Greenhouse gas mitigation by agriculture and livestock intensification in Brazil

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1 Introduction

Brazilian agriculture has experienced a steady increase both in area and production in the last twenty years. The total agricultural area grew from 53 million hectares (Mha) in 1990 to 69.1 Mha in 2012, a 2.1% annual growth rate. The area of pastures, which tripled between 1970 and 2006, reached 160 Mha in 2006 (Brazilian Agricultural Census). This increase in area was accompanied by a steady increase in productivity per area, as shown in Figure 1. This shows that the productivity index (tonnes/ha) evolved from a value of 100 in 1990 to 192 in 2012, after peaking at 201 in 2010. We see too that after a period of static productivity, the index grew rapidly from 2005. This increase in productivity was also observed in livestock production, with important gains in animal performance and pastures productivity. As shown by Martha Jr. et al (2012), 79% of the growth in beef production in the 1950-2006 period can be explained by productivity gains.

This increase in Brazilian agriculture and pastures acreage has raised worldwide concerns about deforestation in the country. Indeed, Hansen et al (2008) showed that 47.8% of all humid tropical forest clearing from 2000 to 2004 occurred in Brazil, nearly four times that of the next highest country, Indonesia.

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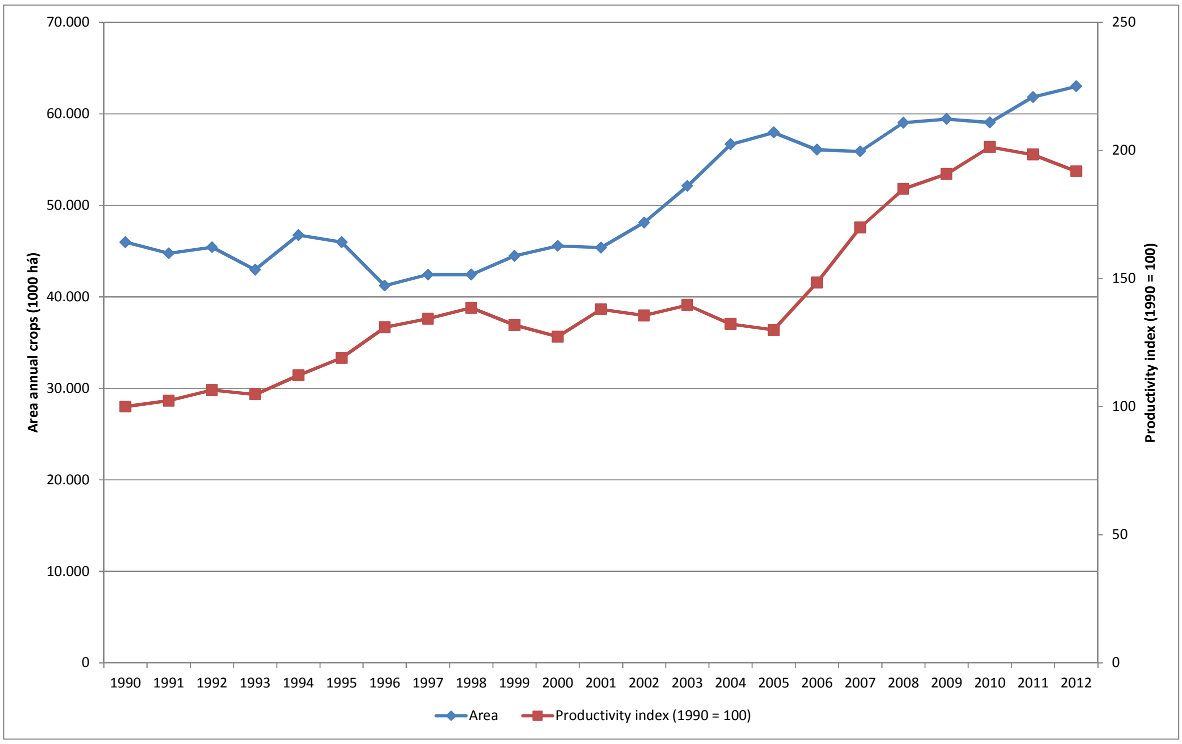

Figure 1. Evolution of annual crops area and productivity in Brazil.

Even though still facing a fast deforestation process, it´s also a fact that the rates at which deforestation have been progressing have been falling markedly in the last years, as can be seen in Figure 2. The rate of deforestation fell from 27,772 square kilometers in 2004 to 5,843 km2 in 2013. In the period 2000 to 2012 the total deforested area in the Amazon region increased by 19.5 Mha, while the area with crops increased by 18.5 Mha.

The conversion of land to different uses happened simultaneously to the increase in greenhouse gases (GHG) emissions in Brazil. Agriculture and change in use of land and forests accounted for about 58% of total GHG emissions in Brazil in 2005, by far the most important single emitting source in the country. Recent estimates show a fall of 38.7% in total emissions in Brazil in 2005-2010, which can be credited mostly to the fall in deforestation shown in Figure 2.

