ENVIRONMENTAL AND WELFARE IMPACTS OF DEFORESTATION REDUCTION IN BRAZIL[1]

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1. Introduction

The current efforts aiming climate change actions require policy measures that will change the current pattern of development. The policies required to meet the IPCC targets for temperature increases represent structural changes in the economies, with associated effects not well understood in all its aspects. This is a matter of concern to institutions like the International Labor Organization - ILO (2015), which points out that the …"economic restructuring, resulting in the displacement of workers and possible job losses and job creation attributable to the greening of enterprises and workplaces" is one of the major challenges involved in this structural change.

Likewise, Smith (2017) states that… "There can be no doubt that a zero-carbon world is possible, but we have choices about how we manage the transition. A just transition ensures environmental sustainability as well as decent work, social inclusion and poverty eradication. Indeed, this is what the Paris Agreement requires: National plans on climate change that include just transition measures with a centrality of decent work and quality jobs".

Deforestation control is an important part of the transition efforts to a less carbon intensive economy, and a critical policy target in the Brazilian intended Nationally Determined Contribution – iNDC. This policy, however, restricting the rate of increase of land supply, restricts agricultural and livestock expansion possibilities, mostly in the agricultural frontier regions, which still concentrates a large share of population and some of the worst welfare indicators in Brazil. Additionally, constraining the rate of

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expansion of the agricultural frontier affects also agricultural product composition in the traditional agricultural areas, through indirect land use change (ILUC) effects.

In spite of the importance of the issue, few studies in Brazil tried to analyze the social impacts of deforestation control policies in Brazil, in a consistent multi-sectoral, quantitative framework. To the best of our knowledge, Ferreira Filho and Horridge (2012), Ferreira Filho et al (2015), and Cabral et al (2015) are the only papers addressing this specific topic. Ferreira Filho and Horridge (2012) and Ferreira Filho et al (2015) approached the problem with a detailed inter-regional Brazilian computable general equilibrium (CGE) model, but restricted the deforestation scenarios to the Amazonia biome. Cabral et al (2015) also used a CGE model to analyze different deforestation reduction scenarios, but with a global model with no regions inside Brazil, in which distribution is approached through an aggregated measure of welfare variation.

In this study, we analyze the potential effects of several scenarios of deforestation reduction in Brazil, with a focus on the distributive side effects of the policy, with the aid of a Brazilian general equilibrium model, the TERM-BR model. The model is designed especially for land use change (LUC) and GHG emissions analysis, and with a fair disaggregation of workers and households at regional level, based on previous work by Ferreira Filho and Horridge (2014, 2017). This paper contributes to the literature in three main aspects. First, it brings new detailed estimates of deforestation and land use in three important biomes in Brazil: Amazonia, Cerrado and Mata Atlantica. This information is available by state and by type of agricultural aptitude, by region and biome, and by type of property right (public or private land). These data were obtained by satellite imagery technics, and allow a detailed representation of the deforestation process by region and biome, with the associated consequences on wages, employment and household consumption. Second, the model allows a detailed accounting of GHG emissions associated with this information. Third, we track the welfare effects of the policies by individual workers, households and regions.

This is the first time all this information is used in a CGE model for the analysis of economic and social impacts of deforestation reduction in Brazil. This allows the creation of a suitable baseline, as well as scenarios, for deforestation, properly accounting for the existing stocks of natural vegetation in each case and illegal deforestation in public lands, increasing the accuracy of the results and bringing new insights.

2. Methodology

The TERM-BR model is a recursive, bottom-up, dynamic computable general equilibrium model that includes a detailed regional representation of Brazil, with 27 regions (26 states plus the Federal District), 110 products and 110 productive activities, 10 types of families (classified by family income bracket) and 10 types of work (classified by salary range).

From the point of view of its dynamic behavior, the model presents solutions for annual periods, evolving in time guided by a dynamic process that consists of four mechanisms:

- A stock-flow relationship between investment in a given period and capital stock in the following period;
- A positive relationship between sectoral investment and the respective rate of profit;
- A positive relationship between real wage variation and regional labor supply; and
- A positive relationship between deforestation in a given period and the available land stock for agriculture and livestock in the following period.

Through these mechanisms is possible, together with other hypotheses, to design a baseline for a given economy, that is, an inertial trajectory of growth in relation to which a second trajectory (policy trajectory), which differs from the first only in terms of the economic policy to be implemented, can be compared. The difference between the two trajectories is the effect of the policy under analysis. The policy scenarios in this study entail various alternative deforestation patterns.

The TERM-BR model has as particular characteristic a land use module and an associated GHG emissions module, described in more details below.

