ENDOGENOUS LAND USE AND SUPPLY, AND FOOD SECURITY IN BRAZIL

by

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1 Introduction

Brazil is one of the few large food-producing countries which still has a large unused agricultural land stock. Brazilian agriculture has been growing rapidly for years, increasing the country´s food and energy feedstock supply and turning it into one of the world's leading food exporters. Brazil is also a traditional producer of sugar cane based ethanol, largely used as a fuel and more recently as an important input to the chemical industry.

The recent food price increases have considerably benefited commodity-exporting countries. Brazil, in particular, was greatly benefited by the price hikes, which have allowed the country to experience GDP growth rates as high as 7%, well above the observed world average GDP growth rates in the 2000-2005 period. As argued by Ferreira Filho (2010), the commodity price increases were also beneficial in distributional terms, generating income effects that largely dominated expenditure effects, even for the poorest.

Morton et al (2006) have pointed out that the region located along the southern and eastern parts of the Brazilian Amazon is the most active land-use frontier in the world, both in terms of forest loss and of fire activity. As the agricultural frontier in Brazil evolves, however, new environmental regulations are likely to restrict agricultural expansion in the future. The rate of deforestation in the Brazilian agricultural frontiers has been considerably reduced in recent years, posing new challenges for agriculture to expand, with important implications for food supply and food security. The relation between the expansion of the agricultural frontier and food supply in Brazil was not quantitatively addressed so far in the Brazilian literature. The purpose of this paper is to assess by how much a freezing of the Brazilian agricultural frontier may affect domestic food prices and agriculture-based exports.

2 The agricultural expansion in Brazil

Brazil's farmed area accelerated in the early seventies, with technological developments that allowed the exploitation of the vast cerrado (savannah) areas in central Brazil. The total agriculture and pasture areas evolved from 65.3 million hectares in 1970 to 165.7 million ha in 2006 (Brazilian Agricultural Censuses 1970 and 2006), as shown in Table 1.

Table 1. Land use variation in Brazil. 1970-2006. Thousand hectares.

	1970	1975	1980	1985	1995	2006
Perennial crops	7,984	8,385	10,472	9,904	7,542	11,612
Annual crops	26,000	31,616	38,632	42,244	34,253	48,234
Planted pastures	29,732	39,701	60,602	74,094	99,652	101,437
Planted forests	1,658	2,864	5,016	5,967	5,396	4,497
Total	65,374	82,567	114,722	132,209	146,843	165,781

Source: Brazilian Agricultural Censuses, various years.

The area of annual crops almost doubled in the period, and the area of pastures tripled. We underline the enormous availability of pasture areas in Brazil. Area under pastures represents 61% of total area under production, and the land use change between pastures and crops is traditionally important for agricultural expansion.

In spite of the increase in land used for agriculture and livestock, the rate of deforestation has been reduced considerably in the recent period. As can be seen in Figure 1, the rate of deforestation falls markedly from 27,772 square kilometers in 2004 to 6,541 square kilometers in 2010 (IBGE/PRODES)[2]. The deforestation values of Figure 1 refer to the Legal Amazon, an administrative region in Brazil that comprises the states of Rondonia, Acre, Amazonas, Roraima, Para, Amapa, Tocantins, Maranhão and Mato Grosso. But the agricultural frontier is mainly located in Mato Grosso, Rondonia and Para, the states on the so-called "Arch of deforestation[3]".

