Closing the yield gap in livestock production in Brazil: new results and emissions insights.

1. Introduction and background

Deforestation control has been a pervasive issue in the Brazilian environmental policies. Past efforts in the field of command and control policies helped to reduce deforestation in the Amazon from a high of 2.9 million hectares (Mha) in 1995 to a low of 0.46 Mha in 2012. Recently, deforestation increased again to reach 0.8 Mha in 2018. Likewise, the country´s commitments to the Paris agreement relies heavily on deforestation control issues (Ferreira Filho et al, 2016).

These efforts contrast with Brazil´s position as one of the most important world´s food producers and exporter, since it represents a constraint in the agricultural land supply increase. A strong argument to sustain this apparent paradox is that the county has a vast "intensive frontier", composed of 170 million hectares (Mha) of pastures, a high share of it with low productivity. This land stock would work as a cushion for the land supply restrictions generated by curbing deforestation.

Another important aspect implied by the view that pastures will supply land for agriculture is that livestock productivity increases will release land for agriculture. Actually, this is also an important part of the Brazilian targets to meet the Paris Agreement, the restoration of 15 million hectares of degraded pasture until 2030 (Brasil, 2015). Together with deforestation reduction and the Brazilian Forest Code, degraded pastures reductions recovery is central for emissions reductions. The recovery of degraded pastures is one of the explicit goals of the ABC Program (Low Carbon Agriculture Program, in the Portuguese acronym), an ambitious rural credit program aimed to support the GHG reductions targets in agriculture[1] (Banco Central do Brasil, 2016).

While the importance of deforestation reduction and the Brazilian Forest Code has been already assessed in the Brazilian economic literature by several studies (Ferreira Filho et al, 2015, Ferreira Filho and Horridge, 2016; Ferreira Filho et al, 2017), the role of pasture intensification remains largely unexplored in a comprehensive economic framework. This paper is a contribution to the field: we analyze the implications of a significant reduction in the livestock yield (productivity) gap in Brazil. We focus on pastures for beef livestock, the vast majority of pastures use in Brazil, where extensive grazing is the main production system.

This study contributes to the existing literature on the role of livestock and pastures intensification for deforestation and GHG emissions reduction in four ways. First, we do a detailed assessment of beef pastures productivity in Brazil, departing from data at municipal level, to calculate the livestock yield gap in the country, at regional level. Second, this data is combined with a classification of land according to its aptitude for

[1] The ABC Program is part of the ABC Plan, and has as one of its objectives the restoration of 15 Mha of degraded pastures. For a recent evaluation of the ABC Program, see Gianeti (2018).

livestock production, obtained from satellite imagery, in order to create a weight to stratify land according to the possibility of yield gap closing. Third, we assess the economy wide effects of livestock intensification through a computable general equilibrium (CGE) model, which allows the analysis both of the socio-economic and environmental implications of the policy. Fourth, we introduce in the analysis new findings related to increasing carbon stock in pasture when pasture productivity increases. To the best of our knowledge, this is the first paper to incorporate this important feature in the pasture intensification field in a CGE simulation in Brazil.

We argue that this is a very important new addition to the discussion. Increasing pasture productivity allows increasing livestock production, but this increase is not proportional to emissions: carbon intensity in production must reduce, mostly due to carbon storage in improved pastures, according to new research results in Brazil (Silva et al, 2016). Not considering this gives the wrong message when analyzing pasture intensification policies, as is the case of the ABC Program, an important credit program in Brazil.

Throughout this text, the term "livestock" will refer to beef livestock. Occasional references to milk livestock, or pastures for raw milk production will be made explicitly.

2. Livestock productivity in Brazil

The Brazilian livestock herd increased from 102 million in 1975 to 207 million in 2005, a 102% increase[2], with the North and Center-west regions increasing the most, respectively by 1683% and 189%. With that those regions increased their participation in the national herd, respectively from 2.1% and 24.3% in 1975 to 19.0% and 32.4 % in 2007 (Valentim and Andrade, 2009). The same authors show that the total pasture areas in Brazil increase only by 4% between 1975 and 2006, from 165.5 Mha to 172.3 Mha. The North region was the only one to show significant increases in pasture areas, while the other regions increased very little (Northeast region, 7%) or decreased (all the others, Table 1).