3. The land use and GHG emissions in the TERM-BR model.

The concept of transition matrices gives support to the model´s land use module. These matrices, elaborated by state and biome, make use of information obtained through satellite images for land use changes observed between 1994 and 2002 (Brazil, 2010). This information was processed to distinguish three major types of land use, Crops (CROP), Pastures (PASTURE) and Forestry (planted forests, FORESTRY), and a residual type identified in the model as UNUSED, which refer to native forests. These transition matrices are detailed by state and, within each state, by six distinct biomes: Amazonia, Cerrado, Caatinga, Atlantic Forest, Pampa and Pantanal.

The transition matrix shows, for example, how many hectares (physical units of land) of the Cerrado biome in the state of Mato Grosso, which was natural vegetation in 1994, became Crops in 2002, or remained as natural vegetation. The model has, therefore, for each biome in every state, a complete transition matrix. The data observed in the period mentioned above was processed to show the probability that each hectare under given use in a certain year will be in another use the following year.

These transitions are also price influenced. Transition from pastures or forests to crops, for example, accelerates with the growth of the relative prices of agricultural products. Moreover, the model is flexible enough to allow exogenous projections of the level of deforestation according to desired patterns, as in the case of this study. In this case, the Transition Matrix ensures information consistency, that is, the increase of pasture, crop and forestry area in a given year must respect the increase in the available area given by deforestation in the previous year.

The transition matrices, then, determine the total land available for each broad land use group (Crops, Pasture, Forestry and Unused). Once the amount of each aggregate category is determined, the model will allocate land among the activities within each category. Crop area, for example, will be allocated among the eleven agricultural activities of the model, through a CES (Constant Substitution Elasticity) function, based on the relative prices of the products of these activities.

The model has two main emissions matrices, which tracks all emissions in the economy. The first emissions matrix tracks emissions in all economy activities (except deforestation), where emissions are associated to each productive sector and final demand, and can be of two broad types: emissions associated to fuel use and emissions associated to the level of activity of each sector (like fugitive emissions in mining, or CH4 emissions in livestock, for example). All emissions are accounted by the original GHG gases, and transformed to CO2 equivalents using the Global Potential Warming for 100 years (GPW-100) coefficients from the IPCC Second Assessment Report –SAR (IPCC, 1996).

The second emissions matrix accounts for emissions in LUC, and is associated to the Transition Matrix in LUC discussed above. The GHG emissions matrix associated to the LUC module, then, shows observed emissions on transitions, by state and biome. This allows a detailed accounting of emissions on transitions, and the computation of sinks on forest restoration.

4. The simulation strategy

As mentioned earlier, a dynamic CGE model requires, for its application, the comparison of policy scenarios with a given economy baseline, i.e. an "inertial" economic path, which would be observed if the states of nature remained as presently (business as usual, or BAU). The construction of this scenario involves two main periods, the historical period and the projection period, which are described in what follows.

The model´s database is for year 2005. This means that the model is calibrated to reproduce the characteristics of the Brazilian economy in that year. Thus, it is necessary to proceed with a historical update of the database up to the current period, what is done by imposing to the model the observed trajectory of the Brazilian economy in the period, in terms of its macroeconomic components. All production data, exports, etc., as well as population variation by state, are updated in order to satisfy the observed macroeconomic (such as the GDP variation) and demographic aggregates.

In addition, we paid special attention to the evolution of deforestation and land use. The values of deforestation in the three previously mentioned biomes (Amazonia, Cerrado and Mata Atlantica) up to 2015 (the historical period) were imposed to the model, as well as the evolution of the total area of crops and forestry. With this, we updated the model database until 2015, when the historical period ended. The period of the projections, therefore, begins in 2016[6] and goes until 2030, generating the baseline for the economy of Brazil. The main features of this baseline are described below:

- Projections of population growth by state (IBGE). This implies an aggregate growth of 20.1% of the population by 2030 (2016/2030), but with faster growth in the states / regions of RestNe (Rest of Northeast) and GoiasDF (Goias plus de Federal District). São Paulo, Minas Gerais would be the states with the lowest population growth in the period.
- Projected growth in real GDP in Brazil of 2.5% per year.

[6] Data availability with the required level of detail was available only until 2015 by the research completion time.

- Deforestation projections per biome and region, based on the last 5 years average for Amazonia and Mata Atlantica, and 3 years average for Cerrado[7]. This leads to total deforestation at the baseline of 13.7 million hectares (Mha) by 2030, of which 7.4 Mha in the Amazonia biome, 6 Mha in the Cerrado biome, and 0.3 Mha in the Mata Atlantica biome.
- Aggregate crop area growth projections, by state and biome, according to observed the five years (2015-2011) average, with an annual increase of approximately 2.5 Mha per year, a total expansion of 37.7 Mha in crop area in the period 2016-2030. These values are imposed to the model, only the Amazonia, Cerrado and Atlantic Forest biomes were contemplated.
- Projected growth of commercial forests area (Eucalyptus and Pinus plantations, or forestry) of 0.49 Mha per year, by 2030, a total expansion of 7.1 Mha in the area planted forests in the period.