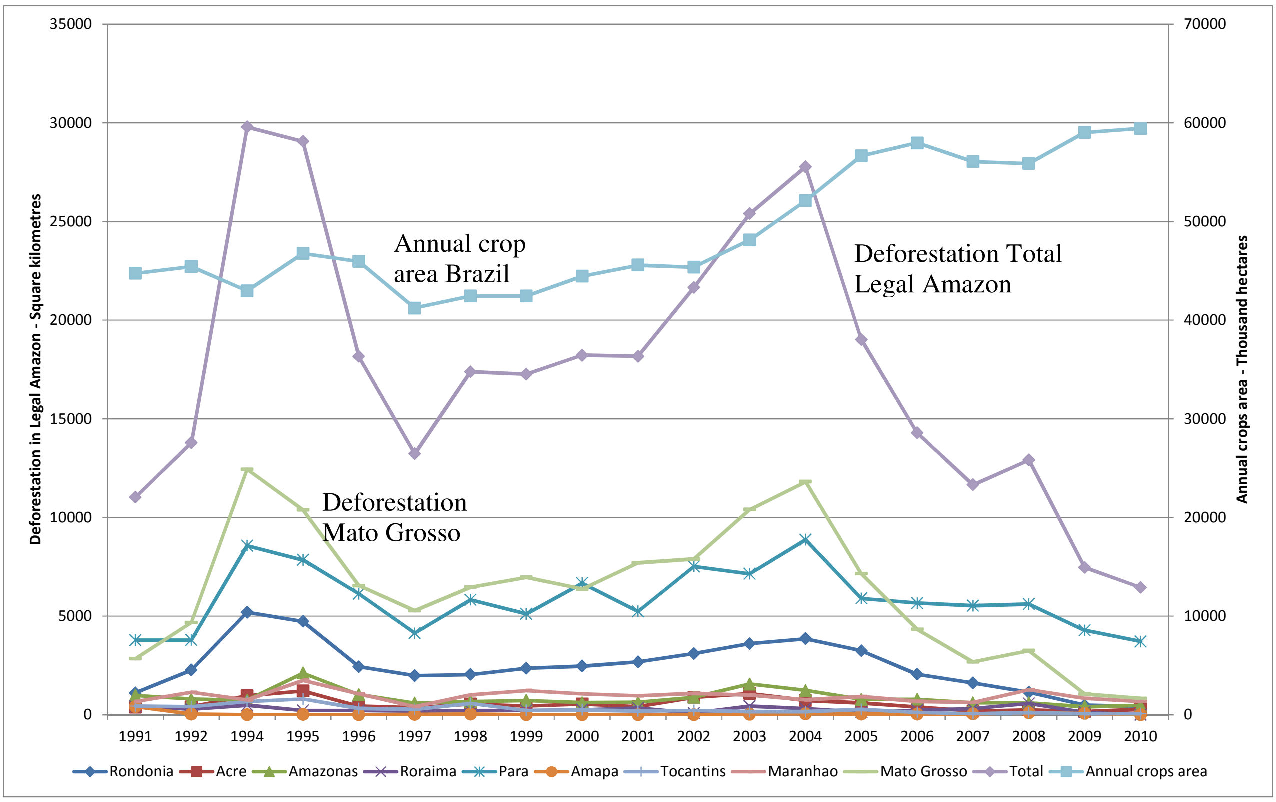

Figure 1. Deforestation in Legal Amazon and annual crops area evolution (total) in Brazil. 1991-2010.

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

Macedo et al (2012) relates the observed fall in deforestation with the fluctuations in the commodities market prices, as well as with the implementation of several measures introduced by the Brazilian government for monitoring and enforcing deforestation controls. The same authors still observe that after 2005 soy production kept increasing, despite the fall in deforestation. The observed trend mentioned by Macedo et al (2012) in the soybeans context, however, is not restricted to soybeans production. Figure 1 shows that despite its fall, the deforestation rate in Brazil is still important, and its relation to food production has a complex pattern. Not only soybeans area have been increasing, but the general agriculture area. The crop area increases suggest that some intensification process as well as that some substitution between

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[2] Available at http://seriesestatisticas.ibge.gov.br/series.aspx?vcodigo=IU12&t=desflorestamento-na-amazonia-legal-3-desflorestamento-bruto-anual-na-amazonia-legal

[3] Sometimes referred to also as the "Arch of fire".

activities inside the agricultural and livestock sector may occur. This is actually a well-known stylized fact in the Brazilian economy, the expansion of agriculture on the "intensive margin", rather than on the "extensive margin". Due to technological reasons, forests are initially converted to pastures which, after a couple of years, are ready to be converted into crops (Macedo et al, 2012; Lapola, 2006). Ferreira Filho and Horridge (2011) have used this important "prior" in their analysis of ethanol expansion in Brazil.

This increase in agriculture production causes food supply in Brazil to be fairly stable. Even the recent increase in world food prices did not reflect strongly on the country´s food price system. As seen in Figure 2, the food and beverages price index, as measured by the Extended Consumer Price Index (IPCA), although with a strong variation, shows a relatively stable trend, as shown by the dashed line.

