ETHANOL EXPANSION AND THE INDIRECT LAND USE CHANGE IN BRAZIL

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1 Introduction

The expansion of biofuels production worldwide has raised concerns about its impact on food security and food supply, due to competition for agricultural land. The recent hikes in food prices have increased the attention to the issue, which was pointed by many researchers as one of the main elements linked to the food price increases.

In Brazil the issue is also highly controversial. Brazil punctuates as one of the world's leaders in ethanol production, with an ethanol production program which started early in the seventies, and led to the development by the automobile companies in the country of the flex-fuel engines. Presently, about 92% (or 2,652,298 cars) of the Brazilian car fleet runs on these hybrid engines, which can run with gasohol (25% blend of gasoline and ethanol presently), hydrated ethanol or any blend of those two fuels. The demand for hydrated ethanol in 2017 is projected by EPE (2008) to be about 73% of total demand of liquid fuels (Otto cycle) in the country.

The production and use of ethanol in Brazil has increased at very high rates since the nineties, although at a somewhat varying pace. However, as pointed out by Bacha (2009), despite the enormous increase in ethanol production in Brazil no food scarcity appeared. On the contrary, the per capita production of fruits, agricultural raw materials, food and beverages has increased in the period (Bacha, 2009). This phenomenon was accompanied by strong productivity increases in agriculture, as well as in the increase in land supply.

As is well known, Brazil is a country with still a vast stock of land, possible to be converted to agricultural uses. Land clearing for agricultural uses is a complex and multi dimensional phenomenon, and a matter of great concern presently in the country. Although the direct amount of land cleared annually is easier to identify nowadays, due to the increase in satellite monitoring technology, the causes behind that are much

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harder to assess, as pointed out by Babcock (2009), who also argues that …"the debate about whether biofuels area a good thing now focuses squarely on whether their use causes too much conversion on natural lands into crop and livestock production around the world". Actually, this debate is has a central economic importance presently, since regulations regarding biofuels will depend crucially on the indirect land use changes (ILUC) caused by the expansion in energy agricultural based products.

Among the studies which try to measure ILUC associated to ethanol expansion in Brazil are those of Nassar et al (2010) and Ferez (2009), with different methodological approaches. In this paper we analyze the indirect land use changes caused by scenarios of ethanol expansion in Brazil, through the use of a detailed General Equilibrium model of Brazil. To accomplish this task we propose a new method of assessing the ILUC.

2 Sugar cane and ethanol expansion and land use in Brazil

Ethanol production in Brazil doubled in the period between years 1990 and 2008. As can be seen in Figure 1 , the ethanol production has been increasing continuously since year 2000, reaching a pike of around 22 billion liters in 2008. In the same figure it's possible to see that the Center-South region is the main producing region, with about 90% of total. In regional terms the state of Sao Paulo in Southeast Brazil is by far the larger producer, with about 60% of total ethanol production in Brazil in 2008. The figure shows that the increase in ethanol production in Brazil happened basically in the Center-South region. Actually, Figure 2 shows that the bulk of expansion of sugar cane planted area happened in Sao Paulo state, where planted area evolved from 1.8 million hectares in 1990 do 4.9 million hectare in 2008.

The abovementioned figures are central to the ILUC discussion addressed previously. Sao Paulo (and most of the other states in South-Southeast Brazil) are regions where the stock of convertible land has basically run out, meaning that the total supply of land is fixed. In this case, the sugar cane expansion has to be done at the expense of other uses, reducing the land area for other agricultural uses, at least inside those state's borders.

However, around 12 million hectares have been incorporated to total crop area in Brazil between 1995 and 2006 according to the Brazilian Agricultural Censuses of 1996 and 2006 (14 million hectares between 1995 and 2009). An extra 1.8 million hectares of planted pastures have been incorporated in the same period.

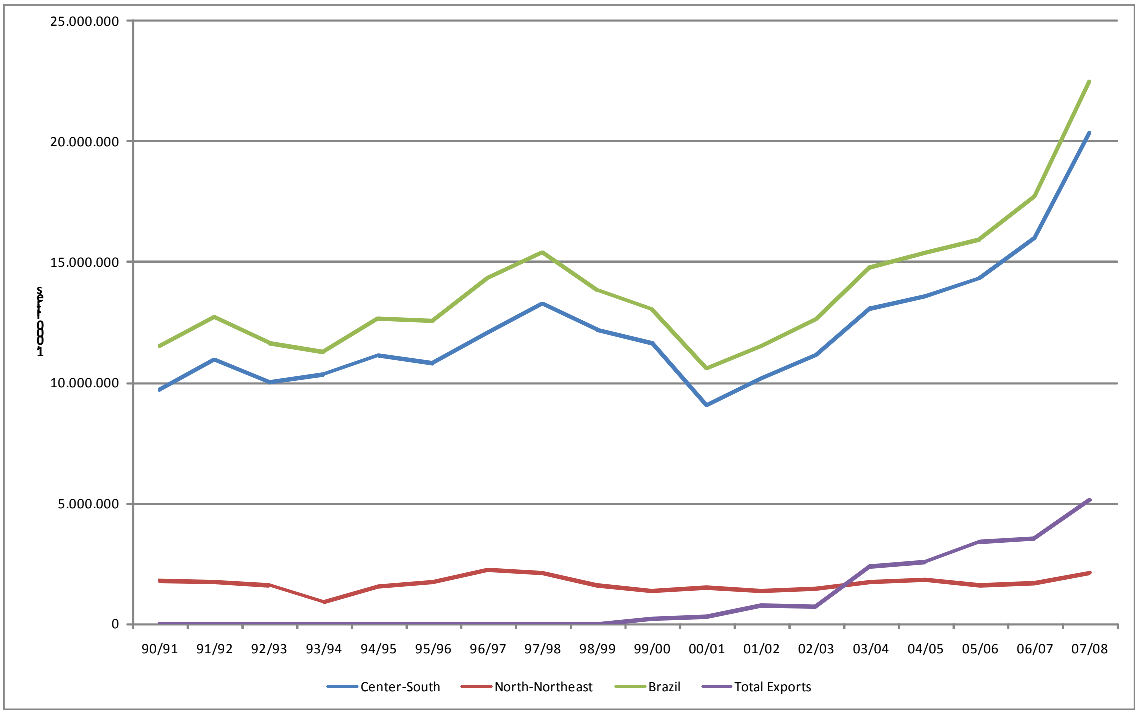

Figure 1. Evolution of ethanol production and exports in Brazil. (1,000 litres).
Source: Secretaria de Comércio Exterior do Brasil (SECEX).