As explained earlier, the use of the Transition Matrix ensures consistency between total land use, i.e. the sum of the changes in crop, pasture and forestry areas must be equal to the change in deforested area. With areas of crops, forestry, and deforestation projected exogenously in the baseline, the pasture area is the variable that adjusts[8]. The projections described above are consistent with a reduction of 31.1Mha in the area of pasture in the baseline, from 2016 to 2030. The choice of pasture area as the adjustment variable entails the idea that agricultural activities have, in general, higher rates of return than livestock. With faster growth of crops and forestry relative to grassland in the base year, projected deforestation is consistent with that decline.

Finally, for the purposes of this study, the model database was aggregated to 16 regions and 38 commodities and sectors, for easy of exposition.

5. The deforestation scenarios

The deforestation scenarios used in this study were designed by Instituto Escolhas (2017), with the aid of satellite imagery information. All scenarios show deforestation trends calculated individually by biome and state (or region), separated in public and

[7] The choice of the 3 years average for Cerrado is due to unusually high deforestation rates in this biome in 2011 and 2012, what would cause a 5 years average rate to be too high compared to the current observed rates.
[8] Soares-Filho (2014), Ferreira Filho et al (2015) and Diniz (2015) use the same hypothesis.

private lands, when possible. As mentioned previously, for the Amazonia and the Atlantic Forest biomes, trends represent the average deforestation rates observed between 2011 and 2015 (period of 5 years), which were replicated year by year between 2016 and 2030 (period of 15 years). In the case of the Cerrado biome, projected deforestation rates are the average of the period between 2013 and 2015.

In all scenarios we assume that deforestation will occur only on stocks of unprotected native vegetation in relation to the requirements of the Brazilian Forest Code (environmental assets), i.e., only native vegetation outside Permanent Protection Areas (APP) and Legal Reserves (RL)[9]. However, none of the scenarios proposes the restoration or compensation of areas with APPs and RLs deficits (environmental liabilities), so that unprotected inventories can be fully converted if required by the projected deforestation rates.

In this paper, we simulate three deforestation scenarios:

- Scenario 1 (DZabs): Absolute zero deforestation. This is the most extreme scenario, in which deforestation is completely interrupted between 2016 and 2030, both in public and private lands.
- Scenario 2 (DZ2): The rate of deforestation on all public lands, and in private lands in the Mata Atlantica biome will follow the current trend until 2020, when it will start to be reduced until it´s stop in 2030. Deforestation in private lands in the Amazonia and Cerrado biomes will follow the current trend, but only over non-protected natural vegetation (legal deforestation), and only on land stocks of high agricultural suitability (or agricultural aptitude above the 0.80 percentile).
- Scenario 3 (DZ3): The rate of deforestation on public lands, and in private lands in the Mata Atlantica biome will follow the current trend until 2020, when it will start to be reduced until it´s stop in 2030. Deforestation in private lands in the biome Amazonia and Cerrado will follow the current trend on existing stocks, irrespective of its agricultural suitability.

The first scenario is only for reference, an upper bound for the economic impacts of deforestation control policies effects. This scenario, although extreme, matches the target proposed by the New York Declaration on Forests, issued in the United Nations

[9] Permanent Protection Areas and Legal Reserves are mandatory legal provisions of native vegetation in farms, required by the Brazilian Forest Code.

Climate Summit 2014 (United Nations, 2014), which Brazil has not endorsed (Ferreira Filho et al, 2015).

The second scenario (DZ2) has as priors the implementation of policies which result in higher governance over public lands, starting in 2017-2018 and taking other two years to generate effects; the effective application of the Lei da Mata Atlantica (the Atlantic Forest Law); and occupation of new lands based on an agro-environmental zoning at national level. Finally, the third scenario is like the second one, but without the agro-environmental zoning rules.

As was the case in the baseline, we assume that pastureland area will fall to compensate for the fall in deforestation. The net result of the above scenarios, in terms of deforestation deviation from the baseline are displayed in Table 1, which shows the avoided deforestation (or the area of lost pastureland) in each scenario, relative to the baseline. In this table the DZabs scenario, which simulates the total interruption of deforestation from 2016, would imply a total increase in the area of native forests of 13.7 Mha from the baseline, accumulated in 2030 (avoided deforestation). In scenario DZ2 the total gain in forest areas (or, what is symmetrical, loss of pasture areas) would be lower, of 5.6 Mha, while in the DZ3 scenario there would be a gain of 0.95 Mha of forests.