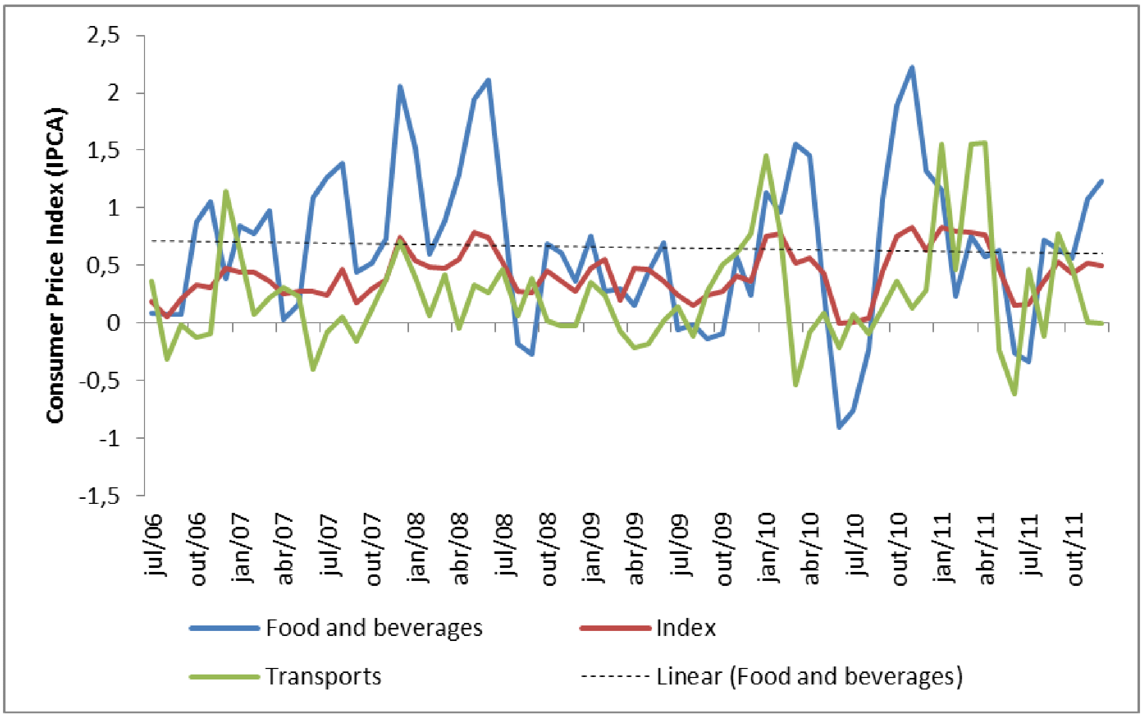

Figure 2. The Extended Consumer Price Index (IPCA) and some of its components evolution in Brazil: 2006 – 2011.

Source: IBGE.

Part of the reason for this relative stability of food prices is that, within the food bundle, only meat is an important export item, but meat's export share is not large in the initial database, around 25% of total production. Soybeans and coffee, other important export agricultural products, represent small shares of the households food bundle. Ferreira Filho and Vian (2011) showed that the Brazilian exchange rate appreciation in the period also had its share in prices stabilization in the context of increasing external prices. But the increase in agriculture acreage certainly has also its contribution to that stabilization effect, since the food production system had to adapt to the competition for land generated by the push on export demands for agricultural tradable commodities. This suggests a link between deforestation and food supply and prices that, however, cannot be directly assessed.

This complex link was analyzed by Lapola (2006), Arima (2012) and Macedo (2011), among others, in different contexts which tried to evaluate the indirect land use change (ILUC) caused by different agricultural activities, mainly soybeans and biofuels. The ILUC effects caused by agricultural expansion, however, are of a broad nature, since all agricultural activities are linked by the land market. For example, we would expect that meats (notably beef) will be the products most seriously affected by a fall in deforestation, due to the fall in the rate of conversion of forests to pastures. The indirect land use effect, however, will affect other land uses, changing the substitution possibilities among agricultural activities and pastures.

3 Methodology

In this paper we use a multi-period computable general equilibrium model of Brazil, based on previous work by Ferreira Filho and Horridge (2011), to analyze the importance of endogenous land supply for agricultural supply in Brazil. The model, TERMBR, is descended from the Australian TERM model (Horridge et al, 2005), but includes, as well as a Brazilian database, many other specific adaptations. 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 model, as presented in Ferreira Filho (2010). The LUC module is based on a transition matrix developed by Ferreira Filho and Horridge (2011) and calibrated with data from the Brazilian Agricultural Censuses of 1995 and 2006, which shows how land use changed across different uses (crops, pastures, forestry and natural forests) between those years. This transition matrix is used to project the deforestation rate (or the increase in total land supply) in the baseline scenario.

As well as the LUC module, the model includes three more recursive-dynamic 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 at work it is 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 total land supply, or the deforestation rate). This difference can be interpreted as the effect of the policy change. The model is run with the aid of RunDynam[4], a program to solve recursive-dynamic CGE models.

3.1 Closure

The main features of our model´s closure are:

- Labor moves between regions and activities, driven by real wage changes, but not between labor categories. Total labor supply increases according to official projections from IBGE;
- Sectoral investment, driven by industry profits, causes capital to accumulate between years;
- Real regional household consumption follows regional wage income (subject to the next rule);
- We force the trade balance to approach zero in the long run -- national household and government consumption adjust together to meet this external constraint.
- The national GDP price index is chosen as the fixed numeraire price. Other price results should thus be interpreted as *relative* to the GDP price index.
- We divided model regions into two groups, Frontier and Land-constrained, based on their proportion of unused land. The region classification is shown in Figure 3. In the base scenario we prevented further conversion of Unused land in the Land-constrained regions, whilst allowing deforestation to continue in the Frontier regions. In the alternate (Policy) scenario, we prevented deforestation in **all** regions.

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[4] RunDynam is part of the GEMPACK economic modeling software [Harrison and Pearson (1996)].

Figure 3. Frontier (blue) and Land-constrained (red) regions of the model

3.2 Land Use in the initial database

Increased farm output 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, Brazil may need to convert unused land to agriculture — at the expense of the environment. To assess these claims, our CGE model needs to model land use explicitly, as 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 industries in 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, as shown by the grouping in column 1 of Table 2. The "Unused" land shown in the penultimate row of Table 2 is defined as the total area of each state minus the used areas: crops, pastures and planted forests, which appear in Agricultural Censuses. It includes all areas not used in agriculture, like natural forests, but also urban areas, mountaintops, lakes and roads. The latter areas, however, are expected to change much less than the land-cleared areas, so the change in "Unused" is used here as a proxy for deforestation, or land clearing for agricultural use.