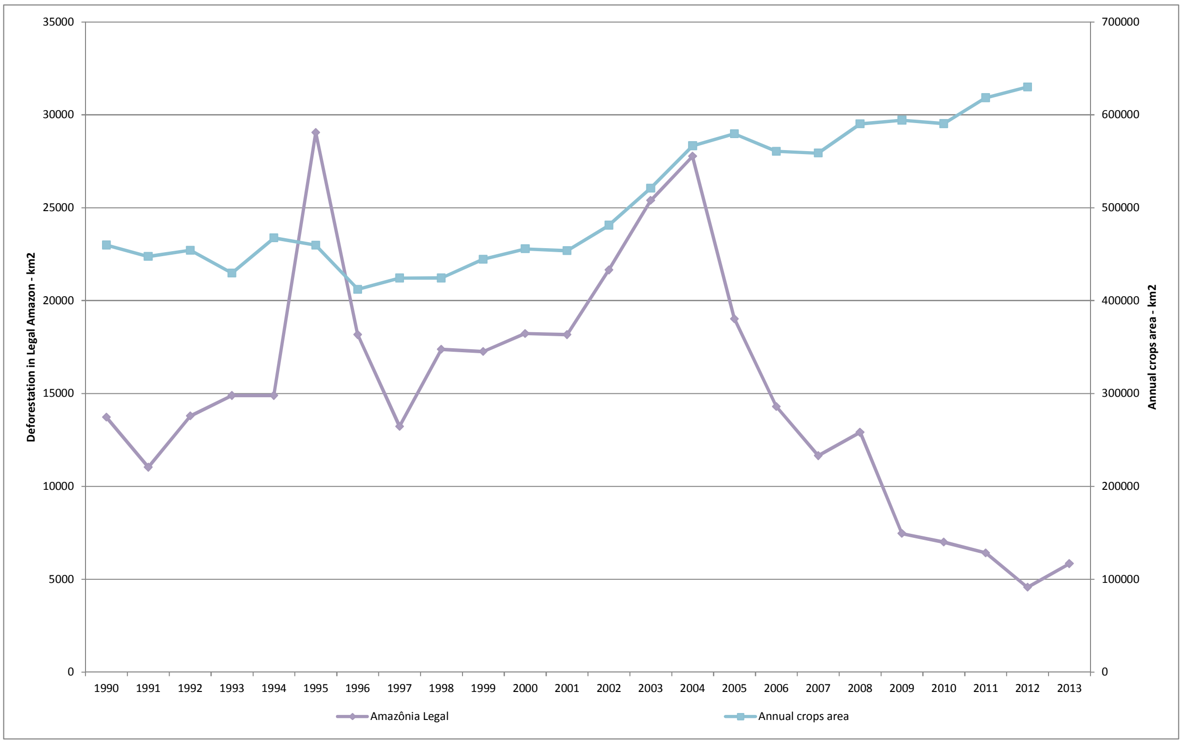

Figure 2. Deforestation in Legal Amazon and annual crops area evolution (total) in Brazil. 1991-2013.

Source: PRODES (INPE) and Pesquisa Agrícola Municipal (IBGE).

World food demand is expected to keep growing at a fast rate in the future, following the increase in population and income. Projections by FAO (2002) show that even though the growth in world demand for agricultural products is expected to fall from an average 2.2 percent a year over the past 30 years it will keep growing at 1.5 percent a year for the next 30. The growth rate of demand for cereals is expected to rise again to 1.4 percent a year to 2015, slowing to 1.2 percent per year thereafter, until 2030.

The same study shows that in developing countries overall, cereal production is not expected to keep pace with demand. The net cereal deficits of these countries, which amounted to 103 million tons or 9 percent of consumption in 1997-99, could rise to 265 million tons by 2030, when they will be 14 percent of consumption. Although less new agricultural land will be opened up than in the past …"in the coming 30 years developing countries will need an extra 120 million ha for crops, an overall increase of 12.5 percent" (FAO, 2002). The same study points out that, referring to the extra land required to meet demand, that…"more than half the land that could be opened up is in just seven countries of tropical Latin America and sub-Saharan Africa".

With its vast stock of natural forests still available, Brazil is expected to take a prominent role in this extra effort to supply food in future years, what conflicts with the actual efforts to control deforestation which have been effective, as shown before. It´s clear from the argumentation above, then, that agricultural intensification will have to play a central role in the Brazilian agricultural of growth in the future. Agricultural intensification can be effective in increasing agricultural supply, and was actually the most important source of increase of supply in the past (FAO, 2002). However, whether intensification is a way of sparing land, or curbing deforestation (and, in the case of Brazil, of reducing its main source of GHG emissions), is a matter of an intense debate presently (Angelsen and Kaimowitz, 2001; Ewers et al, 2009; Rudel et al, 2009; Burney et al, 2010; Cohn et al, 2011; Hertel, 2012; Stevenson et al, 2013). Hertel, 2012, in particular, analyzes the conditions under which the so called "Borlaug hypothesis" (the land sparing effect of increasing agricultural productivities) or the "Jevons paradox" (which relates increases in productivity to expansion in land areas) would prevail.

Harvey and Pilgrim (2010) analyzing the "food, energy and environment trilemma" (Tilman et al, 2009) notice that the competition for land in the next years present high risk of increasing the carbon footprint of agriculture. The same authors still point out that "…we need a more complex, and geographically differentiated, analysis of the interactions between direct and indirect land-use change". The importance of the geographical differentiation of the analysis, obviously important for global approaches also applies for large countries with significant differences in geography and, by consequence, in the distributions of biomes. This is the case of Brazil, where a diversity of biomes coexists in the agricultural frontiers in different states (see Figure 7 in the Appendix). In this case, the GHG emissions intensity depends not only on the type of the existing vegetation, but also on the type of transition from the natural vegetation to the next land use. The change in the carbon footprint involved can be quite different depending on those different transitions.

In this paper we analyze the potential for land sparing and GHG mitigation in Brazil through intensification of agriculture and livestock production, in order to meet future scenarios of food supply. The analysis will be conducted with the aid of a detailed computable general equilibrium model of Brazil, with inter-regional detail. In particular, we will focus on the Borlaug hypothesis, and analyze the conditions under which the intensification of agriculture and livestock production in Brazil would allow a significant reduction in deforestation rates.

2 Methodology

The analysis will be performed with the aid of a general equilibrium model of Brazil, tailored for land use and emissions analysis, the TERM-BR model. The model is based on previous work by Ferreira Filho and Horridge (2014), and was extended to include the new Brazilian emissions matrix of 2005 (Brasil, 2010). It is a multi-period computable general equilibrium model of Brazil with a module of land use that allows the analysis of endogenous land supply for agricultural expansion in the country. It includes annual recursive dynamics and a detailed bottom-up regional representation, which for the simulations reported here distinguished 15 aggregated Brazilian regions. It also has 38 sectors, 10 household types, 10 labor grades, and a land use change (LUC) module that tracks land use in each state. The core database is based on the 2005 Brazilian Input-Output tables.