Table 1. Pasture areas dynamics in Brazil. 1975-2005. Millions of hectares.

Region	1975		1985		1996		2006		Var. 1975-2006
	Hectares	%	Hectares	%	Hectares	%	Hectares	%	%
North	5,28	3,2%	20,88	11,7%	24,39	13,7%	32,63	18,9%	518%
Northeast	30,62	18,5%	35,15	19,6%	32,08	18,1%	32,65	18,9%	7%
Southeast	47,28	28,5%	42,49	23,7%	37,78	21,3%	32,07	18,6%	-32%
South	21,16	12,8%	21,43	12,0%	20,70	11,6%	18,15	10,5%	-14%
Center-west	61,31	37,0%	59,24	33,1%	62,76	35,3%	56,84	33,0%	-7%
Brazil	165,65	100,0%	179,19	100,0%	177,70	100,0%	172,33	100,0%	4%
Legal Amazon	20,33	12,3%	42,73	23,8%	51,15	28,8%	61,60	35,7%	203%

Source: IBGE (2009, 2017); Valentim e Andrade (2009).

[2] The more recent 2017 Brazilian Agricultural Census (preliminary results) show that the herd size reduced from 2005, to approximately 172 million in 2017.

Another important indicator of the evolution of livestock is the stocking rate, defined as the number of animals by unit area (the herd/pasture area ratio), which is an indicator of production efficiency. According to Valentim e Andrade (2009) the stocking rate increased by 83% between 1975 and 2006, from 0.51 animal units per hectare ((UA/ha) to 0.94 UA in the period (Table 2).

Table 2. Livestock stocking rate evolution in Brazil.

Region	1975	1985	1996	2006	Variation 1975-2006
	UA/ha				%
North	0,34	0,35	0,55	0,97	187%
Northeast	0,60	0,62	0,68	0,81	35%
Southeast	0,57	0,66	0,73	0,94	64%
South	0,88	0,96	1,01	1,18	34%
Center-west	0,30	0,45	0,59	0,91	201%
Brazil	0,51	0,58	0,68	0,94	83%
Legal Amazon	0,30	0,36	0,54	0,91	203%

Source: IBGE (2009, 2017); Valentim e Andrade (2009).

Table 2 shows that the stocking rate is consistently increasing in Brazil, although remaining at a very low level in average: According to Cohn et al (2014), the introduction of new management techniques could increase current stocking rates by 2.5 times.

The idea that an increase in livestock productivity can save natural forests from clearing is controversial in the literature, and is the basis for the Borlaug x Jevons effects argument (Stern, 2006; Borlaug, 2007; CGIAR, 2012; Hertel, 2012; Martha et al, 2012; Cohn, 2014; Silva et al, 2017). This gives birth to the concept that increasing livestock productivity is key to reducing emissions via deforestation reduction: with more production per area, relatively less area would be necessary for an increasing demand for beef. Even though emissions in production would increase (due to an increase in herd size), this would be compensated by a reduction in deforestation. Actually, this was the approach used by Silva et al (2017), Ferreira Filho et al (2018, 2017, 2016, and 2015).

In all those studies, emissions per area or per unit or production are constant. A recent strand in the literature, however, is showing that pasture intensification can lead to a reduction in emissions intensity, or emissions per unit of production. This is the case of the studies by Oliveira et al (2017) and Silva et al (2016) for Brazil, which show that pasture productivity increases leads to an increase in carbon storage in soil.

Although the fixed emissions coefficients accounting in pasture is appropriate for extensive pasture area increases, it´s clearly insufficient to deal with the intensification hypothesis. Livestock productivity increases can happen due to many different factors, including improvement in herd quality, management practices and pasture productivity. The point is that when pasture productivity increases, carbon storage in soils also increases. In this paper, we will examine the effects of pasture intensification in Brazil, extending the analysis to include the carbon storage effect.

