainly through the conversion of pasture, which suggests an indirect land use change. The low productivity of livestock in the region and the low price of land remuneration enabled this conversion between uses. Additional deforestation was mainly due to the increase of cropland, although from 2023 it was mainly due to pasture conversion. Although the area of pasture has been reduced, the cattle activity has presented growth related to baseline scenario. This is due to the low productivity of livestock in the region that has more potential for growth without necessarily increasing the agricultural area.

Table IV presents the results of deforestation and land use by region.

Tabela IV – Results on Regional Land Use Change and Deforestation (in km^2)

Regions	State	Deforestation from 2016 to 2025 (policy scenario)*	Total deforestation from 2015 to 2025 (baseline)	Observed Deforestation from 2006 to 2014	Cropland Area from 2016 to 2025 (policy secenario)	Pasture Area from 2016 to 2025 (policy scenario)
Madeira-Guapore	RO	-23.67	-3,102.83	-5,024.76	3.90	15.89
Leste de Rondonia	RO	-18.16	-1,630.50	-2,259.66	22.09	-10.74
Vale do Jurua	AC	-16.19	-373.02	-632.54	10.68	2.44
Vale do Acre	AC	-22.85	-759.07	-1,432.59	15.07	5.50
Norte	AM	-5.58	-45.17	-135.22	2.74	0.21
Sudoeste	AM	-14.47	-217.49	-467.39	9.46	1.61
Centro	AM	-42.81	-729.35	-1,138.39	16.77	11.88
Sul	AM	-35.35	-1,754.29	-2,968.39	8.23	16.61
Norte	RR	-14.02	-386.70	-452.58	8.33	4.13
Sul	RR	-16.49	-937.37	-1,215.47	3.77	8.74
Baixo Amazonas	PA	-119.32	-1,564.55	-1,894.58	80.83	23.83
Marajo	PA	-17.21	-387.89	-976.64	8.40	6.23
Metropolitana de Belem	PA	-0.88	-76.23	108.29	0.67	-0.60
Nordeste	PA	-15.35	-2,236.35	-510.51	8.59	1.97
Sudoeste	PA	-115.24	-6,413.06	-11,162.97	9.21	90.89
Sudeste	PA	-84.48	-9,357.86	-17,824.75	4.71	94.50
Norte	AP	-4.67	-116.63	-79.15	3.74	0.40
Sul	AP	-8.35	-170.94	-206.44	5.85	1.19
Ocidental	TO	0.00	-10.18	1,423.14	152.71	-158.12
Oriental	TO	0.00	-0.50	1,079.90	97.98	-99.99
Norte	MA	-11.62	-573.49	-1,519.00	9.38	-0.07
Oeste	MA	-15.32	-1,262.73	-2,159.39	3.59	6.84
Centro	MA	-14.72	-1,214.96	-3,154.44	4.10	5.24
Leste	MA	0.00	-4.76	-171.37	1.54	-1.12
Sul	MA	0.00	-1.80	-184.47	31.98	-30.47
Norte	MT	-773.44	-6,633.88	-10,521.73	1,331.37	-629.97
Nordeste	MT	-204.20	-1,548.68	-2,303.36	345.78	-161.35
Sudoeste	MT	-21.71	-397.37	-353.24	41.89	-24.97
Centro-Sul	MT	0.00	-3.59	-151.18	40.84	-40.98
Sudeste	MT	0.00	-0.14	94.20	85.94	-81.59

*accumulated deviation relative to baseline

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

The third column shows the additional deforestation related to the baseline scenario that would occur in the scenario of international growth in the demand for commodities from 2016 to 2025. The fourth column, in turn, shows the total deforestation of the baseline scenario from 2016 to 2025 (11 years). It has been considered that deforestation will continue to increase at a moderate rate (average in recent years), while maintaining the assumption that rates will remain low in the region due to increased surveillance and deforestation control programs. And the outcome of the baseline scenario is a 40% lower deforestation than that observed between 2006 and 2014 (column five of the table). The sixth and seventh columns present the results for the cropland and pasture areas, respectively.