Table 2. Initial Data: Land Use by Region, million hectares

	Frontier regions							Land-constrained regions								
areasplus	Amazon	Rondonia	ParaToc	MarPiaui	Bahia	MtGrosso	Central	PernAlag	RestNE	MtGrSul	MinasG	RioJEspS	SaoPaulo	Parana	SCatRioS	**All Brazil**
Rice	0.1	0.1	0.5	0.7	0.0	0.9	0.2	0.0	0.1	0.1	0.1	0.0	0.0	0.1	1.2	3.9
Corn	0.1	0.1	0.4	0.7	0.8	1.0	0.7	0.3	0.9	0.5	1.4	0.1	1.1	2.0	1.7	11.6
Wheat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	1.6	1.1	3.0
Sugarcane	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.8	0.2	0.1	0.4	0.2	3.1	0.4	0.0	5.8
Soybean	0.0	0.1	0.5	0.6	0.9	6.1	2.7	0.0	0.0	2.0	1.1	0.0	0.8	4.2	4.1	23.0
Other agric	0.1	0.1	0.4	0.5	2.0	0.2	0.5	0.5	1.6	0.1	0.7	0.2	0.6	0.7	0.6	8.6
Cassava	0.1	0.0	0.3	0.2	0.4	0.1	0.0	0.1	0.2	0.1	0.1	0.0	0.1	0.2	0.1	2.0
Tobacco	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.5
Cotton	0.0	0.0	0.0	0.0	0.3	0.5	0.2	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.0	1.3
Citrus fruits	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.6	0.0	0.1	1.0
Coffee	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	1.0	0.6	0.2	0.1	0.0	2.3
All Crops	0.4	0.6	2.1	2.8	4.6	9.0	4.5	1.7	3.1	3.0	4.9	1.1	6.6	9.4	9.2	62.9
Forestry	0.2	0.0	0.1	0.1	0.3	0.1	0.1	0.0	0.1	0.1	1.0	0.2	0.4	0.6	1.4	4.7
Meat cattle	2.6	4.3	17.7	7.7	11.7	20.8	13.1	2.2	5.3	20.4	11.2	1.9	5.6	3.3	8.5	136.4
Milk Cattle	0.2	0.4	1.2	0.7	1.3	0.9	3.0	0.6	1.2	0.6	7.5	0.8	1.5	1.6	2.7	24.1
All Pasture	2.8	4.6	18.9	8.4	13.0	21.8	16.1	2.9	6.5	21.0	18.7	2.7	7.1	4.9	11.2	160.5
Unused	205.6	18.5	131.5	47.1	38.6	59.5	13.9	8.1	18.3	11.6	34.1	5.0	10.7	5.1	16.0	623.4
Total	209.1	23.8	152.5	58.3	56.5	90.3	34.6	12.6	28.0	35.7	58.6	9.0	24.8	19.9	37.7	851.5

Source: model database

We may observe from Table 2 that in general the ratio of Cropland to Pasture areas increases as Unused land becomes more scarce. That relationship is shown in Figure 4; the outlier, MtGrSul (Mato Gross de Sul), is an inland southern state especially well-suited to beef grazing.