3. The yield gap concept

The yield gap is a concept frequently used at farm level, or defined using experimental plots (Van der Linden, 2015; Sikkema, 2017), in reference to the concept of "potential productivity". It usually refers to land productivity, or production per unit of area. Fischer et al (2014) present an extensive discussion about the many concepts involved in the definition, based on previous studies by Byerlee (1992), Evans (1993), van Ittersum e Rabbinge (1997), Evans e Fischer (1999), e Connor, Loomis e Cassman (2011).

In this paper, we use the concept of "attainable productivity" as the reference for our analysis. According to Fischer et al (2014), this concept reflects the economic aspects involving both the type of agricultural activity at hand and the region, and experience shows that the attainable productivity is normally between 20% and 30% below the potential. The yield gap concept we use here, then, takes as reference the attainable productivity, measured from data at municipal level in Brazil. In the next section, we present in detail the methodology used for the yield gap estimation.

4. Methodology

Our methodological approach involves several steps. We first identify the yield gap in livestock in Brazil, and then use this information to perform a simulation using a detailed CGE model. The next sections describe in more details the procedures.

a. Identifying the yield gap in Brazil: outliers and general results.

We used satellite imagery information generated by LAPIG (Images Processing and Geoprocessing Laboratory, University of Goias, Brasil) for year 2014. Due to the nature of the information, a previous important step for the calculations is to identify measurement errors in the data, notably extreme values, since it can strongly affect the yield gap measurement. We have tested different methods and chosen the Tukey method to identify measurement errors in the data, which had a best result for this dataset. After identification and treatment of the extreme values in the data, we performed the yield gap calculation.

In our calculation, we select the 10% most productive municipalities, to calculate the average productivity of this quantile. The yield gap is expressed in reference to this top productivity average, by region:

$$H_r = \frac{\alpha_{r10} - \beta_r}{\beta_r}, \qquad (1)$$

Where

H_r is the livestock yield gap in region *r*;

β_r is the total regional average productivity in region *r*; and

α_{r10} is the average productivity of the top 10% municipalities in region *r*.

With the above calculation, we have the yield gap in livestock, by region, or the distance between the average regional productivity and the top 10%. It would be, however, unrealistic to simulate the closing of the yield gap calculated by this method in the whole pasture area. The top 10% productivity are generally located in the best agricultural areas, in terms of soil quality, precipitation and other important physical characteristics for production. To deal with this problem, we used information on land aptitude for pasture, by region[3], to create a weighting system for our yield gap measure. The weight consists of the share of land with very high and high aptitude (net of areas with already high productivity) for pastures in the total pasture area, by region. We weight the yield gap by this ratio, by region, creating the weighted yield gap used in the simulations (Table 3).

Table 3. Productivity yield gap in Brazilian livestock.

Region	Average productivity	Top 10% average productivity	Weights	Weighted yield gap
AcreRond (N)	1.96	2.73	0.66	0.51
AmazRor (N)	1.38	4.66	0.41	1.36
ParaAmap (N)	1.47	5.38	0.51	2.00
Tocantins (N)	1.08	1.81	0.33	0.24
Maranhao (NE)	0.95	2.08	0.14	0.16
RestNe (NE)	0.89	3.38	0.19	0.46
Bahia (NE)	0.60	2.03	0.23	0.32
MinasG (SE)	0.81	1.59	0.42	0.33
RestSE (SE)	1.17	3.76	0.35	0.91
SaoPaulo (SE)	1.07	2.73	0.71	1.18
Sul (S)	0.79	4.31	0.40	1.28
MtGrSul (CW)	1.07	1.68	0.48	0.29
MtGrosso (CW)	1.22	1.88	0.50	0.33
GoiasDF (CW)	1.44	2.52	0.41	0.45

Source: author´s own elaboration with data from LAPIG (2017). Regions: N (North), NE (Northeast), SE(Southeast), S (South), CW (Center-west).