Table 1. Deforestation, percent variation from the baseline, by region. Million hectares.

States/Regions	DZabs	DZ2	DZ3
1 Rondonia	0.97	0.48	0.16
2 Acre	0.41	0.25	0.05
3 Amazonas	0.76	0.14	0.09
4 Roraima	0.20	0.03	0.02
5 Pará	3.15	1.90	0.31
6 Amapa	0.02	0.01	0.00
7 Matopiba	4.40	2.01	0.18
8 PernAlag	0.00	0.00	0.00
9 RestNE	0.00	0.00	-0.01
10 MinasG	0.56	0.09	0.05
11 SaoPaulo	0.00	-0.01	-0.02
12 RestSE	0.00	0.00	0.00
13 Sul	0.00	-0.02	-0.02
14 MtGrSul	0.21	0.02	0.01
15 MtGrosso	2.64	0.68	0.13

16 GoiasDF	0.38	0.04	0.01
TOTAL	13.72	5.60	0.95

Source: model results.

In the next section, we discuss main simulation results and its implications.

6. Results

Since the economic activity has an uneven distribution in the territory and pasture productivity is not equal in all regions, the economic impacts of deforestation control are not directly proportional to the loss of deforested area in the policy scenarios. To better analyze this point, we will initially verify the impact of the scenarios on some macroeconomic variables (Table 2).

Model results show that GDP loss accumulated in 2030 is small in relative terms. The highest observed loss would be in the DZabs scenario, a fall of 0.62% of GDP accumulated until 2030. This is the social cost of avoided deforestation (or the shadow value of deforestation) once computed all associated economic losses in the economic system. In monetary terms, GDP losses accumulated up to 2030 and expressed in 2016 values are estimated in US$ 12.9 billion (US$ 862 million per year) for the DZabs scenario, US$ 4.7 billion (US$ 312 million per year) for the DZ2 scenario, and US$ 639 million (US$ 43 million per year) for the DZ3 scenario. Only as a reference for the orders of magnitude involved, the total rural credit volume made available in 2016 in Brazil was US$36.7 billion (Banco Central do Brasil, 2017).

Table 2. Model results. Macroeconomic variables. Percent variation, aggregated in 2030.

	DZabs	DZ2	DZ3
Household consumption	-0.58	-0.21	-0.03
Real investment	-3.32	-1.35	-0.22
Real government consumption	-0.58	-0.20	-0.03
Exports volume index	1.94	0.76	0.13
Imports volume index	-0.85	-0.36	-0.06
GDP (real)	-0.62	-0.22	-0.03
Wages (real)	-1.23	-0.48	-0.08
Total GHG emissions	-16.20	-11.91	-3.48

Source: model results.

As can be seen, the social cost of avoiding deforestation, as measured by the GDP loss is small, and determined by the small share of livestock in the total Gross Value Added of the Brazilian economy, which was approximately 1.5% in the base year (2005). Considering grassland area in the base year was approximately 160 Mha, the simulated loss of pastureland accounts for less than 10% of the total area in the base year. The composition of these values determine the observed small loss of GDP, even after the computation of upstream and downstream losses in the livestock production chain.

As mentioned previously, deforestation reduction is one of the main targets for GHG reductions in Brazil. The share of LUC emissions in total emissions in Brazil drop from 69.6% in 2005 to 27.46% in 2010 (MCT, 2016), an enormous progress in terms of deforestation reduction. At the same time, agriculture and livestock increased their share from 14.35% in 2005 to 32.3% in 2010. Deforestation control, then, although still very important, is continuously reducing its importance for total GHG emissions in Brazil, due to the continuous growth of agriculture and livestock the increase of thermal energy sources use. Model results show that deforestation reduction would significantly reduce emissions in 2030 (Table 2). In Scenario 2 (DZ2), for example, when deforestation would progress but under a better governance pattern, total emissions would be reduced by 11.91%, accumulated in 2030.

Losses in pasture areas lead to a general relocation of agriculture and livestock production in the territory (Table 3), with the largest relative drop in the production of livestock activities, which directly use pastures.

Table 3. Production. Percentage changes from base, accumulated in 2030.