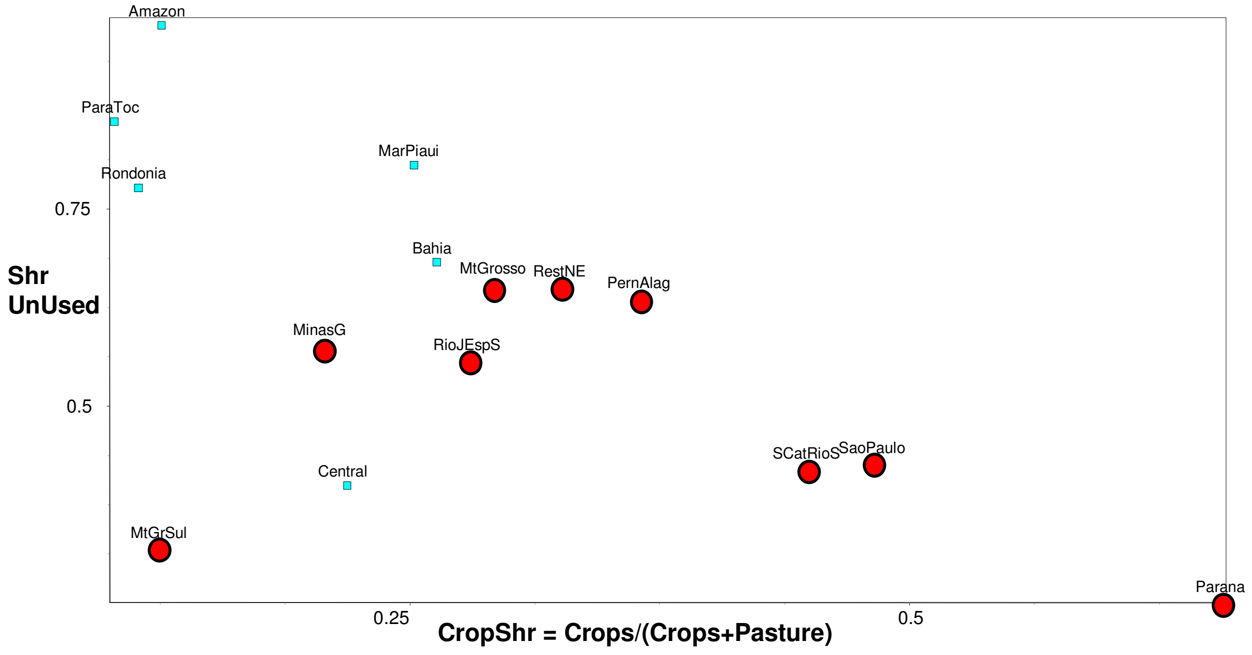

Figure 4. Emptier regions (blue) prefer Pasture; Full regions (red) prefer Crops

Notice also the potential role played for the expansion in the intensive margins in states like São Paulo, Santa Catarina and Rio Grande do Sul, and Paraná, states were the stock of lands for conversion has run out long time ago. Parana, on the other hand, has the smallest share of crops on crops plus pastures areas, what suggests that for this state the possibilities of agricultural expansion on the intensive margin would be more restricted.

Table 3. Initial Data: Land Productivity relative to São Paulo

	Frontier regions							Land-constrained regions							
adjprd0 reportbase	Amazon	Rondonia	ParaToc	MarPiaui	Bahia	MtGrosso	Central	PernAlag	RestNE	MtGrSul	MinasG	RioJEspS	SaoPaulo	Parana	SCatRioS
Rice	0	0	41	30	0	46	38	0	0	0	0	0	100	0	138
Corn	0	0	62	0	51	75	111	0	0	56	129	0	100	108	70
Wheat	0	0	0	0	0	0	0	0	0	0	0	0	100	52	47
Sugarcane	0	0	0	0	0	76	94	60	0	0	89	0	100	78	0
Soybean	0	0	0	127	119	107	106	0	0	78	118	0	100	106	35
Other agric	0	0	43	0	33	0	51	50	18	0	83	155	100	59	115
Cassava	67	0	40	27	29	44	0	38	30	0	154	0	100	61	151
Tobacco	0	0	0	0	0	0	0	0	0	0	0	0	100	98	96
Cotton	0	0	0	0	179	466	159	0	0	136	0	0	100	0	0
Citrus fruits	0	0	160	0	106	0	0	0	102	0	212	287	100	0	95
Coffee	0	37	0	0	81	0	0	0	0	0	107	73	100	85	0
Forestry	0	0	391	138	180	0	0	0	0	88	35	49	100	106	45
Meat cattle	0	109	62	65	63	52	64	109	82	49	78	0	100	131	103
Milk Cattle	0	0	64	0	63	0	64	106	82	0	78	90	100	131	112

Source: model database (zeroes shown where region produces < 2.5% of national output)

3.3 *Modeling changes in Land Use*

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. A transition matrix approach is used, as illustrated in Table 4 below, which shows 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.

Table 4. Transition matrices for land use change (Mha). Average annual changes.

São Paulo	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.

Above, row and column values reflect current land use and the average rate of change of land use during the last 11 years (1995 to 2006), drawn from the Brazilian Agricultural Censuses of 1996 and 2006[5]. 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.

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:

$$S_{pqr} = \mu_{pr} . L_{pqr} . P^{\alpha}_{qr} . M_{qr} \qquad = \text{(alternatively)} \;\; . L_{pqr} . P^{\alpha}_{qr} . M_{qr} \, / \sum_{k} L_{pqk} . P^{\alpha}_{qk} . M_{qk}$$

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 S_{pqr}

P^{α}_{qr} = 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

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[5] 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).

The sensitivity parameter **α** was set to 0.35 to give a “normal” (close to observed) past evolution of crops areas 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 M_{qr} variable).

In summary, the model allows for, say, Soybean, output to increase through:

- 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 Soybean, 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 mechanisms above characterize the indirect land use change (ILUC) examined in this paper.

3.4 The policy scenario and model running strategy

This paper compares two scenarios for the evolution of the Brazilian economy. The first (Base) scenario assumes endogenous agricultural land supply in Frontier regions; while the second (Policy) scenario fixes total land supply in all regions, meaning no deforestation would occur. Probably Brazil will chart a course between these two extremes, which we chose to highlight the role played by the expansion of the agricultural frontier in Brazil. Our simulation consists of:

- Baseline scenario: shocking our model with the commodity (average) price shocks in international markets for the historical period (2005 to 2009), and projecting the economy until 2025 based on past observed trends for GDP, population, and other variables, with an endogenous land stock adjustment pattern explained above. After the historical period we assume that commodity prices will annually grow 1% faster than manufacturing prices. Based on these assumptions, the model generates a path of deforestation projected from the transition matrix and the general adjustment of prices in the economy.
- Policy scenario: the same as above, but a halt in deforestation is exogenously imposed.

Model results, then, show how restrictions on deforestation might restrict economic growth or otherwise affect the Brazilian economy.