The information on yield gap presented above was used to simulate the economy wide consequences for Brazil of its reduction, using a CGE model described below. We will analyze the impacts of closing 50% of the calculated yield gap in Brazil.

b. The TERM-BR model

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;

[3] The information was obtained from IMAFLORA and GEOLAB (ESALQ/USP), using the method proposed by Sparovek et al (2018).

- 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.

c. **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 or Pasture 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 (sources): 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[4], 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).

All the above-mentioned emissions are in fixed coefficients in either fuel use or the level of sector activity. In the case of livestock, however, we have also accounted emissions in an alternative way, where emissions in livestock vary with pasture productivity variation. This is discussed further in the next section.

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 land use transitions, and the computation of sinks on forest restoration.

d. Livestock productivity increases and carbon intensity changes

As mentioned previously, the model accounts emissions in pastures in two alternative ways: using fixed coefficients and varying with productivity. For the second method, we use information from Silva et al (2016), who measured the change in emissions at different pasture productivity levels. Notice that in our model, emissions in livestock and in pastures are accounted together, in the "Activity" source. Emissions in livestock should increase under pasture intensification, due to the increase in herd size, but emissions in pasture transitioning from low productivity to high productivity should reduce, due to higher carbon storage in soil. According to Silva et al (2016), the balance is a net gain in emissions (sink) with intensification[5], when computing emission in those two sources only[6]. We have adapted the changes observed by the authors from two different pasture types and their emissions, to calculate an emissions/land productivity elasticity[7]. The value estimated for this elasticity is -0.0043, meaning that a 1% increase in land productivity (production/hectare) in livestock production would cause a 0.0043% fall in emissions in the "Activity" source.

We used information from Silva et al (2016) to calculate the investment cost required for intensification. We used the cost differential between pasture types D (lower productivity) and B (higher productivity) as the cost of intensification in our

[4] Of particular interest for this paper is emissions in "Activity" source in the livestock sector. In this case, emissions in both the herd and pastures are aggregated together.

[5] The calculations by Silva et al (2016) are for the Cerrado biome only. We generalize those values for all biomes, due to the lack of information at this point. Future ongoing research must improve this information.

[6] Silva et al (2016) compute emissions in all sources, including input use and deforestation. The TERM-BR model properly accounts for the other sources, so we have only used information on emissions variations for the herd and pasture.

[7] We have used the emissions/productivity differential between systems type D (lower productivity) and type B (higher productivity). The intensification costs are also for those two types of pastures.

model[8]. In this case, we were able to calculate a cost/productivity elasticity, which stablishes a relation between those two variables in the model, and which assumes value 5.76. This means that in our model each 1% increase in livestock productivity is obtained through a 5.76% in investment in the activity[9].

5. Simulation strategy

We simulate a 50% reduction in livestock productivity gap in Brazil, in a 15 years' period. The model´s initial database (2005) was updated to 2015 through a historical simulation, 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.

The evolution of deforestation and land use followed the procedure proposed by Ferreira Filho et al (2018). Deforestation figures for the three most important biomes (Amazonia, Cerrado and Mata Atlantica) were updated up to 2015 (the historical period) as well as the evolution of the total area of crops and forestry. The period of the projections, therefore, begins in 2016 and goes until 2030, generating the baseline for the economy of Brazil. The main features of this baseline are:

- Projections of population growth by state (IBGE): 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.
- Deforestation projections per biome and region, based on the last 5 years average for Amazonia and Mata Atlantica, and 3 years average for Cerrado. Total deforestation at the baseline of 12.8 million hectares (Mha) by 2030, of which 7.5 Mha in the Amazonia biome, 5 Mha in the Cerrado biome, and 0.17 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 37.5 Mha in crop area in the period 2016-2030 (Amazonia, Cerrado and Atlantic Forest biomes only).
- 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.

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

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[8] The highest productivity type in Silva et al (2016) is type A. Type B is the second highest productivity, which we have chosen as reference.

[9] At this point we don´t distinguish between increases in production due to pasture increases or in herd quality, a point which deserves better future elaboration.

in the baseline, the pasture area is the variable that adjusts. The projections described above are consistent with a reduction of 30.4 Mha 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.