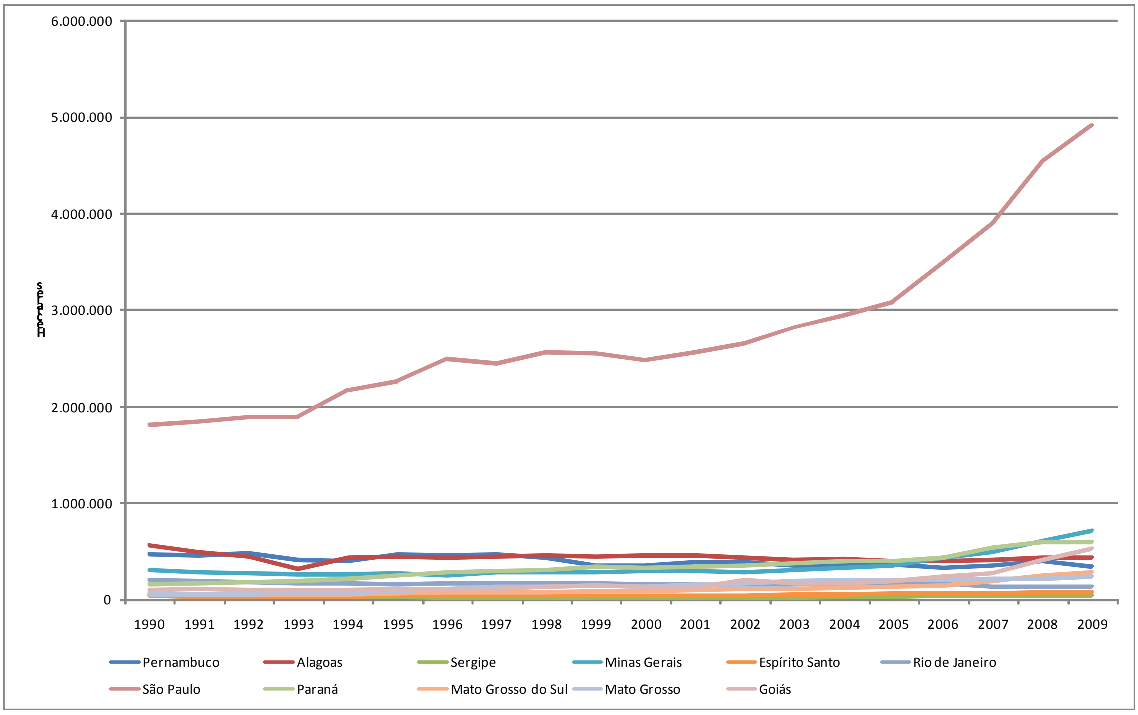

Figure 2. Evolution of sugar cane planted area in Brazil, by state. Hectares.

This incorporation of agricultural and pastures new areas in Brazil has, of course, regional peculiarities inside the country. The expansion agricultural areas in Brazil are located in some states in Center-west Brazil, in North Brazil, and in some states in

Northeast Brazil, notably those closer to the Center-west Cerrados areas. Figure 3 shows the evolution of broad definitions areas between the last two Brazilian Agricultural Censuses (1995 and 2006). In the figure the location of states in the Brazilian Macro Regions definition is:

- North: Rondônia, Acre, Amazonas, Roraima, Para, Amapá, Tocantins.
- Northeast: Maranhão, Piauí, Ceara, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe and Bahia.
- Southeast: Minas Gerais, Espirito Santo, Rio de Janeiro and São Paulo.
- South: Paraná, Santa Catarina and Rio Grande do Sul.
- Center-west: Mato Grosso do Sul, Mato Grosso and Goiás.