Commodity	Dzabs	DZ2	DZ3
1 Rice	-1.51	-0.55	-0.08
2 Corn	-1.47	-0.55	-0.08
3 Wheat and other cereals	1.74	0.82	0.11
4 Sugar cane	-0.45	-0.16	-0.02
5 Soybean	2.06	0.74	0.12
6 Other agriculture	0.61	0.25	0.04
7 Cassava	-1.32	-0.48	-0.07
8 Tobacco	0.42	0.16	0.03
9 Cotton	-0.65	-0.22	-0.03
10 Citrus	-1.08	-0.38	-0.06
11 Coffee	1.67	0.62	0.10

12 Forestry	1.32	0.54	0.08
13 Livestock	-8.54	-3.41	-0.56
14 Milk (primary)	-4.83	-1.82	-0.30
15 Hogs, Poultry, Eggs	-1.61	-0.60	-0.09
16 Mining	1.15	0.43	0.07
17 Meats	-3.05	-1.15	-0.18
18 Oils	-4.42	-1.68	-0.27
19 Dairy	-1.62	-0.62	-0.10
20 Rice (processed)	-0.77	-0.29	-0.05
21 Sugar	-4.21	-1.58	-0.25
22 Coffee (processed)	-1.26	-0.48	-0.08
23 Other food	-1.93	-0.72	-0.11
24 Textile and Apparel	0.19	0.13	0.03
25 Cellulose and paper	1.65	0.62	0.10
26 Gasoline	1.21	0.43	0.07
27 Gasoline C (ethanol blend)	-0.57	-0.20	-0.03
28 Ethanol	1.18	0.44	0.07
29 Combustible oil	1.60	0.60	0.10
30 Diesel oil	0.09	0.03	0.01
31 Petrochemicals	1.56	0.58	0.09
32 Other manufactures	-0.19	-0.07	0.00
33 Automobiles and trucks	-0.50	-0.18	-0.02
34 Metallurgy products	0.25	0.11	0.02
35 Electricity, Gas, Water, Sewage	-0.36	-0.12	-0.01
36 Trade	-0.34	-0.12	-0.02
37 Transport	0.66	0.27	0.05
38 Services	-0.55	-0.19	-0.02

Source: model results.

Another interesting aspect to note is that the policy does not generate a negative effect on all agricultural products. Products with a significant exported share, either directly as a primary product, or indirectly through their processed products, or even imported, have their domestic production increased. This is because the policy shock generates a real exchange rate devaluation, with an equivalent terms of trade loss, benefiting exports (soybeans, coffee and forestry, mining), as well as products with high imported share (wheat). These products tend to benefit from the policy, by expanding their production to the detriment of others.

In regional terms, the distribution of social losses (GDP) are uneven (Table 4). As can be seen, GDP fall, which is quite small when considered in the Brazilian aggregate, is significantly higher in some states. In all scenarios, states in the agricultural frontier would typically lose more than the average, since at the baseline deforestation progresses mainly at the frontier. The states of Rondonia, Acre, Pará and Mato Grosso would be the most affected states, in general.

Table 4. Percentage changes of regional GDP. Accumulated in 2030.

Real GDP	DZabs	DZ2	DZ3
1 Rondonia	-3.07	-1.53	-0.59
2 Acre	-4.53	-2.88	-0.54
3 Amazonas	-0.55	-0.12	-0.06
4 Roraima	-1.47	-0.32	-0.14
5 Para	-2.05	-1.35	-0.23
6 Amapa	-0.64	-0.19	-0.05
7 Matopiba	-1.04	-0.45	-0.04
8 PernAlag	-0.40	-0.15	-0.02
9 RestNE	-0.44	-0.15	-0.02
10 MinasG	-0.48	-0.13	-0.03
11 SaoPaulo	-0.38	-0.13	-0.01
12 RestSE	-0.17	-0.06	0.00
13 Sul	-0.65	-0.21	-0.02
14 MtGrSul	-1.11	-0.30	-0.04
15 MtGrosso	-3.17	-0.91	-0.14
16 GoiasDF	-0.99	-0.29	-0.04

Source: model results.

Considerations about the distribution of social costs between regions are crucial elements for the political economy of any policy. Deforestation reduction policies should take into account these asymmetric losses, in order to get political support of different actors to the process: compensation mechanisms for states that lose the most may be important to the success of policies to contain deforestation.

Table 2 also shows a fall in the real wage of the economy, in the three scenarios, due to economic activity reduction, expressed by the fall in GDP. The fall in real wages, however, is not uniform for workers of different types of qualification, as can be seen in Table 5. In this table, workers are classified into ten different types according to their wages, as a "proxy" for labor productivity, such as the OCC1 category is the least qualified representative worker, and OCC10 the most qualified.

Table 5. Model results. Percentage changes in real wages, by type of work occupation, accumulated in 2030.

Occupation type	Dzabs	DZ2	DZ3
1 OCC1	-2.61	-1.08	-0.15
2 OCC2	-2.60	-1.12	-0.16
3 OCC3	-1.70	-0.67	-0.11
4 OCC4	-1.63	-0.64	-0.09
5 OCC5	-1.73	-0.70	-0.11
6 OCC6	-1.59	-0.62	-0.10
7 OCC7	-1.48	-0.58	-0.09
8 OCC8	-1.36	-0.53	-0.09
9 OCC9	-1.09	-0.41	-0.07
10 OCC10	-1.06	-0.40	-0.06

Source: model results.