As well as the LUC module, the model includes three recursive-dynamic mechanisms: (i) a stock-flow relation between investment and capital stock, which assumes a one year gestation lag; (ii) a positive relation between investment and the rate of profit; and (iii) a relation between wage growth and regional labor supply.

The land use module in the previous version of the TERM-BR model used in Ferreira Filho and Horridge (2014) was based on a transition matrix calibrated with data from the Brazilian Agricultural Censuses of 1995 and 2006. This version of the TERM-BR model presents two main differences from the previous model:

- A new transition model calibrated from satellite imagery physical observations between 1994 and 2002. This new transition matrix has an extra dimension, the Biome dimension, which allows a much more detailed accounting of emissions in transitions;
- A GHG emissions module associated with all the transitions, including deforestation, with a regional (state level) detail. This means that the transitions from natural forests to pasturelands, for example, can contribute differently for GHG emissions, depending on the type of natural forests present in each state. The model, than, allows the accounting of emissions associated to deforestation in Brazil.

The original data on transitions presented by Brasil (2010) brings originally 15 different transitions (Non-managed forests, Managed forests, Secondary forests, Forests with selective timber extraction, Reforestation, Non-managed fields, Managed fields, Field with secondary vegetation, Planted pastures, Crops, Urban areas, Rivers and lakes, Reservoirs, Other uses, and Non classified areas) for 6 biomes (Amazon, Cerrado, Caatinga, Atlantic Forest, Pampa, and Pantanal), by state in Brazil. This database was modified to generate an operational transition matrix with four different transitions (Crops, Pastures, Planted Forests, and Unused land) for the six biomes previously mentioned, for 27 regions in Brazil (26 states plus the Federal District). The version used in this paper was aggregated to 15 regions, as stated before.

The model, then, allows a detailed accounting of emissions, which can come from:

- The economic activities, with emissions associated to fuel use or the production level (as is the case of fugitive emissions, for example). This is the traditional approach to emissions.
- In the case of land use change, emissions on the transitions which allow capturing the details of emissions linked to the land use transitions dynamics.

The emissions associated with the transitions in Brazil, aggregated to the model´s operational level can be seen in Table 1 below, where the figures are the total for all biomes. In this representation, we disaggregated the land use change into four categories. Emissions are expressed in gigagrams of carbon dioxide equivalent (Gg CO2 eq) emitted by the conversion of a particular category of land use of the initial period, 1994 into other uses in the final period, 2002. Negative values represent carbon removals (sinks), while positive values are net emission. For example, the total amount of land under the "Unused" category (native vegetation, parks, reserves and other areas) in 1994 converted into pastures generates in the final period the amount of 9,388,356 Gg net CO2eq, aggregated over all biomes.

Table 1. Emissions associated with transitions in Brazil. Gg, 1994-2002.

TRNS	1 Crop	2 Pasture	3 PlantForest	4 Unused	Total 1994
1 Crop	0	-50588	-14409	5754	-59243
2 Pasture	204441	126974	-18220	-25453	287742
3 PlantForest	11243	15412	0	363	27018
4 Unused	2221596	9388356	28339	-1522657	10115634

Total 2002	2437280	9480155	-4290	-1541993	10371151

Source: model database.

Table 2, in turn, presents the total emissions generated by the conversion of the four categories of land use of the initial period, 1994 into Crops and Pastures in the final period, 2002, now disaggregated by biome, what highlights the different carbon contents present in different biomes. For example, the conversion from Unused (1994) into Crops (2002) produces a total of 974,514 Gg CO2 eq.) in the Amazon Biome and 1,054,510 in the Cerrado biome, whereas, in Pampa the total released is only 4 Gg CO2eq. In the conversion to Pastures the figures were 7,303,090 and 1,218,275 Gg CO2eq for the biomes Amazon and Cerrados respectively. This table then shows the specificities of the Brazilian territory in terms of emissions potential associated to land use change, an important issue to support the development of accurate policies.

Table 2. Total emissions associated with transitions to Crops in Brazil, by biome. Gg, 1994-2002.

	Transition to crops						
TRNS	Amazonia	Cerrado	Caatinga	AtlanticForest	Pampa	Pantanal	Total
1 Crop	0	0	0	0	0	0	0
2 Pasture	20,758	175,848	2,581	3,893	10	1,351	204,441
3 PlantForest	1,163	9,554	0	527	0	0	11,243
4 Unused	974,514	1,054,510	151,148	27,365	4	14,055	2,221,596
Total	996,435	1,239,912	153,729	31,784	14	15,406	2,437,280
	Transition to pastures						
1 Crop	-24,005	-25,430	-383	997	-10	-1,758	-50,588
2 Pasture	18,918	96,562	2,861	4,767	0	3,867	126,974
3 PlantForest	29	11,971	0	3,412	0	0	15,412
4 Unused	7,303,090	1,218,275	185,118	566,147	1	115,726	9,388,356
Total	7,298,032	1,301,378	187,595	575,323	-9	117,835	9,480,155

Source: model database.

Notice that the above table shows the total emissions in the observed transitions in the period, and not emissions per hectare. Even though the per hectare emissions in the Amazon biome is higher than in the Cerrado biome, the total amount of emissions in the conversion of Cerrado to crops in the period was larger because a larger amount of the Cerrado Biome was converted to agriculture than the Amazon Biome, both being located in the Amazon region.