4 Results from the Base Scenario

Figure 5 shows growth of several macro variables in our baseline scenario. The first 4 years of the scenario mimic recent Brazilian history, including an investment boom, a tripling of imports, and the effects of the 2008 world financial crisis. After that the economy follows a fairly smooth growth path, with most real macro variables growing at around 3.8% pa, as shown in Table 5. However, our base scenario includes a continuing improvement in Brazil's terms of trade (ToT). Since we force exports to approach imports in nominal terms (balance of trade trends to zero), we see that real imports continue to grow faster than exports. The ToT improvement also allows real household spending to grow faster than GDP.

Table 5. Model results, Base scenario, Macro variables: total growth 2005-25 and terminal annual growth rates

	RealHou	RealInv	RealGov	ExpVol	ImpVol	RealGDP	Employ	Realwage	CapStock
Cumulative % growth	121.2	142.9	104.1	69.8	237.0	103.0	27.4	67.2	94.0
Terminal Growth Rate %	3.9	3.6	3.9	3.8	4.2	3.8	1.2	2.5	3.8

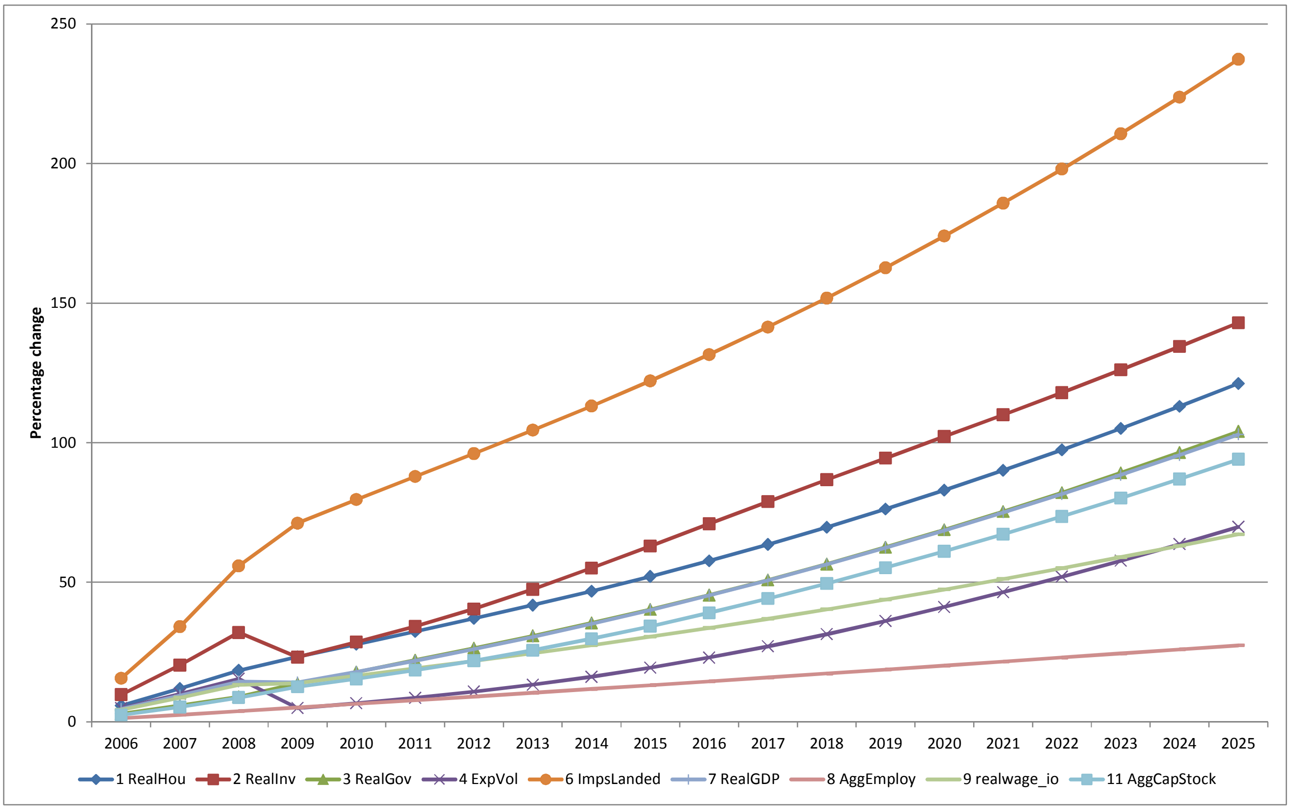


Figure 5. Macro variables, baseline. Percentage change, accumulated.

The results for the agricultural sectors expansion implied by our baseline scenario can be seen in Table 6, while Table 7 shows the corresponding land use variation. As it can be seen, the growth scenario projected to 2025 would imply a strong increase in agricultural production and land use in most Brazilian regions, but especially in the frontier regions. This, of course, is due to our assumption about the agricultural frontier expansion in those states, what would make agricultural expansion easier. It can be seen from Table 7 that the total new land required, or deforestation, would amount to 36.96 million hectares of land.