Model results show that the wages of the least skilled workers would fall more than those with higher qualification would. Agriculture is relatively more labor (low skill) intensive than the average economy, what explains the result. As the policy shock (reduction of deforestation) primarily affects agriculture and livestock, low skilled workers (OCC1) tend to show a larger decline in real wages than the high skilled ones (OCC10).

From a consumption point of view, two effects must balance to explain household consumption: the income and the expenditure effects. The model tracks individual incomes to household incomes, through a detailed mapping from labor occupations wages to household group incomes, showing that changes in wages have distinct effects on household group incomes and, consequently, household consumption. Considering that the lowest wage earners are concentrated in lower income families, and vice versa, the greater fall in the salary of the less skilled workers tends to affect more negatively the incomes of the poorest families, and their consumption.

To the effect mentioned above one must also add the effect of the composition of the consumption baskets of the different income families. Poorer households carry a greater weight of food in their consumption basket than the richer ones, who have a relatively greater weight of services in their consumer baskets. The combined result of these effects can be seen in Table 6, where families classified as POF1 are those with the lowest income and POF10 the richest: real consumption falls more in the poorest families. The richest families (POF10) would even increase consumption (in real terms) in scenarios DZ2 and DZ3. This is associated to the composition of their consumption basket, as previously mentioned. In the richest families (POF10), consumption of Services represents about 32% of the total expenditure in the base year, whereas for the poorest (POF1) this item represents only 2.2%.

The service-producing sector, however, is also an important low-skilled employer, whose salary has fallen, as seen before. Thus, while food products tend to increase their price in simulations, service prices tend to reduce, benefiting relatively more households that have a larger share of Services in their consumer basket (the richest).

Table 6. Percentage changes in real household consumption. Accumulated in 2030.

	Dzabs	DZ2	DZ3
1 POF1	-1.80	-0.72	-0.10
2 POF2	-1.59	-0.63	-0.09
3 POF3	-1.24	-0.48	-0.07
4 POF4	-1.11	-0.42	-0.06
5 POF5	-0.82	-0.30	-0.05
6 POF6	-0.64	-0.23	-0.03
7 POF7	-0.44	-0.15	-0.02
8 POF8	-0.28	-0.08	-0.01
9 POF9	-0.10	-0.01	0.00
10 POF10	-0.03	0.02	0.01

Source: model results.

Therefore, reducing deforestation would tend to affect the poorest of the economy more negatively. Deforestation reduction, however, is probably the main “green policy” under consideration in Brazil presently, and the social negative effect observed here is an associated pitfall of the policy. As discussed previously for regional losses, this is also an important result. All economic policies generate winners and losers, a consequence of the resources restriction in any economy. The identification of these agents is an important policy consideration, as it allows the design, if necessary, of adequate compensatory policies.

It´s worth to note that, for the results hitherto presented, no technical progress (or technological change) is at work, in the classical sense of the term. The model generates endogenous substitution between productive factors, which changes the partial productivity of the factors of production, but this is a purely allocative effect, not a displacement of the production function. The magnitude of the observed social loss (small in general) suggests that relatively small rates of technical progress above the trend could compensate for these losses, an issue always present in the discussions about the expansion of Brazilian agriculture in the presence of reductions in land supply due to deforestation control.

The model allows an estimation of these effects, that is, it allows calculating what would be the variation of land productivity (production per hectare) necessary to maintain the production at the base year level, once implemented the policy (deforestation reduction). In particular, it is interesting to know the variation required in the productivity of livestock to keep livestock production at the levels observed in the base year in the states where a fall in production occur. These values can be seen in Table 7, where all results refer to Scenario 2 (DZ2) only.

Table 7. Annual percentage changes in land productivity between 2016 and 2030 required to maintain livestock production (beef and milk) at baseline levels in Scenario 2 (DZ2).

States/Regions	Beef cattle	Milk cattle
1 Rondonia	0.49	0.49
2 Acre	1.03	1.04
3 Amazonas	0.45	0.45
4 Roraima	0.21	0.21
5 Para	0.79	0.80
6 Amapa	0.12	0.11
7 Matopiba	0.45	0.45
8 PernAlag	0.00	0.00
9 RestNE	0.00	0.00
10 MinasG	0.00	0.00
11 SaoPaulo	0.00	0.00
12 RestSE	0.00	0.00
13 Sul	0.00	0.00
14 MtGrSul	0.00	0.00
15 MtGrosso	0.52	0.52
16 GoiasDF	0.00	0.00
Brasil	0.29	0.13

Source: model results.