3 The scenarios to be simulated

In this paper we analyze the potential for deforestation reductions in Brazil arising from productivity increases in agriculture (or the sparing effect of land use known as the *Bourlag Hypothesis*) as well as its impacts in terms of GHG emissions, in a simulation from the 2015-2030 period. The simulated shocks take into account two stylized facts in the Brazilian agriculture. First, although productivity gains in pastures could be obtained all over the country in principle, we believe that this gain is potentially higher for pastures located in the agricultural frontiers states, and that their potential for productivity increases is higher than in agriculture. Second, agriculture productivity in the frontier for the main products (soybeans, corn, cotton) is as high or higher than in the non-frontier states. Besides, it´s also generally agreed that future gains in agriculture productivity in Brazil will probably slowdown in the next years, due to the already high productivity levels of the main agricultural activities. Our simulation, then, takes this fact into account projecting a lower productivity increase in agriculture than in livestock, but a gain which happens all over the country, and not only in the frontier states. The productivity shocks to be considered are as follows:

- Livestock shocks: a 1% per year increase in primary factor productivity in livestock production above trend, for five years (2015-2019) in the agricultural frontier states (defined below).
- Agriculture shocks: a 0.5% per year increase in primary factor productivity in agriculture production above trend, for five years (2015-2019), in every region in Brazil.

In both cases the shocks end after the periods mentioned above. We separate the productivity gains in livestock from those arising from agriculture in order to have insights about their relative importance, and will refer to the separate effects when useful for the analysis. In what follows other important characteristics of the simulations are presented.

4 The model closure

The main features of our model's closure are:

- Real wage change drives the movement of labor between regions and activities (but not between labor categories). Total labor supply increases, according to official projections from IBGE.
- Capital accumulates between periods following the dynamic investment rule. Furthermore, the capital stock is updated through the new capital price, e.g., the start-of-period price.
- Regional consumption follows labor income. Moreover, regional real government spending demand follows regional real household demand.
- The national GDP price index is chosen as the fixed *numeraire* price. Other prices should thus be interpreted as relative to the GDP price index.
- The national balance of trade as a percentage of the real GDP is forced to adjust gradually to zero in the long run. National household and government consumption adjust together to meet this external constraint.
- We divided the regions of the model into two groups: Land-constrained (LndUsed, where the agricultural land is consolidated) and Frontier (region where there are available lands to the expansion of agriculture), as shown in Figure 1. This allows model to allocate new land only in areas in the Frontier.

Figure 3. Frontier (green) and land-constrained (yellow) regions of the model.

5 Baseline and model running strategy

To analyze the economic effects of productivity increases, firstly, we developed a baseline scenario for the economy, projecting trends for the main macroeconomic aggregates. Then we carried out a policy simulation, which consists in an alternative forecast simulation with the productivity increase. The effects of the policy change are measured as deviations of variables in the alternative forecast from their baseline levels.

In the baseline scenario the model database was updated to 2012 (the historical period) with observed values for the macroeconomic aggregated variables in GDP from the expenditure side, as well as of international prices. The baseline projections after 2010 to 2030 assumes moderate economic growth until 2020, around 3.0% increase in real GDP per year, together with IBGE's projections for population increase by state.

Table 3. Model results, base scenario. Macro variables (real values): total growth 2005-2030 and terminal annual growth rates.

	Househ.	Invest.	Gov.	Exports	Imports	GDP	Employ	Real wage	Capital stock
Cumulative % growth	143.5	139.9	114.9	91.2	405.1	110.3	27.9	82.0	113.6
Terminal Growth Rate %	2.9	2.9	2.9	2.7	3.6	2.7	0.9	2.0	2.8

Source: Model results.

For the forecast period 2015 to 2030 we assume that the growth pattern of the Brazilian economy will follow its historical path, but at progressively lower rates. We can see, for example, that aggregated GDP in the baseline would growth 110.3% accumulated in 2030, and that the rate of growth of GDP in the final year was 2.7%.

The implications of this projected base scenario for the economy, in terms of deforestation and emissions, can be seen in Figure 4. The area under crops would increase by 34% accumulated in 2030, pastures would increase by 31.9%, and deforestation would increase by 12.0% in relation to 2005. This projected deforestation rate would imply the loss of approximately 76.8 million hectares (Mha) of natural forests, accumulated in 2030.

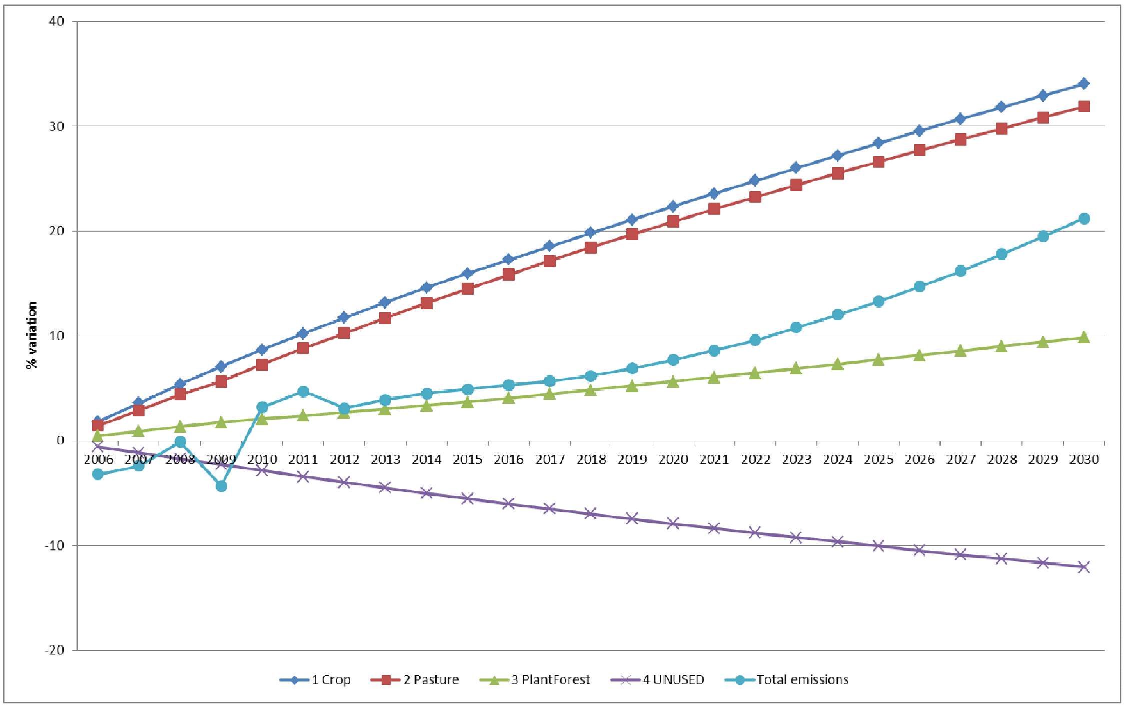

Figure 4. Baseline. Land use and total emissions, percentage change variation, accumulated in 2030.