As mentioned before, our simulation comprises a 50% reduction in livestock productivity gap in Brazil. For this sake, we transform information on the fourth column of Table 3 into annual variations in land productivity, by state, which is defined as the (percentage change in the) ratio of livestock production/pasture area. This increase is obtained with additional investment expenses in the livestock sector (Table 4).

Table 4. Annual productivity increases, and investment costs to close 50% of yield gap in livestock production in Brazil. Percentage changes.

Regions	Productivity	Investment
1 AcreRond	0.82	4.72
2 AmazRor	2.71	15.6
3 ParaAmap	3.52	20.27
4 Tocantins	0.7	4.03
5 Maranhao	0.54	3.11
6 RestNe	1.54	8.87
7 Bahia	1.59	9.16
8 MinasG	1.24	7.14
9 RestSE	2.21	12.73
10 SaoPaulo	2.97	17.1
11 Sul	3.04	17.5
12 MtGrSul	0.85	4.89
13 MtGrosso	0.85	4.89
14 GoiasDF	0.97	5.59

Source: author´s calculations, based on Silva et al (2016).

The investment increase in livestock production to reach the targeted productivity increase is sizeable. We didn´t specify explicitly the mechanism to fund this productivity. Rather, we fixed aggregate investment in the economy in the baseline. This means that some investment redistribution mechanism is operating, such as a public credit line redirected toward livestock[10]. Even though this represents a severe constraint for the economy expansion in the simulation, it suits the main purpose of the paper, which is to shed light in the role of carbon storage in pasture intensification.

Finally, for the purposes of this study, the model database was aggregated to 14 regions and 38 commodities and sectors.

6. Results

[10] Actually, Brazil has currently an important public credit line for livestock production, which includes pasture productivity investments, the Programa ABC (the Low Carbon Agriculture Program).

Closing the yield gap in livestock production in Brazil would have important effects in the economy (Table 5). Even though we have used a conservative hypothesis regarding the pasture area involved, namely closing 50% of the yield gap in areas with very high and high aptitude for livestock production, the productivity shocks still applies to 66 Mha of pastures, or 37% of total pasture area in the base year.

Table 5. Model results. Macroeconomic variables. Percent variation in relation to base, accumulated in 2030.

Variable	% variation
Household consumption	-0.05
Investment	0
Government spending	-0.05
Exports (Volume)	1.85
Imports (Volume)	-0.31
Real GDP	0.43
Real wage	0.81
Capital stock	-0.60

Source: model results.

Notice that the general economic adjustment would imply a reduction in production of some commodities, as is the case of soybean (Table 6). This happens due to land and other primary factors competition in the traditional regions, where there is no land expansion (or deforestation) in the baseline, since natural stocks were depleted long time ago. The yield gap is notably high in the South (Sul) region, an important soybean production region in Brazil. With total investment fixed at baseline level in the closure, the increase in investment in livestock must reduce investment, and capital accumulation, in other activities, generating negative impacts in production.

Table 6. Model results. Agricultural production variation. Percent variation in relation to base, accumulated in 2030.

	Brazil	Frontier region	Traditional region
Rice	5.3	6.7	4.3
Corn	2.3	2.6	1.8
Wheat	-2.7	-0.9	-2.8
Sugar cane	2.4	3.1	2.3
Soybean	-0.8	-0.2	-2.4
Other agric	-1.1	-0.3	-1.7
Cassava	2.7	3.0	2.1
Tobacco	-0.5	2.4	-0.5
Cotton	2.6	2.6	-0.5
Citrus fruits	3.9	4.0	3.9
Coffee	-0.7	-0.4	-1.7
Forestry	-2.1	-1.2	-2.8
Livestock	23.5	18.4	35.5
Raw Milk	6.4	7.0	4.3

Source: model results.