Table 6. Model results. Agricultural output, base scenario, cumulative percent change 2005- 2025, base scenario

	Frontier regions							Land-constrained regions							
agricxtota	Amazon	Rondonia	ParaToc	MarPiaui	Bahia	MtGrosso	Central	PernAlag	RestNE	MtGrSul	MinasG	RioJEspS	SaoPaulo	Parana	SCatRioS
Rice	166	88	116	68	94	151	96	42	48	83	74	59	65	78	69
Corn	163	87	114	69	78	139	88	39	46	70	66	55	62	76	66
Wheat	49	7	19	-5	3	40	21	-16	-15	5	2	-10	-7	3	-1
Sugarcane	256	137	169	88	135	215	135	61	67	109	95	81	99	105	97
Soybean	191	85	132	81	87	167	102	35	46	82	65	65	68	85	70
Other agric	137	59	81	43	65	111	76	29	39	61	46	46	52	59	49
Cassava	164	93	120	80	105	140	96	66	72	80	78	68	70	85	74
Tobacco	193	101	136	80	85	194	107	48	55	86	80	63	66	78	67
Cotton	98	37	63	34	50	108	58	12	19	40	33	18	21	28	20
Citrus fruits	184	94	125	70	93	193	108	47	56	91	72	64	74	88	75
Coffee	166	81	110	61	84	169	97	36	38	76	66	53	57	66	57
Forestry	147	61	117	124	85	96	94	81	70	50	69	84	51	44	83
Meat cattle	184	159	135	124	93	128	73	84	84	72	66	66	56	44	67
Milk Cattle	178	150	129	104	79	127	76	76	72	73	68	70	62	67	75

Table 7. Model results. Land areas, base scenario, cumulative ordinary change 2005- 2025, base scenario. Million hectares.

	Frontier regions							Land-constrained regions								
del_AREAS PLUS	Amazon	Rondonia	ParaToc	MarPiaui	Bahia	MtGrosso	Central	PernAlag	RestNE	MtGrSul	MinasG	RioJEspS	SaoPaulo	Parana	SCatRioS	**All Brazil**
Rice	0.05	0.03	0.2	0.05	0.01	0.69	0.04	0	-0.01	0.01	0.01	0	0	0.01	0.05	1.14
Corn	0.06	0.04	0.16	0.05	0.15	0.78	0.11	-0.05	-0.11	0.04	0.06	0	0.02	0.27	0.04	1.62
Wheat	0	0	0	0	0	0	-0.01	0	0	-0.03	-0.01	0	-0.02	-0.38	-0.31	-0.76
Sugarcane	0.01	0	0.01	0.01	0.04	0.23	0.08	-0.05	0	0.04	0.06	0.02	0.59	0.11	0	1.15
Soybean	0.03	0.02	0.22	0.08	0.21	5.45	0.64	0	0	0.29	0.05	0	0.03	0.73	0.17	7.92
Other agric	0.07	0.02	0.09	-0.02	0.26	0.1	0.05	-0.1	-0.25	0	-0.04	-0.01	-0.02	0.03	-0.03	0.15
Cassava	0.11	0.01	0.14	0.03	0.11	0.1	0.01	0	0	0.01	0.01	0	0	0.03	0.01	0.57
Tobacco	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0.02
Cotton	0	0	0	0	0.01	0.27	0	0	-0.01	0	-0.01	0	-0.02	-0.01	0	0.23
Citrus fruits	0.01	0	0.01	0	0.01	0.01	0	0	-0.01	0	0	0	0.04	0	0	0.07
Coffee	0.01	0.05	0	0	0.03	0.01	0.01	0	0	0	0.05	-0.03	0	0.01	0	0.14
All Crops	0.34	0.16	0.83	0.2	0.85	7.65	0.93	-0.22	-0.39	0.36	0.18	-0.03	0.63	0.82	-0.06	12.25
Forestry	0.09	0	0.04	0.04	0.05	0.02	0.02	0	0	-0.02	0.02	0.03	-0.04	-0.12	0.15	0.28
Meat cattle	2	3.41	7.57	2.76	1.82	8.21	-0.52	0.15	0.3	-0.29	-0.52	-0.05	-0.58	-0.56	-0.29	23.41
Milk Cattle	0.15	0.3	0.46	0.19	0.11	0.36	-0.08	0.02	0	-0.01	-0.28	-0.01	-0.11	-0.11	0.01	1
All Pasture	2.15	3.71	8.03	2.95	1.93	8.57	-0.6	0.17	0.3	-0.29	-0.8	-0.06	-0.68	-0.66	-0.28	24.44
Unused	-2.58	-3.88	-8.9	-3.19	-2.83	-16.24	-0.34	0.04	0.09	-0.05	0.61	0.06	0.1	-0.04	0.19	-36.96
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