In the base scenario, the growth of Brazilian agricultural production follows trends of previous decades, especially for some crops as soybean, sugarcane, corn and other grains. Model projections show agricultural growth both in frontier and in land-constrained regions, but the source of growth in those regions is different. While the increase in production in the land constrained region has as its main driver the projected increase in primary factor productivity in the baseline, in the frontier the land area effect is another important source of production growth. As it can be seen in Table 4 the increase in production in the frontier can be done without the fall in area of any important agriculture or livestock activity, while in the land constrained region the competition for land reduces the area of some activities, mainly livestock (pastures) and coffee[4]. The expansion of agriculture and livestock production in the frontier is backed by a 15.2% fall in Unused areas what, in our model, means deforestation or clearing of natural vegetation.

The model's baseline presented in Figure 4 follows the Brazilian predominant pattern of land use of the last decades, which is characterized by the substitution of native vegetation (forests, grasslands) to pastures and/or croplands. The accumulated reduction of 76.8 million of hectares (Mha) in 2030 in Unused land was matched by a 22.8 Mha increase in crops area, 53.5 Mha of pastures, and 0.5 Mha of Planted forests in the same period.

Regionally, the "Unused" category has shown the greatest reduction accumulated in ParaToc (-22.6 Mha), MtGrosso (-20.9 Mha), MarPiaui (-11.8 Mha), Bahia (-10.3 Mha) and, Rondonia (-5.6 Mha). Pasture category area increased the most in the same regions where native vegetation reduced the most, as in ParaToc (19.2 Mha), Mato Grosso (15.6 Mha) MarPiaui (9.1 Mha), Bahia (6.7 Mha), and Rondônia (4.4 Mha), accumulated to 2030, highlighting the substitution of forests for pastures in the model.

[4] Wheat is not an important activity in the frontier, and of very small importance in Brazil as a whole, so we don´t concentrate our attention to this culture.

Table 4. Agricultural output and land area variation, cumulative percent change 2005-2030 (base scenario)

	Output		Land area variation	
Activity	Frontier	Land constrained regions	Frontier	Land constrained regions
Rice	148	94	92	13
Corn	134	89	79	8
Wheat	-15	-16	-23	-42
Sugarcane	203	124	100	17
Soybean	196	148	88	39
Other agric	96	62	61	-1
Cassava	162	99	105	15
Tobacco	129	88	75	0
Cotton	107	85	43	13
Citrus fruits	173	89	108	2
Coffee	203	82	173	-4
Forestry	136	89	53	2
Livestock	174	73	85	-8
Milk Cattle	169	95	83	2
Unused	-	-	-15	-1

Source: Model results.

A more detailed picture of land use evolution by state in the model is displayed in Table 5. The conversion of Unused land to pastures, and of pastures to crops is of particular importance in ParaToc, MtGrosso, Bahia and Rondonia. These regions (shaded), with the exception of Bahia[5], form the so-called "arch of deforestation", due to the high index of conversion of natural vegetation in other uses. Soybean, corn, rice and other grains are the crops with the highest rate of area growth in those regions.

[5] In spite of not being included in the arch of deforestation, the project fall in Unused in the state is also very high, mostly in the Cerrados and Caatinga biomes, to be seen in what follows.

Table 5. Land areas of base scenario, cumulative ordinary change 2005-2030 (million hectares).

	Frontier regions						Land-constrained regions								
Activity	Amazon	Rondonia	ParaToc	MarPiaui	Bahia	MtGrosso	Central	PernAlag	RestNE	MtGrSul	MinasG	RioJEspS	SaoPaulo	Parana	SCatRioS
Rice	0.05	0.19	0.78	0.64	0.02	0.36	0.15	0.00	0.01	0.06	0.01	0.00	0.00	0.00	0.01
Corn	0.06	0.25	0.58	0.57	0.52	0.43	0.38	-0.01	0.10	0.21	0.04	-0.02	-0.12	0.07	0.02
Wheat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02	-0.02	0.00	-0.03	-0.72	-0.43
Sugarcane	0.01	0.00	0.03	0.05	0.13	0.15	0.23	0.09	0.06	0.13	0.08	-0.06	0.33	0.08	0.00
Soybean	0.05	0.18	1.08	0.84	0.89	4.10	3.04	0.00	0.00	1.70	0.10	0.00	-0.01	0.58	0.45
Other agric	0.05	0.14	0.35	0.26	1.17	0.04	0.23	-0.07	0.06	0.03	-0.07	-0.06	-0.08	-0.04	-0.05
Cassava	0.12	0.05	0.50	0.23	0.32	0.06	0.02	0.01	0.06	0.02	0.00	-0.01	0.00	0.01	0.00
Tobacco	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cotton	0.00	0.00	0.00	0.02	0.15	0.16	0.09	0.00	0.00	0.02	-0.01	0.00	-0.03	-0.01	0.00
Citrus fruits	0.01	0.00	0.05	0.00	0.05	0.00	0.02	0.00	0.01	0.00	0.00	0.00	-0.02	0.00	0.00
Coffee	0.01	0.42	0.01	0.00	0.16	0.01	0.03	0.00	0.00	0.00	0.10	-0.19	-0.02	0.00	0.00
Crops	0.36	1.24	3.39	2.62	3.42	5.30	4.18	0.01	0.29	2.15	0.24	-0.35	0.01	-0.03	0.01
Forestry	0.10	0.00	0.06	0.09	0.20	-0.03	0.00	0.00	0.01	0.07	-0.01	0.01	0.01	0.01	-0.03
Livestock	3.64	3.99	17.99	8.44	6.11	14.95	-3.31	0.11	-0.06	-2.14	-0.19	0.20	-0.12	-0.17	-0.17
Milk Cattle	0.29	0.37	1.20	0.68	0.58	0.70	-0.60	0.04	-0.02	-0.05	0.37	0.15	0.10	0.18	0.19
Pastures	3.93	4.36	19.19	9.12	6.7	15.64	-3.91	0.15	-0.07	-2.19	0.18	0.36	-0.03	0.01	0.02
Unused	-4.39	-5.59	-22.64	-11.83	-10.31	-20.91	-0.27	-0.17	-0.23	-0.03	-0.42	-0.01	0	0	0.01