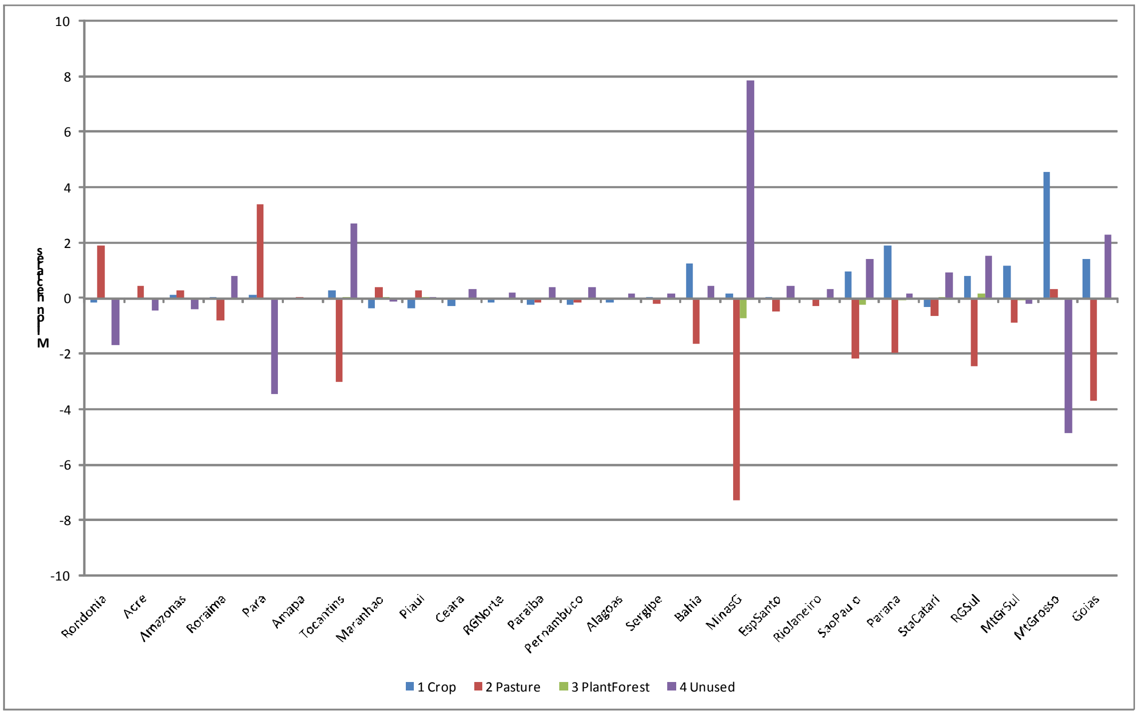

Figure 3. Land use change in Brazil, by state. Variation between 1995 and 2005.
Source: Brazilian Agricultural Censuses 1995 and 2006.

The definition used in Figure 3 for Unused land is the total area of each state minus the used area with crops, pastures and planted forests, as shown in each respective Agricultural Census. It includes, then, all areas not used in agriculture, like natural forests, but also urban areas, lakes and cities. These areas, however, are expected to change much less than the land cleared areas, and it’s used here as a proxy for deforestation, or land clearing for agricultural uses.

As it can be seen from Figure 3, the fall in unused land occurred mostly in the states of Rondonia and Para, in the North (Amazon) region, and in the state of Mato

Grosso, also in the Legal Amazon. However, while in Rondonia and Para there was a strong increase in pastures, in Mato Grosso the increase was in crops areas (which was used mostly for soybean). It's possible to see also that in Sao Paulo, the most important sugar cane expansion region, the unused land area actually increased in the period, as well as the land for crops, while pastures areas have decreased.

This suggests, of course, that land substitution for sugar cane expansion in São Paulo occurred at the expense of land use for pastures, and not deforestation, since, as noticed before, land stocks are run out in this state. But this seems to be the case of most other states in Brazil, apart from those three states mentioned above. In Parana state, for example, the 1.9 million hectares increase in area under crops in the period was matched by a 1.97 million hectares fall in pastures area. In Rondonia state, on the other hand, the 1.8 million hectares increase in pastures area was matched by a 1.7 million hectares fall in unused land.

This illustrates the complexity of analyzing the ILUC process, as stated by Babcock (2009). How much of the increase in pastures in Rondonia can be imputed to any particular crop area expansion in Southeast Brazil?

A trial area transition matrix can be seen in Table 1. This matrix shows in the last column the total area for each use in 1996 and in the last row the correspondent value in 2006. The off diagonal values in the body of the table are the transition (calibrated) between those two periods, and show the amount of each land category which is transformed in the other. Although the table only brings the values for the states of Sao Paulo and Mato Grosso and Brazil, values for all the other states are available.

Table 1. Land use change matrix between 1996 and 2005 in Brazil. Millions hectares.

SaoPaulo	Crop	Pasture	PlantForest	Unused	Total
Crop	5,44	0,03	0,00	0,37	5,84
Pasture	1,36	6,77	0,02	0,91	9,06
PlantForest	0,02	0,10	0,34	0,13	0,60
Unused	0,00	0,01	0,00	9,31	9,33
Total	6,82	6,90	0,37	10,73	24,82
MatoGrosso	**Crop**	**Pasture**	**PlantForest**	**Unused**	**Total**
Crop	3,48	0,02	0,00	0,00	3,50
Pasture	3,71	17,71	0,00	0,03	21,45
PlantForest	0,01	0,05	0,01	0,00	0,07
Unused	0,84	4,01	0,06	60,41	65,32
Total	8,04	21,78	0,07	60,44	90,34
Brazil	**Crop**	**Pasture**	**PlantForest**	**Unused**	**Total**
Crop	44,78	1,07	0,03	4,89	50,78
Pasture	15,48	146,02	0,61	15,59	177,70
PlantForest	0,11	0,85	3,50	0,93	5,40
Unused	1,03	10,93	0,36	605,29	617,61
Total	61,41	158,88	4,50	626,70	851,49

Source: original data from IBGE.

As it can be seen from the table, the total crop area in Brazil in 1996 was around 50.8 million hectares, which has changed to 61.4 million hectares in 2006. These figures were drawn from the respective Brazilian Agricultural Censuses. In the period about 15.48 million hectares of pastures were converted to crops in Brazil, while just 1.03 million hectares were directly converted from unused land to agriculture. It can also be seen that for the period the total area under pastures has decreased from 177.7 million hectares do about 158.9 million hectares[3].

The transition, however, is markedly different across states. While in São Paulo virtually no unused land was converted for any other use in the period, in Mato Grosso (where part of the agricultural frontier is located) about 840 thousand hectares were directly converted from unused to crop, and 4 million hectares to pastures. This information, by state, will be used later to generate a transition matrix which will show the year rate of change (or conversion) of each use to the other, and is the base for our transition matrix approach to land use change in the model.

3 Methodology

[3] This includes planted and natural pastures.