The increase in livestock productivity is not the only effect increasing GDP. This increase is equivalent to an increase in land availability for the economy, or a displacement of the production possibility frontier: the transition matrix approach allocates land spared in livestock production for other agricultural activities, or even for sparing natural stocks. Closing the yield gap would allow a 23.5% increase in livestock (beef cattle) production, while reducing 4.24 Mha in pasture area used in livestock production in relation to the base, accumulated in 2030 (Table 7). This represents a 1.5% per year increase in livestock production above the baseline trend. The reduction in pasture area for livestock would be relocated to agriculture (1.41 Mha, including forestry), milk livestock (1.96 Mha), and spare forests from clearing (0.88 Mha), with both economic and environmental benefits. In the table, "Frontier" refers to the agricultural frontier region, where deforestation occurs, while "Traditional" refers to the older agricultural regions, where natural forests stocks run out.

Regionally, however, the land use effects vary, depending on the regional production composition (Table 7). Soybean, for example, increases land use (and reduces production) in the agricultural frontier region by 0.69%, but reduces in the traditional region (South and Southeast Brazil), where there is no room for land expansion in aggregate, and where competition for land is more intense. This suggests that land relocation in the frontier (where land availability increased) induces an endogenous fall in soybean productivity. Tobacco, on the other hand, does not change land use in all aggregated regions, but production decreases in the main (South) producing region, due to competition for labor and capital.

Table 7. Land use change (Million ha). Frontier and traditional agriculture regions. Accumulated in 2030.

	AGGREGATED REGION		
Activities	FRONTIER	TRADITIONAL	TOTAL
Rice	0.18	0.06	0.24
Corn	0.40	0.10	0.50
Wheat	0.00	-0.02	-0.02
Sugar cane	0.11	0.08	0.19
Soybean	0.55	-0.19	0.36
Other agric	0.03	-0.05	-0.02
Cassava	0.06	0.01	0.07
Tobacco	0.00	0.00	0.00
Cotton	0.06	0.00	0.06
Citrus fruits	0.01	0.03	0.04
Coffee	0.00	-0.01	-0.01
Forestry	0.00	0.00	0.00
Livestock	-3.85	-0.39	-4.24
Milk	1.57	0.39	1.96
UNUSED (Natural forests).	0.88	0.00	0.88

Source: model results.

The change in land use composition triggered by closing 50% of the yield gap in livestock production has different regional economic impacts (Table 8). The higher GDP impact would happen in the ParaAmap region, which comprises the states of Para and Amapa, in North Brazil. Those states, apart from showing a high yield gap (see Table 3) have a high share of livestock in the regional total value of production.

The regional composition of economic activities, of course, is determinant for the regional benefits of closing the yield gap in livestock. The largest gap appears in the Sul (South) region, which has a diversified economy, and gets a smaller GDP increase than MtGrSul (in the Center West region), for example, which has a much smaller yield gap, but where livestock has a higher share in regional GDP.

Table 8. Regional results, macroeconomic variables. Percentage change, accumulated in 2030.

	Real GDP	Household	Real wage	Yield gap
AcreRond (N)	2.58	-1.33	-0.01	0.51
AmazRor (N)	0.09	0.14	1.20	1.36
ParaAmap (N)	6.95	2.68	3.27	2.00
Tocantins (N)	2.59	-1.04	0.41	0.24
Maranhao (NE)	0.44	-0.94	0.50	0.16
RestNe (NE)	0.67	0.46	1.24	0.46
Bahia (NE)	0.49	-0.40	0.57	0.32
MinasG (SE)	-0.05	-0.63	0.33	0.33
RestSE (SE)	-0.58	-1.00	-0.02	0.91
SaoPaulo (SE)	-0.13	-0.12	0.72	1.18
Sul (S)	0.83	0.74	1.40	1.28
MtGrSul (CW)	4.16	0.35	1.07	0.29
MtGrosso (CW)	3.49	0.45	1.18	0.33
GoiasDF (CW)	0.98	-0.02	0.80	0.45

Source: model results. N: North; NE: Northeast; SE: Southeast; S: South; CW: Center West (Midwest).

We mentioned before that emissions on LUC is an important target in the Brazilian iNDC, and livestock is an important component inside LUC emissions. Traditionally, livestock is associated with GHG emissions in two main ways: through a process of clearing forests for pasture expansion, and through increases in emissions by the herd. The last source of emissions is mainly CH4, with a high Global Warming Potential (GWP).