Source: Model results.

It is worth to highlight that the land use data, as stated before, is based on satellite imagery, which permitted us to build the transition matrices – the core of land data of the model. Those matrices, once calibrated, capture the deforestation pattern of the last decade in Brazil, and show a decrease in the clearing of new areas.

The continuous increase in deforestation in the baseline, as seen in Figure 4, has it´s correspondence in an increase of associated emissions, as can be seen in Figure 5. The most affected (by deforestation) biomes, Amazonia and Cerrado, are the ones where higher emissions would occur. These two biomes are the ones located on the arch of deforestation. But notice that emissions associated to the Amazonia biome (the tropical forest) grow faster than those associated to the Cerrados. As the frontier expands, more of the Amazonia biome will start to be explored, leading to a faster increase in emissions associated to forests conversion in Brazil.

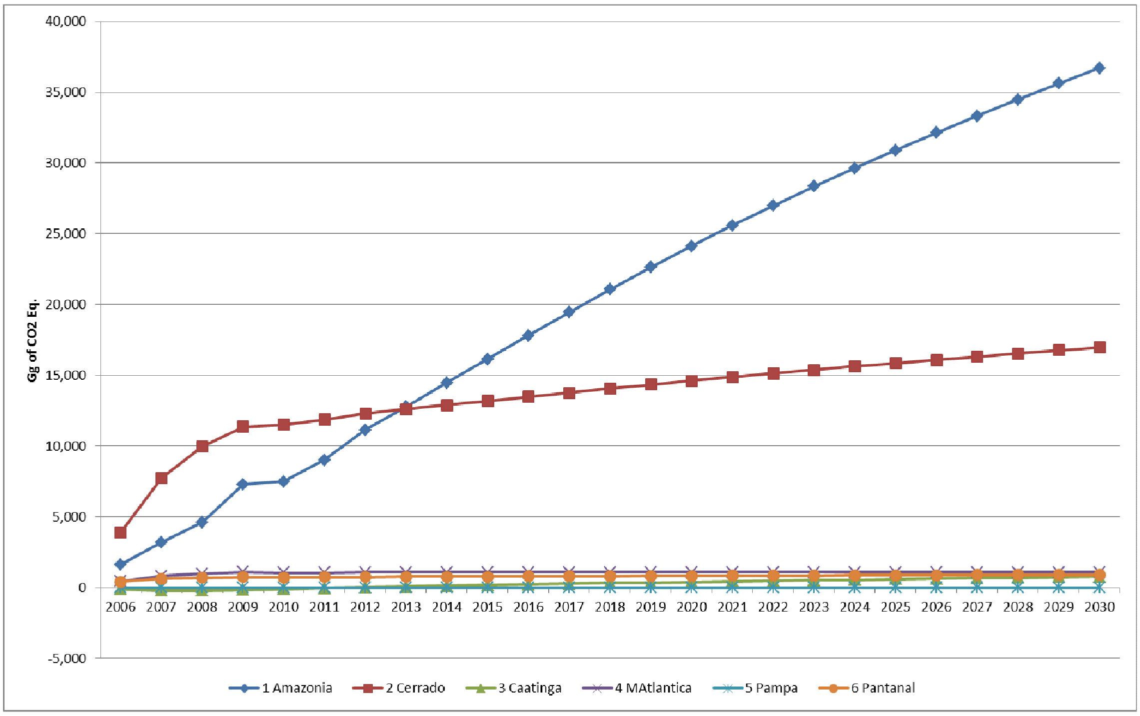

Figure 5. Emissions in land use transitions, by biome. Gg of CO2 equivalents. Baseline, accumulated.

In terms of regional GHG emissions associated to deforestation, Rondonia and Paratoc are the two most important regions in emissions in the Amazonia biome, while Mato Grosso, MarPiaui and Minas Gerais are the most important for Cerrado. And, finally, MarPiaui and Bahia are the most important in emissions from Caatinga conversion.

4. 1 The policy scenario

Table 6 shows the main macroeconomics results of the policy shocks. The productivity shocks have the expected positive impacts on the economy, as can be seen by GDP increase. The total GDP growth due to the productivity shocks would amount to 0.54% accumulated in 2030, 0.12% due to the Livestock shock and 0.42% due to the Agriculture shock.

Table 6. Policy/Base deviations, macro variables: total growth 2005-2030 and terminal annual growth rates.

Cumulative % growth	Househ	Invest.	Gov.	Exports	Imports	GDP	Employ	Real wage	Capital stock
Total shocks	0.48	0.73	0.48	0.86	0.8	0.54	0	0.74	0.65
Livestock	0.09	0.22	0.09	0.16	0.14	0.12	0	0.13	0.19
Agriculture	0.39	0.51	0.39	0.69	0.66	0.42	0	0.60	0.45

Source: Model results.