In this paper we use a computable general equilibrium model of Brazil to analyze the ILUC effects of the projected sugar cane expansion in the country. It is a dynamic General Equilibrium Model of Brazil which has its theoretical foundations in previous work of Ferreira Filho and Horridge (2010). It is an inter-regional, bottom-up, annual recursive dynamic model with detailed regional representation, which in the present version distinguishes up to 15 aggregated Brazilian regions, 38 sectors, 10 household types and 10 labor grades, and has a land use change (LUC) model which tracks land use by each state, to be described in details below. The core database is based on the 2005 Brazilian Input-Output model, as presented in Ferreira Filho (2010). The model has as one of it distinctive features a ethanol/gasohol substitution module, as used by Ferreira Filho and Horridge (2009).

The recursive dynamics included in the model consists basically of three mechanisms: (i) a stock-flow relation between investment and capital stock, which assumes a 1-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. With these three mechanisms it's possible to construct a plausible base forecast for the future, and a second, policy, forecast – different only because some policy instruments are shocked to different values from the base (eg, the ethanol expansion scenarios). This difference can be interpreted as the effect of the policy change. The model is run with the aid of RunDynam, a program to solve recursive-dynamic CGE models.

3.1 Modeling Regional Land Use

Increased production of biofuels may arise from technical progress, or by using more inputs, such as capital, labor or land. The last of these, land, is in restricted supply. Some fear that to produce more biofuels, Brazil may need to divert land from other crops, raising food prices, or convert unused land to agriculture -- at the expense of the environment. Others claim that sugarcane acreage could be doubled, without much affecting land available for other crops. To assess these claims, our CGE model needs to model land use explicitly, what is described in this section.

To begin we emphasize that agriculture and land use are modeled separately in each of 15 Brazilian regions with different agricultural mix; and, clearly, land cannot move between regions. This regional detail captures a good deal of the differences in soil, climate and history that cause particular land to be used for particular purposes.

Table 2 is drawn from the model database and shows land used by agricultural industry in São Paulo (specializing in sugar and citrus), Mato Grosso (soy and beefcattle), and the whole of Brazil, in year 2005. Nationwide, around 60% of agricultural land is used for beef cattle grazing.

Brazilian land area statistics by the Instituto Brasileiro de Geografia e Estatísticas - IBGE distinguish 3 types of agricultural land use, Crop, Pasture, and Plantation Forestry. We assumed that each industry mapped to one of these types, shown in the last column of Table 2.

Table 2. Land used by agriculture in Brazil, 2005. Million hectares.

	SaoPaulo	MtGrosso	Brazil	LandType
Rice	0	0.9	3.9	Crop
Corn	1.1	1	11.6	Crop
Wheat	0.1	0	2.9	Crop
SugarCane	3.1	0.2	5.8	Crop
Soy	0.8	6.1	23	Crop
FruitVeg	0.6	0.2	8.6	Crop
Cassava	0	0.1	2	Crop
Tobacco	0	0	0.5	Crop
Cotton	0.1	0.5	1.3	Crop
Citrus	0.6	0	1	Crop
Coffee	0.2	0	2.3	Crop
Forestry	0.4	0.1	4.7	PlantForest
BeefCattle	5.6	20.8	136.4	Pasture
Dairy	1.5	0.9	24.1	Pasture
Total Agriculture	14.1	30.9	228.1	
Unused	10.7	59.4	623.4	
Total	24.8	90.3	851.5	

Source: Brazilian Agricultural Censuses of 1995 and 2006.

Within each region, the area of "Crop" land in each year is pre-determined. However, the model allows a given area of "Crop" land to be re-allocated among industries according to a CET rule:

$$A_{jr} = \lambda_r . K_{jr} . R_{jr} . 0.5$$

where Ajr is the area of crop land in region r used for industry j, and Rjr is the unit land rent earned by industry j. Kjr is a constant of calibration while the slack variable λr adjusts so that

$$\sum_j A_{jr} = A_r = \text{ predetermined area of Crop land.}$$

The same mechanism is used to distribute Pasture land between Beef and Dairy uses. Forestry land has only one use.

The final row of Table 2 shows total area of each region -- which considerably exceeds the amount used for agriculture. The difference, called "Unused", accounts for 73% of Brazil's total area. It should include land used for cities and other housing, roads and road verges, rivers and their banks, land too steep, dry or swampy to use, environmental reserves, and many other uses. It also includes land which could be used for crops or grazing, but is not yet so used. The North and West of Brazil contain large areas both of cultivable savanna and of forests that could be felled for grazing.

Between one year and the next the model allows land to move between the Crop, Pasture, and Forestry categories, or for unused land to convert to one of these three. Departing from information displayed in Table 1 (which shows land use changes between 1996 and 2005), a transition matrix approach is used, as illustrated in Table 3 below. As before, we show extracts for São Paulo (around the size of UK), Mato Grosso (France+Germany), and the whole of Brazil (non-Alaskan USA). The transition matrices show land use changes in the first year of our simulation. Row labels refer to land use at the start of a year, column labels to year end. Thus the final, row-total, column in each sub-table shows initial land use, while the final, column-total, row shows year-end land use. Within the table body, off-diagonal elements show areas of land with changing use.

Row and column totals are drawn from IBGE Brazilian Agricultural Censuses figures, in some cases using extrapolation or interpolation. They reflect current land use and the average rate of change of land use during the last 11 years (1996 to 2005), drawn from the Brazilian Agricultural Censuses of 1996 and 2006[4].

Numbers within the table bodies are not observed but reflect an imposed prior: that most new Crop land was formerly Pasture, and that new Pasture normally is drawn from Unused land. The prior estimates are scaled to sum to data-based row and column totals.

[4] The Brazilian Agricultural Census of 1996 has as references the periods between August, 1, 1995 and July, 31, 1996. The 2006 Agricultural Census has as reference the year of 2006 (IBGE, available at http://www.ibge.gov.br/home/estatistica/economia/agropecuaria/censoagro/brasil_2006/default.shtm).

Table 3. Transition matrices for land use change (million hectares).