To those two effects, we add in this paper a third one: carbon storage in pasture, as pasture productivity increases. In increasing livestock productivity, then, we consider three effects for emissions: a land sparing effect, a herd increasing effect, and a pasture intensification effect. For the sake of comparison, we perform the accounting of emissions in the "Activity" source in livestock production in two different ways: the traditional one, in which emissions are in fixed coefficient with the level of production, and an alternative one, in each emissions in the "Activity" source varies with productivity increase.

Those three effects were discussed before, and here we present the net emissions effects associated (Table 9). This table displays the percent variation in emissions by source, computed by the two alternative methods. As it can be seen, the difference between the two methods is in the "Activity" source, which is much smaller in the second (Alternative) method.

Table 9. Model results. Variation in emissions, by emitting source. Accumulated in 2030.

	Traditional (%)	GgCO2eq	Alternative (%)	GgCO2eq
Mining	-1.21	-3,087.0	-1.21	-3,087.0
Gasoline	-1.49	-1,283.5	-1.49	-1,283.5
Gasoline C (gasoline + ethanol)*	-0.55	-118.1	-0.55	-118.1
Combustible oil	0.03	13.4	0.03	13.4
Diesel oil	-0.32	-621.6	-0.32	-621.6
Other Petro	-0.73	-202.5	-0.73	-202.5
Activity	13.67	99,008.7	1.58	9,571.6
LUC	-9.71	-8,176.5	-9.71	-8,176.5
Brazil	5.91	85,533.1	-0.29	-3,904.1

Source: model results. * Gasoline C is the regular gasoline used in Brazil, a mix of pure gasoline and ethanol (27%).

Data in Table 9 shows that the 9.7 % fall in emissions associated to the land sparing effect (8,176.5 Gg CO2 eq) is not enough to compensate for the increase in emissions from other sources, notably emissions linked to Activity, when emissions are accounted by the traditional method. When we compute the emissions savings in pasture (alternative method), however, we see that our yield gap closing scenario would generate a net fall in emissions in Brazil. Note that emissions in the "Activity" source would grow by 13.67% in the traditional accounting method and only by 1.58% in the alternative one. Emissions in the other sources remain the same in both methods.

The Brazilian intended Nationally Determined Contribution – iNDC has as a goal the reduction of 37% in GHG emissions until 2025, and of 43% until 2030, based on the 2005 emissions of 2.1 GtCO2. The increase in net emissions associated with closing the livestock yield gap in the traditional accounting method, then, is in clear contrast with Brazilian some policy instruments to control emissions. This is the case of the ABC Program mentioned before, and where the restoration of 15 Mha of degraded pasture is one of the most important goals. Increasing livestock productivity will increase profitability and, by consequence, the increase in production, offsetting the gains in emissions originating in spared forests, if emissions savings in pasture are not accounted.

This effect can be further analyzed through the carbon intensity (emissions intensity) in production, defined as the carbon content of each unit of production. Emissions intensity include all emissions in fuel use and in the "Activity" source, but does not include emissions in LUC. Table 10 displays the results for both accounting methods.

Table 10. Model results. Emissions intensity, deviation from the baseline, two emissions accounting methods. Percent variation, accumulated in 2030.

	Emissions accounting method	
Activities	Traditional	Alternative

Rice	0.21	0.21
Corn	0.08	0.08
Wheat	0.01	0.01
Sugar cane	0.03	0.03
Soybean	0.04	0.04
Other agric	-0.02	-0.02
Cassava	0.14	0.14
Tobacco	0.01	0.01
Cotton	-0.01	-0.01
Citrus fruits	-0.01	-0.01
Coffee	-0.02	-0.02
Forestry	-0.05	-0.05
Livestock	0.90	-18.29
Milk	0.57	0.57

Source: model results.