It can be seen that the productivity shock applied to agriculture has a greater positive economic effect than the one applied to livestock even then it was a smaller shock in percentage terms. This is due to the greater importance of agriculture in the Brazilian economy, when compared to livestock. The value of production of all agricultural activities in the base year accounts for 2.7% of total value of production of all activities in Brazil, while livestock accounted for 0.7%. As it will be seen later in this paper, however, this is in contrast to the environmental effects of both shocks.

The intensification of livestock and agriculture production in Brazil will have very different impacts on the indirect land use (ILUC) effects. This can be evaluated looking first at the aggregated impacts on land use in the Brazilian frontier, as displayed in Table 7.

Table 7. Simulation results. Land use evolution in Brazil. Mha, accumulated in 2030.

	Total shocks	Subtotal Livestock	Subtotal Agriculture
1 Crop	-0.24	0.27	-0.50
2 Pasture	-0.17	-0.76	0.58
3 PlantForest	-0.01	0.02	-0.03
4 UNUSED	0.42	0.48	-0.06

Source: model results.

The figures in Table 7 show that crops area would be 240,000 ha less in relation to the model baseline, accumulated in 2030, due to the simulated productivity increases, a balance between 270,000 ha increase due to the livestock productivity shock and a 500,000 ha reduction due to the agriculture shock. Pastures area, on the other hand, would be reduced by 170,000ha in 2030 due to the shocks, again with different impacts from the shocks in livestock or agriculture.

A point favoring the Borlaug hypothesis appears in Table 7. The productivity shocks would spare 420,000 ha of natural forests (UNUSED), compared to the baseline. Notice, however, that this result is a balance between the positive impacts on deforestation (less deforestation) arising from the livestock shock and a negative effect arising from the agriculture shock. This happens because when the productivity shock appears in livestock, the transition matrix commands a large transfer of pastures to agriculture, allowing agriculture to expand. When the productivity shocks are applied only in agriculture, however, the land release effect for livestock is relatively smaller, since the observed transition from crops back to livestock is smaller than the other way out, a stylized fact in land use transitions in Brazil brought into the model by the transition matrix. Our results, then, would support the “Borlaug hypothesis” for productivity increases in livestock and at the same time the “Jevons paradox” for the productivity increases in agriculture, at least for the range of shocks tested in this paper.

We can see, then, that the productivity shocks really have a potential to reduce deforestation in Brazil. Once occurring in a period it becomes permanent in the model, allowing agriculture and livestock production to be more efficient. The dynamics of the process, however, is limited, as can be seen in Figure 6.

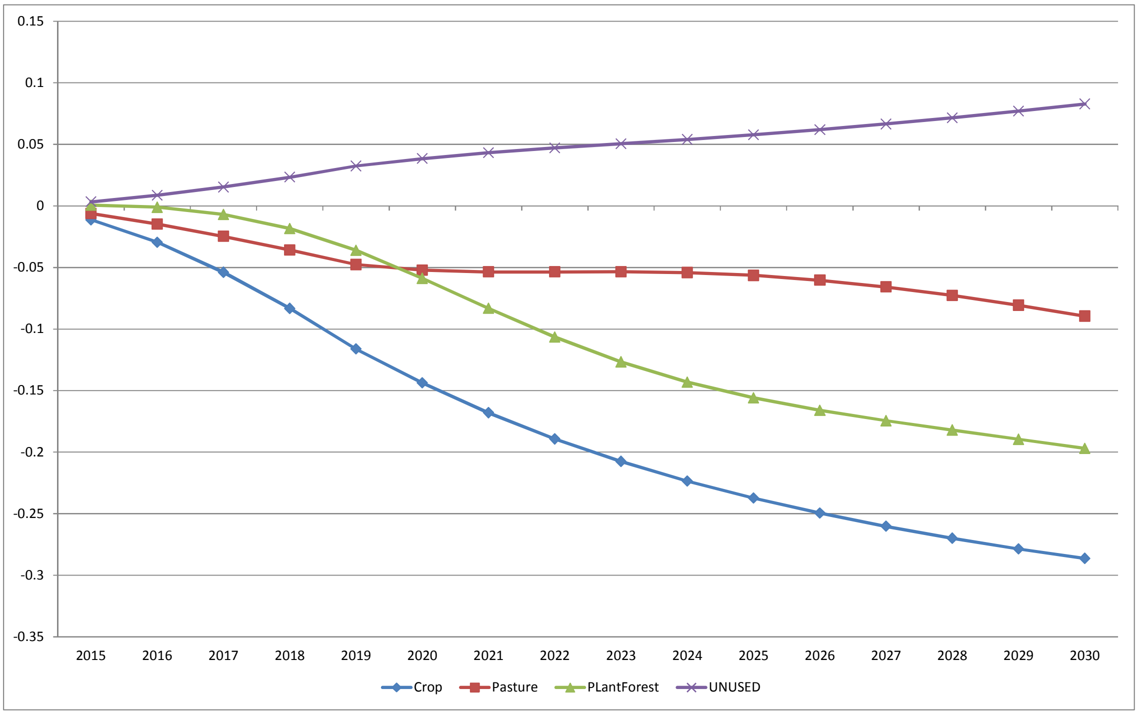

Figure 6. Model results. Land use variation due to the productivity shocks. Policy scenario, % change, accumulated.

It´s apparent, from Figure 6, that the dynamics of the land use sparing effect is stable in time, even after the productivity shocks ceases. Our shocks to the model were applied during five years, from 2015 to 2019. The land sparing effect is more pronounced in this period, but keeps effective thereafter, although at a somewhat smaller rate. The opposite movement can be seen with the areas variation under crops and pastures: after the productivity shocks the (negative) variations start to diminish, leading to a decrease in the rate of deforestation reduction.

The biome which would benefit the most with the increase in productivity would be the Amazonia biome, as can be seen in Table 8. A total of 181,000 ha of land would be spared from deforestation in that biome, against 127,000 ha in the Cerrado biome. In the Amazonia biome the gains would come from reduction both of Crops and Pastures areas, while in Cerrado it would come mainly from Crops.