SaoPaulo	Crop	Pasture	PlantForest	Unused	Total
Crop	6.4	0.1	0	0.1	6.6
Pasture	0.4	6.6	0	0.1	7.1
PlantForest	0	0.1	0.3	0	0.4
Unused	0	0.1	0	10.6	10.7
Total	6.7	6.9	0.4	10.8	24.8
MatoGrosso	**Crop**	**Pasture**	**PlantForest**	**Unused**	**Total**
Crop	8.7	0.2	0	0.1	9
Pasture	1	20.6	0	0.1	21.8
PlantForest	0	0.1	0	0	0.1
Unused	0	0.9	0.1	58.4	59.4
Total	9.7	21.8	0.1	58.7	90.3
Brazil	**Crop**	**Pasture**	**PlantForest**	**Unused**	**Total**
Crop	59.2	1.6	0	2	62.9
Pasture	5	153	0.4	2.1	160.5
PlantForest	0	0.9	3.6	0.1	4.7
Unused	0.1	3.7	0.6	619	623.4
Total	64.3	159.2	4.6	623.3	851.5

Source: primary data from IBGE.

The transition matrices could be expressed in share form (ie, with row totals equaling one), showing Markov probabilities that a particular hectare used today for say, Pasture, would next year be used for crops. In the model, these probabilities or proportions are modeled as a function of land rents, via:

$$S_{pqr} = \mu_{pr}.L_{pqr}.P_{qr}^{\alpha}.M_{qr}$$

where (the r subscript always denoting region):

S_{pqr} = share of land type p that becomes type q in region r

μ_{pr} = a slack variable, adjusting to ensure that $\sum_q S_{pqr} = 1$

L_{pqr} = a constant of calibration = initial value of Spqr

P_{qr}^{α} = average unit rent earned by land type q

α = a sensitivity parameter, with value set to 0.35.

M_{qr} = a shift variable, initial value 1

The sensitivity parameter **α** was calibrated and set to 0.35 to give a “normal”, i.e, close to observed past pattern evolution for crops area in the baseline.

Thus, if Crop rents rise relative to Pasture rents, the rate of conversion of Pasture land to Crops will increase. To model the rate of conversion of Unused land we needed to assign to it a fictional rent -- we chose the regional CPI. However, in our scenarios we only allowed the amount of Unused land to decrease in selected frontier regions, namely Rondonia, Amazon, ParaToc, MarPiaui, Bahia, MtGrosso, and Central. In the other, mainly coastal regions, total agricultural land was held fixed (by endogenizing the corresponding Mqr variable).

In summary, the model allows for, say, SugarCane, output to increase via:

- assumed uniform primary-factor-enhancing technical progress of 1.5% p.a. (baseline assumption);
- increasing non-land inputs;
- using a greater proportion of Crop land for sugar cane, in any region;
- converting Pasture land to Crops, if Crop rents increase, in any region; and
- converting Unused lands to Pasture or Crop uses, in frontier regions.

The last three of the above topics characterize the indirect land use change (ILUC) which is the object of our scrutiny in this paper.

4 Model baseline and scenario simulation

As stated before, the model database is for year 2005. Model running strategy comprises a three year historical simulations, updating the database to 2008 with historical observed data, and then simulating the ethanol expansion scenario for year 2020. A baseline is settled with a moderate increase for the economy until 2020, around 3.5% increase in real GDP per year, with projections for population increase by state by IBGE.

The purpose of this paper is to analyze the ILUC effects associated to an aggressive expansion of ethanol production in Brazil. For this reason, is of our interest to compare a moderate scenario with a more aggressive one, analyzing the differences in land use in both situations. With this in mind, the baseline projections for ethanol entail a moderate expansion in exports as well as in household use in Brazil, around 4% per year. These projections result in an equivalent 4% per year increase in ethanol production in Brazil, in the baseline[5].

The policy scenario, on the other hand, is based on the projections by EPE (2008), and comprises a 12.8% a year increase in ethanol exports, from 2008 to 2020, and a

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[5]The observed expansion in ethanol exports in Brazil in the historical simulation period, from 2005 to 2008 was much higher than that, around 25% a year.

9.2% a year increase in household use of ethanol, in the same period. No endogenous technological change was considered for the simulations.

4.1 Closure

In the closure used in the model, labor is mobile between regions and activities, driven by real wages changes, but does not move between labor categories. Capital accumulates between periods driven by profits, as discussed before. In order to properly approach the sugar cane expansion in Brazil, a few other closing rules were used in the simulations:

- Capital in the ethanol industry was allowed to accumulate only in some regions, where ethanol expansion is expected to occur in Brazil (Ferreira Filho and Horridge, 2019). These regions are Minas Gerais (MinasG), São Paulo, Parana, Mato Grosso do Sul (MtGrSul), Mato Grosso (MtGrosso) and Central.
- Exports of agricultural raw products, food, textiles and mining were kept fixed in the simulations.

5 Results

In what follows we first present the model baseline for land use in Brazil until 2020, generated by our projections for the economy and the transition matrix approach used.