The largest variations in land productivity would be required in some of the northern states (Rondônia, Acre, Amazonas and Pará), in the region of Matopiba (Maranhão, Tocantins, Piauí and Bahia), and in the state of Mato Grosso. The state of Para, for example, would need an average annual increase in beef cattle productivity of 0.79% to keep production at levels observed in the baseline, in the simulation period

(2016-2030). For most regions, however, the required annual productivity gains above the baseline trend are relatively low, and could probably be achieved with adequate incentive policies.

As a reference, Dias et al (2016) estimated that the average pasture-stocking rate in Brazil increased at an annual rate of 2.56% in the period 1990-2010, while Valentin and Andrade (2009) calculated, for the same variable, growth of 1.98% in the period 1975-2006. It should be noted that the stocking rate (number of animals / ha) is a lower limit for productivity gain, since animal performance (weight gain / head) also affects overall performance. Guidotti et al. (2017) estimate, for Brazil as a whole, gains in terms of animal units per hectare (reflecting the average gain of animals weight) of 1.31% per year in the period 1975/2014[10].

7. The states of Para and Mato Grosso

A closer look at results for states located in the agricultural frontier reveal other important features related to deforestation control. In this section, we analyze in more details the states of Para and Mato Grosso, which are amongst those with the highest rate of deforestation presently.

The first thing to note is that the projected deforestation in those states is concentrated in the Amazonia biome (Table 8). Only 2.63 Mha out of 13.69 Mha in the baseline deforestation would be in the Cerrado biome (in Mato Grosso) in those two states, second only in relation to the Matopiba region in the baseline deforestation.

Table 8. Baseline deforestation, states of Pará and Mato Grosso. Millions of hectares, 2016-2030.

	Biome			
	Amazonia	Cerrado	Mata Atlântica	Total
1 Rondonia	0.91	0	0	0.91
2 Acre	0.42	0	0	0.42
3 Amazonas	0.75	0	0	0.75
4 Roraima	0.19	0	0	0.19
5 Para	3.12	0	0	3.12
6 Amapa	0.02	0	0	0.02
7 Matopiba	0.32	3.95	0.12	4.39
8 PernAlag	0	0	0	0
9 RestNE	0	0	0.01	0.01

[10] Although not directly comparable, these studies give an idea of the rates involved.

10 MinasG	0	0.46	0.12	0.58
11 SaoPaulo	0	0.02	0	0.02
12 RestSE	0	0	0.01	0.01
13 Sul	0	0	0.04	0.04
14 MtGrSul	0	0.21	0.01	0.22
15 MtGrosso	1.64	0.99	0	2.63
16 GoiasDF	0	0.39	0	0.39
Total	7.37	6.02	0.3	13.69

Data in Table 8, therefore, represent the policy shock in the DZabs scenario, that is, the total interruption of deforestation in Brazil. Although projected deforestation is higher in the state of Para, the state of Mato Grosso show a relatively higher GDP loss (Table 9) in the DZabs scenario. This happens because livestock (beef and milk) represents a larger share of the total production value in the base year (5.4%) in the state of Mato Grosso than in the state of Pará (4.2%). In addition, the Mining sector (which, as previously seen, gets benefits from exports) is also relatively more important in the state of Pará (10.6% of the state's total production value in the base year), compared to Mato Grosso (0.4%), which is decisive for the aforementioned result.

Table 9. Regional macroeconomic variables. Percentage changes accumulated in 2030.

	Para			Mato Grosso		
	Dzabs	DZ2	DZ3	Dzabs	DZ2	DZ3
Real household consumption	-1.90	-1.13	-0.17	-2.23	-0.55	-0.10
Real GDP	-2.05	-1.35	-0.23	-3.17	-0.91	-0.14
Aggregate employment	-0.11	-0.10	-0.01	-0.19	-0.02	0.00
Real wage	-2.29	-1.21	-0.19	-2.29	-0.70	-0.13

In the DZ2 scenario, however, where deforestation would only evolve in areas of high and very high agricultural aptitude, the result reverses, i.e., GDP loss is highest in the state with the highest deforestation (Pará). In this case, what happens is that deforestation is higher in relative terms in Pará than in Mato Grosso: while in DZabs the Pará / Mato Grosso ratio of deforestation is 1.2 in DZ2 this same ratio is 2.8 (see data from Table 1). This means that, according to the physical survey (satellite imagery), there is still more unprotected high and very high quality agricultural land available in the state of Mato Grosso than in Pará. The DZ3 scenario is intermediate to the other two, with very low GDP losses.

The same type of result appears in the variations of real wages and employment in both states, which fall more in DZabs in Mato Grosso and more in DZ2 in Pará in general. Again, the same distributional result pattern previously seen at the national level emerges (Table 10), i.e. losses are higher for the less skilled workers (OCC1) in both states, and lower for the more qualified workers (OCC10).