Table 8. Model results. Land use variation, by biome in Brazil. Mha. Accumulated in 2030

	Biome					
	1 Amazonia	2 Cerrado	3 Caatinga	4 MAtlantica	5 Pampa	6 Pantanal
1 Crop	-0.098	-0.11	-0.038	-0.004	-0.001	0.003
2 Pasture	-0.079	-0.013	-0.059	-0.033	0	-0.009
3 PlantForest	-0.004	-0.003	-0.001	0	-0.001	-0.001
4 UNUSED	0.181	0.127	0.098	0.037	0.001	0.007

Source: model results.

We call the attention for the difference between regions and biomes concepts. The Amazonia biome is distributed in many states in Brazil, and not only in the Amazon state, and the same is true for the other biomes. While the fall of both Crops and Pastures area are important in the Amazonia biome, the fall in Pastures area is more important in Amazon state than in Crops[6], which, on the other hand, are more important in Mato Grosso, both states with natural areas belonging to the Amazonia biome.

Following the land use changes pattern, the model allows tracking emissions in the process. The productivity changes would considerably reduce emissions associated to LUC in Brazil, as can be seen in Table 9. The share of land use was about 0.63 of total emissions in Brazil in 2005, and would fall to 0.39 in the terminal period, 2030. The share of emissions associated to fuel burning (Gasoline, Gasohol and Combustible oil) would increase from 0.085 to 0.147. The reduction in emissions associated to LUC would turn emissions associated to the activity the most important source of emissions in Brazil. Model results show that the reduction in emissions associated to LUC in the period would fall by 32.5%[7].

Table 9. Total emissions and emissions by source in the initial and terminal periods.

	2005		2030	
	Gg CO2 eq	Share	Gg CO2 eq	Share
Mining	113,664.96	0.05	262,710.72	0.10
Gasoline	32,705.03	0.02	86,274.51	0.03
Gasohol	9,448.62	0.00	24,732.65	0.01
Combustible oil	139,590.80	0.07	261,476.95	0.10

[6] Not shown in the table.

[7] To put this number into perspective, at the United Nations climate summit in Copenhagen in 2009 Brazil has committed to reducing its greenhouse-gas emissions by 36–39% by 2020.

Petrochemicals	15,363.88	0.01	29,031.45	0.01
Activity	479,532.75	0.23	977,078.69	0.39
LUC	1,329,081.13	0.63	897,374.00	0.35
TOTAL	2,119,387.17	1	2,538,678.97	1

Source: model database (2005) and model results (2030).

It can be seen, then, that increasing agricultural and livestock productivities can play a central role in deforestation and emissions control in Brazil. The policies at hand which, as seen before, have already been effective in reduction deforestation in the country would have their effectiveness increased by the productivity increases.

6 Final remarks

The simulation performed in this paper suggests mixed evidence in the "Borlaug x Jevons" debate. It gives support to the Borlaug hypothesis in the case of increases in livestock productivity in Brazil, but also to the Jevons Paradox in the case of agriculture productivity increases. According to the Borlaug effect, productivity gains in livestock can save land, avoiding more deforestation. The intensification of policy actions strengthening productivity increases in agricultural activities in Brazil, then, should be regarded as complements for deforestation control policies. This is the case of agricultural research policies. Brazil has a long and successful tradition in agricultural research, which supported the incorporation of vast areas of the Brazilian Cerrado in the past, and more recently of areas from Amazonia and Caatinga biomes. This public research effort has been somewhat reduced in recent times, with the private sector assuming a more important share in agricultural technology generation.

But the pace of technology adoption on livestock has been much smaller than in agriculture, despite the improvements in the last years. Our results suggest that a particular focus should be put on livestock productivity improvements, as complements for deforestation control policies. Agriculture productivity increases, on the other hand, would slightly increase deforestation (the Jevons paradox), a result which deserves more attention for the future work.

Among the biomes analyzed in this paper, the Amazonia biome seems to be the one which would benefit the most of the simulated productivity increases, followed closely by the Cerrado biome. But notice also that there would be a significant impact in the Caatinga biome, an important biome located mostly in northeast Brazil. This biome is much smaller than the Amazonia or the Cerrado, but recent expansion of agriculture in northwest Bahia and south Piaui has been advancing considerably in these areas, with important losses in biodiversity.

And, finally, another point to be noticed here is that the productivity gains seem to be permanent and lasts long even after the shocks. The increase in productivity in pastures, mainly, increases the "intensive frontier", reducing the need for new land for agricultural expansion. Increasing pastures productivity in Brazil should be integral part of the country´s efforts to reduce deforestation.

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APPENDIX

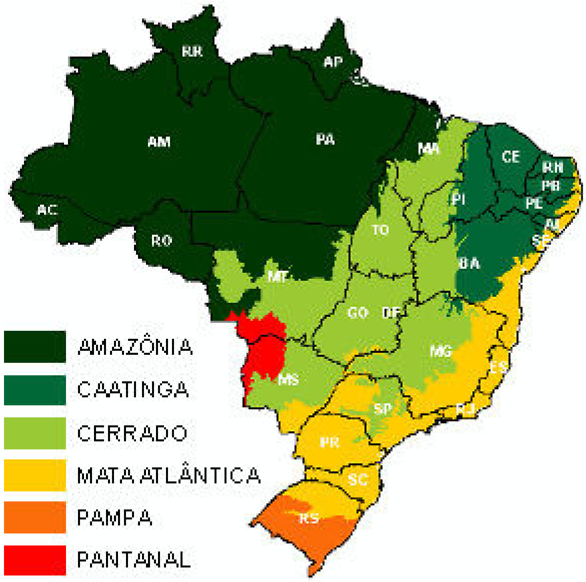

Figure 7. Brazilian biomes and states.