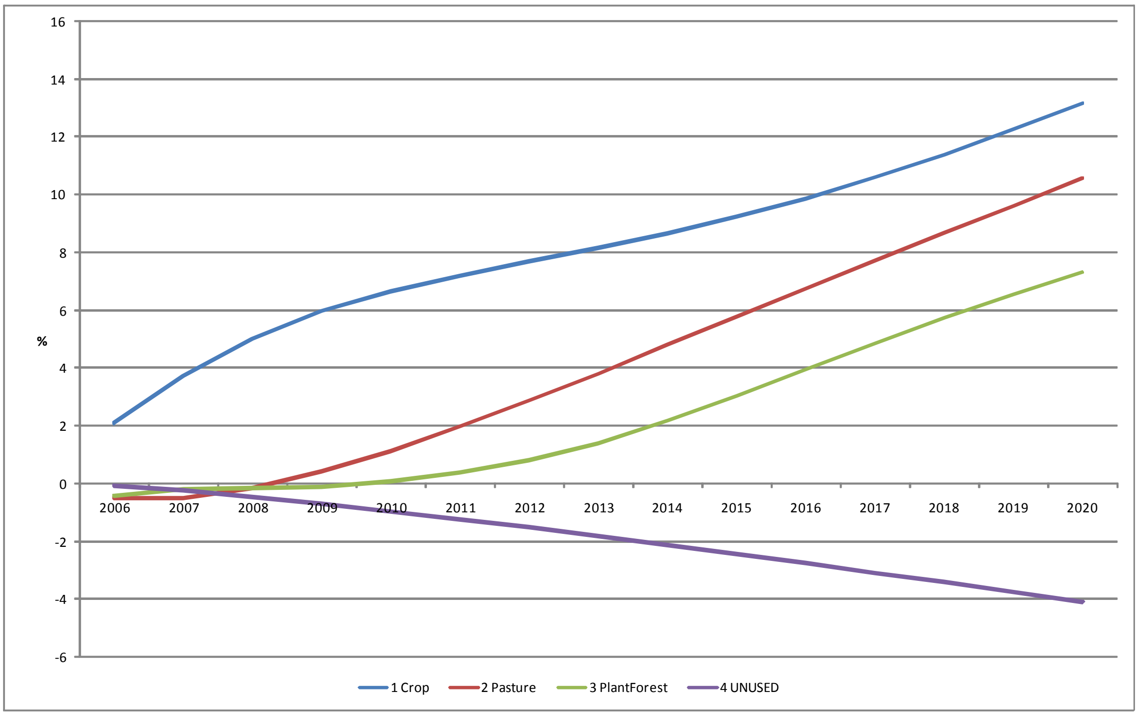

Figure 4. Baseline evolution of broad categories of land use in Brazil. Percent variation, accumulated.

Our baseline scenario entails a 4.1% fall in unused land in Brazil, accumulated in 2020, matched by a 13.2% increase in area for crops, 10.6% increase in area for pastures, and 7.3% increase in area used for planted forests. This represents an extra 25.6 million hectares coming from unused land to the production of crops (8.3 million hectares), pastures (16.9 million hectares) and planted forests (0.34 million hectares). These baseline projections, of course, result from our projections for the expansion of the Brazilian economy until 2020, as explained before, and the "normal" rate of land use change observed in the past, as expressed by our transition matrix[6].

The simulated increase in ethanol use and exports in Brazil results in an aggregated 14.8% increase in sugar cane production above the baseline, in year 2020. This increase happens at the expense of the other agricultural products, which have their production slightly reduced, as can be seen in Table 4. Livestock related activities increase production slightly due to capital attraction in those activities, since exports of meats were fixed in the closure.

Table 4. Change in production and land use in agricultural activities. Deviation from baseline, accumulated, year 2020. Percent variation.

Agricultural product	Production	Land use

[6] We have, however, restricted the expansion of agricultural areas only to the expansion regions, as explained before.

Rice	0,10	-0,34
Corn	-0,26	-1,28
Wheat	-1,46	-2,09
Sugar cane	14,81	8,17
Soybean	-0,04	-0,86
Other agric	-0,65	-1,67
Cassava	0,03	-0,71
Tobacco	0,13	-0,37
Cotton	-0,26	-0,73
Citric fruits	-0,65	-2,98
Coffee	-0,01	-1,10
Forestry	-0,51	-0,73
Livestock	0,03	-0,30
Dairy	0,06	-0,37
Other livestock	0,10	0,00

Source: model results.

Through competition in the primary factor markets, the expansion in sugar cane area would take land from other agricultural activities. The projected variation in each land use can also be seen in the last column of Table 4. To match the expansion in sugar cane area the other agricultural activities would reduce their area, compared to the baseline. Citric fruits would reduce its area the most, what happens because this activity is located mostly in Sao Paulo state, the main sugar cane producer. With total land supply fixed in this state (which is not an agricultural frontier state) the sugar cane expansion must happens exclusively due to land attraction from other cultures.

Notice that while sugar cane production increases 14.8% accumulated in the end of the period, its land use increases less, by 8.17%. The reason is that sugar cane is expanding in regions with higher productivity than the Brazilian average. São Paulo, the state with the highest sugar cane productivity in Brazil, is the state where sugar cane expands the most, as can be seen in Figure 5. This effect is relevant for the ILUC discussions regarding sugar cane expansion in Brazil, since the higher the productivity of the expanding culture the smaller the land displacement required, for each unit of product.