We can observe that additional deforestation generated on demand growth for commodities scenario is small. The largest additional deforestation occurred in the Norte of Mato Grosso (12%

more than the projected deforestation). This result can be attributed to the high soybean growth in the region, since it is the largest soybean producer and exporter in the Amazon. But it is worth noting that soybean growth in the region is mainly due to conversion of areas that were formerly pasture. Other regions that stand out with an additional deforestation of about 12% above the baseline scenario are Nordeste of Mato Grosso and Norte of Amazonas. In the Nordeste of Mato Grosso there is also a big share of soybean in the production in the economy of the region. In the case of Norte of Amazonas, the result seems to suggest that additional deforestation has occurred both to increase cropland area as pasture areas.

Another interesting result is that even though the pasture area of the whole Amazonia has decreased, some regions have presented an increase in pasture areas, notably the Sudoeste, Sudeste and Baixo Amazonas of Para, Madeira-Guapore in Rondonia, Sul do Amazonas, and in the state of Roraima. These results seem to suggest that there may be a movement of cattle to other regions due to cropland growth, especially soybean in the Amazon.

3.4. Simulated National Results

The increase in demand for exports also has a positive impact on the Brazilian macroeconomic results. Table V presents the accumulated results for Brazil from 2016 to 2025 related to the baseline scenario. As the second column shows, the accumulated deviation on exports is estimated to be 0.08%. This result is directly induced by FAO's projections, and points that, despite reductions in exports for some products, the overall effect is still positive for the economy as a whole. Last column indicates that the positive effect is boosted by the rise in soybean, which alone would increase exports by 0.21%.

The national results, in general, are positive, but they are not as strong as the impacts of some regions in the Legal Amazon, such as Sudeste and Nordeste of Mato Grosso. This is explained by the larger share of soybean activity in these regional economies than in the Brazilian economy as a whole. Even so, it shows the economic importance of agricultural commodities in the Brazilian economy. As detailed previously, such a rise in exports induces rises in prices and consequently creates incentives for investment, not only in sectors directly affected by exports but also in sectors related to them. The result of this interactions is a rise in 0.99% of national investment above baseline scenario. With more investments, and exports, we also have a greater production and national income, inducing the rise in all other components of real GDP.

We can observe that the Brazilian GDP would grow around 0.3% in addition. The effect of the increase in the demand for beef does not have much influence on this result, however, it is noted that the increase in the international demand for soybean, accounts for 22% of this result over GDP, showing the importance of this commodity to the Brazilian economy. As expected, the higher level of activity also positively influences employment. The soybean effect on employment accounts for almost 35% of the total impact.

Tabela V – Simulated Impacts on National Macroeconomic Indicators of commodity demand growth from 2016 to 2025 – accumulated deviation relative to baseline (in % change).

Indicators	Total	Cattle effect	Soybean effect
Real GDP	0.31	0.00	0.07
Household consumption	0.31	0.00	0.07
Investment	0.99	0.00	0.19
Exports	0.08	0.00	0.21
Imports	0.90	0.01	0.37
Government expenditure	0.28	0.00	0.05
Employment	0.34	0.00	0.10

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

4. Final Considerations

This article aimed to project the economic and land use impacts of the growth of international demand for agricultural commodities from 2016 to 2015 in the Brazilian Legal Amazon. Amazon is a region that has its economy based on farming, mainly in the production of cattle and soybean. With the growth of global environmental concerns, notably on climate change, Brazil has affirmed its commitment to reduce its emissions, largely by reducing deforestation. Control and surveillance programs have caused deforestation rates to decline since the early 2000s. As one of the most important drivers of deforestation is the expansion of agricultural land in the region, there is concern that increasing global demand for agricultural commodities negatively threatens deforestation rates in the region.

In this context, FAO projections (2016) for increasing world demand for commodities up to 2025 were used in a regional dynamic computable general equilibrium model, REGIA, which represents the economy of 30 regions of the Amazon and the rest of Brazil considering 27 sectors. This model, which has built in Carvalho (2014), has a land use module that represents the conversion of different uses of land over time. The results indicate that soybean would have a stronger effect on both the economy and land use of Amazon and that its growth could lead to a shift of cattle towards other forest areas. However, it should be noted that although the results has pointed out to this fact, the additional deforestation caused by the increase in the demand for commodities is not very large in most of the regions, only marginally impacting annual rates.

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