We see from the table that the emissions intensity in livestock production would increase by 0.90% in the traditional accounting method, but decrease by 18.29% when carbon storage in pasture is accounted[11]. The alternative method, then, seem the appropriate one to deal with pasture productivity increases. It shows that it is possible to increase livestock production in tropical conditions without seriously compromising the emissions reductions targets. Intensification in livestock production is desirable because not only it spares forests, but also because it increases carbon storage in soils, further contributing to offset emissions originated in the herd.

The recognition of this fact if very important for agricultural policies in Brazil. The country is one of the world´s major beef exporters, and one of the few countries in the world that still has potential for significant increases in beef production. The current environmental constraints, however, will slow down the agricultural frontier expansion, reducing land supply for agriculture and livestock production. The expansion via intensification is not just possible, but desirable, in both economic and environmental terms.

The cost of this intensification, however, remains a challenge. According to our calculations, investment in livestock production necessary to guaranty the productivity improvement simulate in this paper would be sizeable, reaching 6 times the investment value in the baseline, accumulated in 2030. This amounts to an extra R$0.9 billion per year in average for 15 years, or about R$13.7 billion in 15 years. With that, investment in livestock would change from 0.5% of total investment in Brazil in the baseline in 2030 to 2.7% of total investment in 2030. To put those numbers in perspective, total rural credit in Brazil in 2018 amounted to R$151 billion, out of which R$40 billion was for investment expenses. The ABC Program, the credit line most closely linked to pasture intensification currently in Brazil, received R$2 billion in 2018.

7. Final remarks

[11] For the sake of illustration, Silva et al (2016) found an approximate 31% reduction in emissions intensity in pasture intensification, for the Cerrados biome.

In this paper, we shed light on the importance of pasture intensification for emissions reductions in Brazil. Increasing livestock productivity is seen in the literature as important for both saving forests and reducing GHG emissions in Brazil. Our results support this view, but only when carbon storage in pasture is included in the calculations. Livestock productivity increases can be important for sparing forests from clearing, but the increase in herd emissions would offset that effect if the carbon storage improvement when pasture productivity increase is not accounted.

Closing the yield gap under the hypothesis used in this paper would release 4.69 Mha of pastures for other uses, which would be directed partially to crops (1.7 Mha), and avoided deforestation (1.13 Mha), while increasing GDP. The same increase in productivity, however, would have adverse effects on emissions, in spite of the land sparing effect, in the traditional emissions accounting method. Rather, the net benefits of pasture intensification in terms of emissions come from carbon storage in the soil, as pasture productivity increases. We argue that this is a very important effect to take into account for policy design. In a country with a high natural resources base, as is the case of Brazil, and already with a large livestock herd, the profitability increases brought by increasing productivity can generate strong increases in herd size. Emissions in livestock are mostly due to CH_4, a GHG with a high GWP. Failing to account for carbon storage in pastures gives the wrong message for policy analysis: policies to improve pasture productivity would increase, and not reduce, emissions. Our present results, however, support the opposite view.

The cost of pasture intensification is an important issue. As we have shown, it would be necessary a massive investment in livestock productivity, which should include both the herd and pasture, to achieve the simulated productivity gains. Given the present fiscal constraint in Brazil, it´s not likely that this funding will come from public sources in the coming years. The ABC Program, for example, the most important credit program targeting emissions in agriculture and livestock production, was allocated the amount of R$2 billion in the 2018/1019 season. The importance of pasture intensification for emissions reductions, as shown in this paper, suggests that this would be an efficient instrument for climate policy, for both Brazil and the world. Mechanisms like the Fundo Amazonia, which mobilizes resources for actions in the Amazon region, could be considered.

Finally, we call the attention for the limitations of our analysis. We use parameters adapted from the literature (Silva et al, 2016), a study conducted for the cerrados biome, and we have extended it to the other biomes in Brazil. New ongoing studies in the field will better inform the parameters for future simulations. The same applies to the cost of pasture intensification, adapted from the same study. Emissions in livestock activity, either in pastures or in livestock digestion is an active research field in animal sciences, and the incorporation of these developments to economic models should be in the forefront of land use and emissions modeling efforts.

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