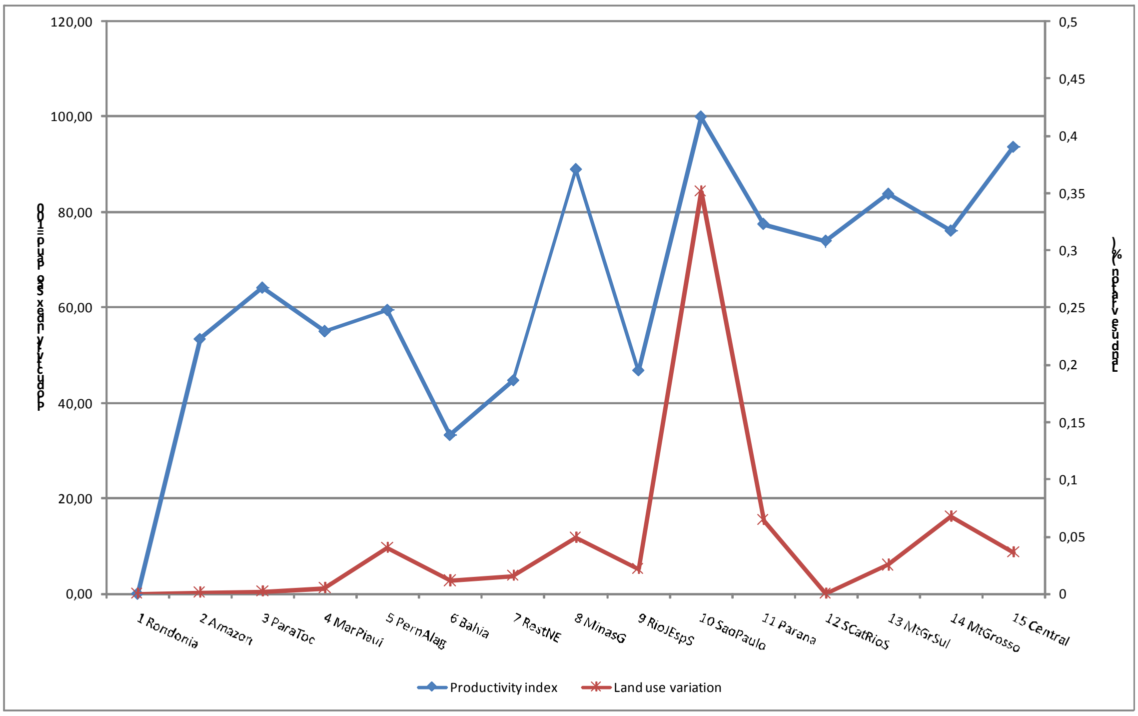

Figure 5. Sugar cane area variation (% accumulated in 2020) and productivity index, by region.

As discussed before, the main interest of this paper is on the ILUC effects of the ethanol expansion in Brazil. For this purpose we have computed the overall land use change in Brazil, according to broad land areas categories caused by the ethanol expansion, by state. Here, however, we present only the national aggregates. The evolution of broad definition land use variation caused by the ethanol expansion scenario simulated can be seen in Figure 6.

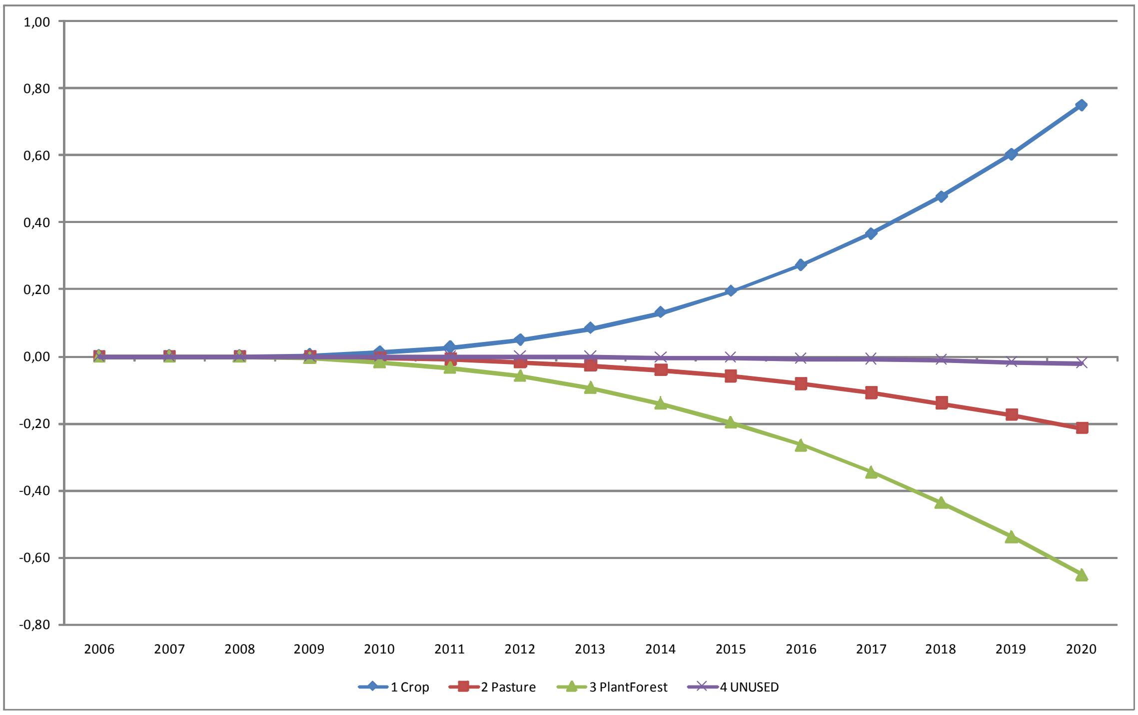

Figure 6. Simulation results. Land use variation in Brazil. Percent variation.

Model results show that a 0.75% expansion in crops area would be required, accumulated in year 2020, to accommodate the simulated ethanol expansion scenario. Pasture land would fall by 0.21%, Planted forest land by 0.65%, and Unused land would fall by 0.02%. In physical terms this would account for an extra 530 thousand hectares of crops[7], and a reduction of 380 thousand hectares of pastures, 30 thousand hectares of planted forests, and 120 thousand hectares of unused land.

Nassar et alii (2010) in a study about the relation of sugar cane expansion and land use change in Brazil with physical data for the period 2005-2008 concluded that the ILUC caused by sugar cane was around 8%, meaning that for each extra hectare of sugar cane in the period only 0.08 hectares of new land, or deforestation, was observed in Brazil as a whole. Our results allow the same type of calculation, shown in Figure 6, which shows the period average of the ratio, in physical units, of the change in sugar cane area and the change in unused or pastures areas.

Table 5. Simulation results. Average ILUC in Brazil.

	Ratio (hectares)
Unused/sugar cane	-0,14
Pastures/sugar cane	-0,47

[7] Sugar cane itself would require 680 thousand hectares more, but it would attract land from other activities, reducing the total requirement of crop land.