Note the higher real wages losses in the DZabs scenario for the less qualified workers (OCC1 to OCC4), which would fall 6.30% in Pará and 6.50% in Mato Grosso, accumulated in 2030. These observations only reinforce the point raised previously regarding the asymmetry of regional impacts, and that should be taken into account in the analysis of deforestation control policies.

Table 10. Percentage changes in regional real wages. Accumulated in 2030.

	DZabs		DZ2		DZ3	
	Pará	Mato Grosso	Pará	Mato Grosso	Pará	Mato Grosso
1 OCC1	-3.14	-5.18	-1.54	-1.85	-0.23	-0.31
2 OCC2	-6.30	-5.80	-3.79	-1.84	-0.58	-0.33
3 OCC3	-3.13	-5.68	-1.74	-1.67	-0.28	-0.32
4 OCC4	-2.54	-6.50	-1.42	-1.72	-0.22	-0.32
5 OCC5	-3.72	-4.73	-2.17	-1.36	-0.34	-0.26
6 OCC6	-3.31	-4.88	-1.89	-1.47	-0.30	-0.28
7 OCC7	-2.58	-2.95	-1.45	-0.94	-0.23	-0.16
8 OCC8	-1.82	-1.72	-1.01	-0.49	-0.16	-0.09
9 OCC9	-0.27	-1.50	-0.07	-0.45	-0.01	-0.08
10 OCC10	-1.95	-1.50	-1.10	-0.45	-0.17	-0.09

Finally, the heterogeneity of wage variations effects on household incomes assumes a particular aspect at regional level. Although the observed pattern follows the one previously observed at the national level, there is a sharper drop in the consumption of lower skilled workers in the two states, compared to the national, but particularly in the state of Mato Grosso, where the accumulated loss in 2030 would reach 6.03% for the poorest families (Table 11).

Table 11. Percentage changes in real regional household consumption. Accumulated in 2030.

	DZabs		DZ2		DZ3	
Household	Pará	Mato Grosso	Pará	Mato Grosso	Pará	Mato Grosso
1 POF1	-3.60	-6.03	-2.08	-1.71	-0.32	-0.32
2 POF2	-3.61	-4.91	-2.13	-1.36	-0.33	-0.25

3 POF3	-2.67	-3.91	-1.53	-1.07	-0.24	-0.19
4 POF4	-2.28	-3.92	-1.33	-1.00	-0.21	-0.18
5 POF5	-2.04	-2.75	-1.14	-0.76	-0.18	-0.13
6 POF6	-1.47	-1.02	-0.92	-0.17	-0.14	-0.03
7 POF7	-0.98	-1.30	-0.63	-0.25	-0.10	-0.05
8 POF8	-1.15	-0.63	-0.78	-0.07	-0.12	-0.01
9 POF9	-0.43	-0.73	-0.31	-0.13	-0.05	-0.02
10 POF10	-0.22	-0.03	-0.20	0.12	-0.03	0.02

8. Final remarks

Environmental policies, like any other policy, may present undesirable indirect outcomes, and this is the case of deforestation control policies in Brazil. Together with desired GHG emissions reductions, and in spite of low associated GDP losses in the time span considered, states located in the agricultural frontier would bear a disproportionally high share of this adjustment costs. The same is true for the poorest households. As shown here, this policy has regressive potential, penalizing more the poorest families, both from the income (wages) and the expenditure sides. This phenomenon is even more intense when one considers the frontier states, where deforestation is still high and where there is still potential for considerable deforestation on private lands and in unprotected areas.

Recognizing these asymmetries is important for the discussion of policies to reduce deforestation in Brazil, especially given the still high level of poverty in the country. As seen in this study, the relatively higher share of agriculture and livestock in the regional GDP of states located in the agricultural frontier makes them more dependent on the expansion of this activity, which makes deforestation a relevant economic issue for them. Anticipating these results may be important in the design of compensatory policies aimed at their compliance to the Brazilian efforts for deforestation reduction, which, as discussed by Ferreira Filho and Horridge (2017) is central for the Brazilian commitments to COP21.

Our results also show that technological progress could compensate, in terms of livestock supply, the losses of simulated pasture areas. Moderate to small incremental gains in productivity, in most cases, would compensate for the effect of reduced pasture caused by reduced deforestation. Historical observed rates show that these gains would be possible, and are probably ongoing. Although reduced availability of land for pasture can induce technological progress by itself, there would certainly be room for public policies that may facilitate the adoption of existing technology. This is much more a question of relative prices than of technology availability.

Finally, we point out that the environmental gains from less deforestation have not been analyzed here. As noted earlier, these gains are not captured by the circular flow of income in the economy, and are probably very high when computed in all its dimensions. Indeed, this is a frontier area in applied economic research, and one with high priority in future methodological development efforts.

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