As it can be seen from the figure, in the average of the period considered (2008-2020, since the 2005-2007 simulated period was just the historical simulations for database updates) each extra sugar cane hectare was associated to a 0.14 hectares fall in unused land, and a 0.47 hectares fall in pastures. Our model's projected ILUC, then, is somewhat higher than the one reported by Nassar et alii (2010).

Our reported value for ILUC above is an average for the period, as stated before. This is because in a dynamic setting the value is generated every year, and changes according to the general equilibrium settings. An interesting point to notice in this regard is that model results for the values for ILUC varies from -0.014 in 2009 to -0.268 in 2020, with an average value of -0.14, reported before. Besides, the values increase monotonically (in absolute values), from 2009 to 2020. The reason why this happens in the model is related to the differential sugar cane land productivity, as discussed before. As sugar cane expands in São Paulo, the state with higher productivity, attracting land from other uses, the price of land start to increase faster, making this substitution harder. This makes the rate of expansion of the culture to become higher in areas were the productivity is smaller, what increases the land area required for each ton of sugar cane. In the end, this process causes an increasing ILUC. Figure 7 shows the rate of expansion of sugar cane areas on the simulation, by state, for selected relevant states in Brazil.

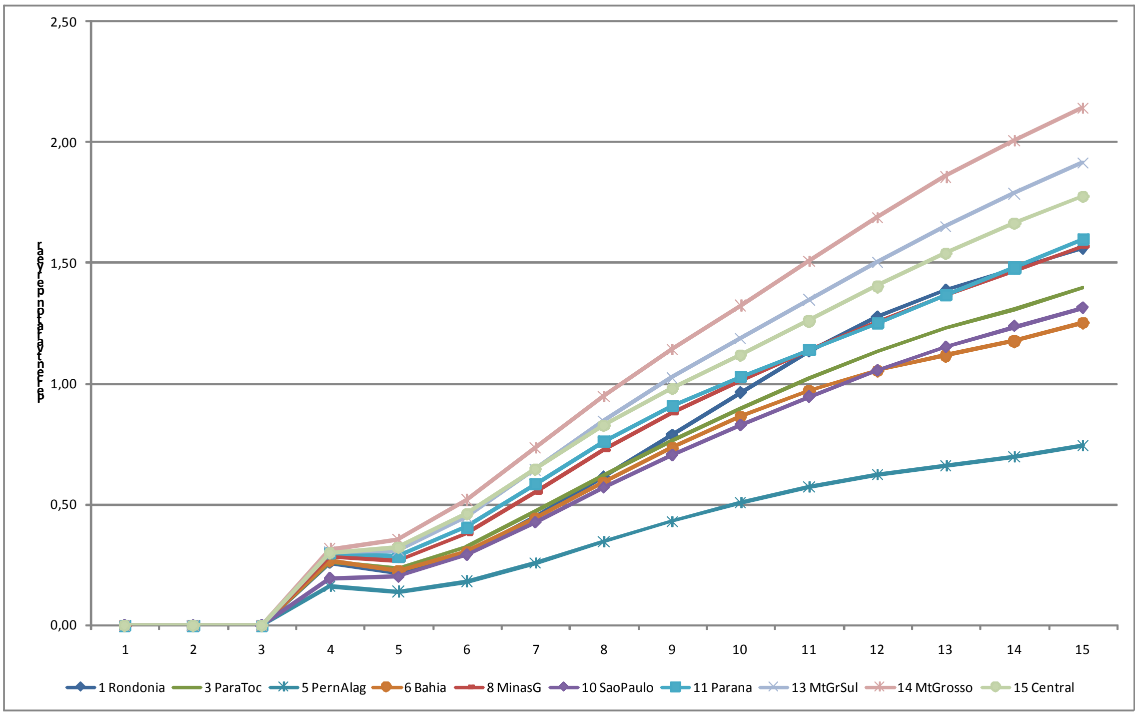

Figure 7. Model results. Land use variation in sugar cane, by region. Percent variation, year on year.
Source: model results.

As it can be seen from Figure 7, the rates of expansion of sugar cane in important regions other than São Paulo (the state with the higher productivity) happens at increasing rates, higher than in the state.

Of course, this happens in the simulations because we have kept productivity fixed across years. But this sheds light on the importance of productivity increases for the biofuels x deforestation issue. The higher the productivity increases the smaller the amount of new land necessary to match a given increase in biofuels production. At the same time, ILUC associated to sugar cane expansion would be reduced if the expansion to new areas is accompanied by productivity increases.

6 Final remarks

The expansion of agricultural based biofuels became an issue of concern worldwide, especially in the light of the recent increases in food prices. The diversion of land previously used in food production towards energy crops is considered one of the variables behind those food price hikes. Our simulation, however, shows that this is not the case in Brazil. With the projected "normal" rate of increase in land supply in the Brazilian agricultural frontier the amount of new land required for sugar cane production would be relatively small, and the same is true for the fall in other crops or livestock production. The rate of ILUC found here, although higher than that found by previous studies, cannot be considered very high: only 0.14 hectares of extra land would be required for each extra sugar cane land.

Another very important point in this discussion, addressed by our results, is what relates to agricultural productivity. As shown, the expansion of sugar cane in the region with higher agricultural productivity actually saves land, in relative terms. However, it’s expected that land prices will increase due to this attraction, fostering the sugar cane expansion in the new regions. The average productivity in those regions was shown to be higher than in some traditional regions, but smaller than the one observed in the Sao Paulo state. This sheds light on an important topic for public policies, since the higher the productivity gains in sugar cane production, the smaller will be the ILUC effect. Agricultural research policies, then, important as they are in the general context of food security, can also be regarded as important instruments to reduce ILUC effects of biofuels expansion.

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