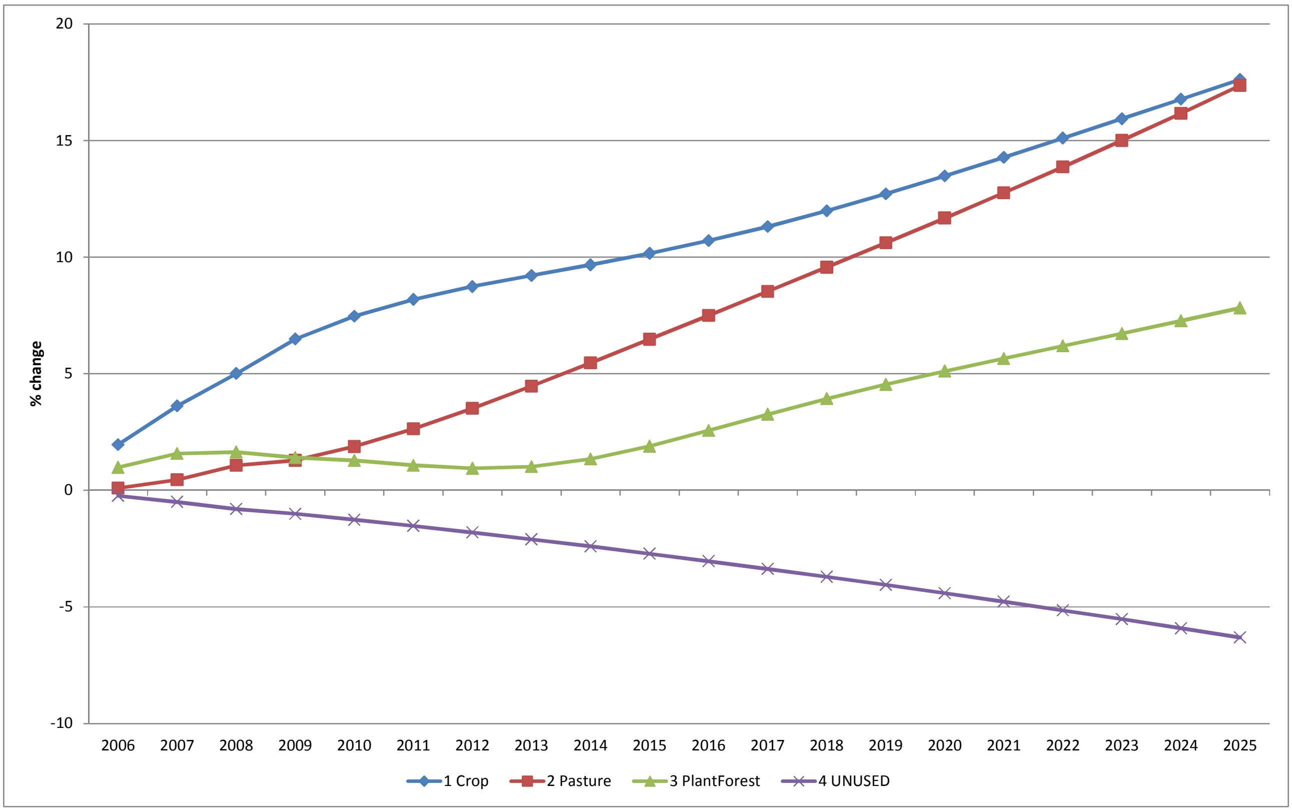


Figure 6. Model results. Broad land use type variation in the baseline. Percentage change, cumulative.

5 Results: effects of restricting deforestation

As explained before, results show the impact on the economy generated by the endogenous land use supply in Brazil, or the "shadow value of deforestation" for the economy. Needless to say, this concept doesn´t involve any environmental valuation consideration, but only economic effects. The increase in land supply represents a displacement of the production possibility frontier of the economy, increasing the stock of a primary resource. Considering that this increase is not uniform across the territory, it generates also a change in composition of production, both in the regions where total land supply increases and also in the other regions, through the change in market conditions. The results of the simulation are presented below.

Initially, Figure 6 shows the evolution of the broad type definitions of land use in the baseline. The lines in the figure show the accumulated percentage change in the amount of each broad type of land use, namely crops, pastures, planted forests and natural forests (UNUSED land, for short) in the business as usual scenario. The fall in the stock of unused land (deforestation) reaches an accumulated 6.3% fall in total natural forests area on year 2025. The counterpart of this fall in UNUSED land area is an increase of 17.6% in total area under crops and a 17.4% increase in pastures area, and a 7.8% increase in planted forests area.

This result would amount to an extra 37.0 million hectares of land incorporated to the production process in year 2025, with 12.3 million ha going to crops, 24.5 million ha for pastures, and 0.3 million hectares for planted forests, accumulated in year 2025.

This increase in the stock of a primary resource in the economy has macroeconomic impacts, some of which can be seen in Figure 7. As it can be seen, the halt of deforestation would decrease Brazilian GDP by about 0.50% in 2025, relative to the baseline, while real wages and real exports would fall by about 1%. This fall in GDP can be regarded as the “shadow value of deforestation” in the context of our baseline and policy assumptions. A 0.5% fall in national GDP doesn´t seem to be too high a value, especially if compared to the potential environmental benefits which would accrue associated to the fall in deforestation.

Table 8. Model results, Policy/Base deviation, Macro variables: total growth 2005-25 and terminal annual growth rates

NatSelMacro	RealHou	RealInv	RealGov	ExpVol	ImpVol	RealGDP	Employ	Realwage	CapStock
Cumulative % growth	-0.17	-1.91	-0.16	-1.02	-0.87	-0.50	-0.02	-1.08	-0.76
Terminal Growth Rate %	-0.03	-0.17	-0.03	-0.10	-0.09	-0.06	0.00	-0.11	-0.09

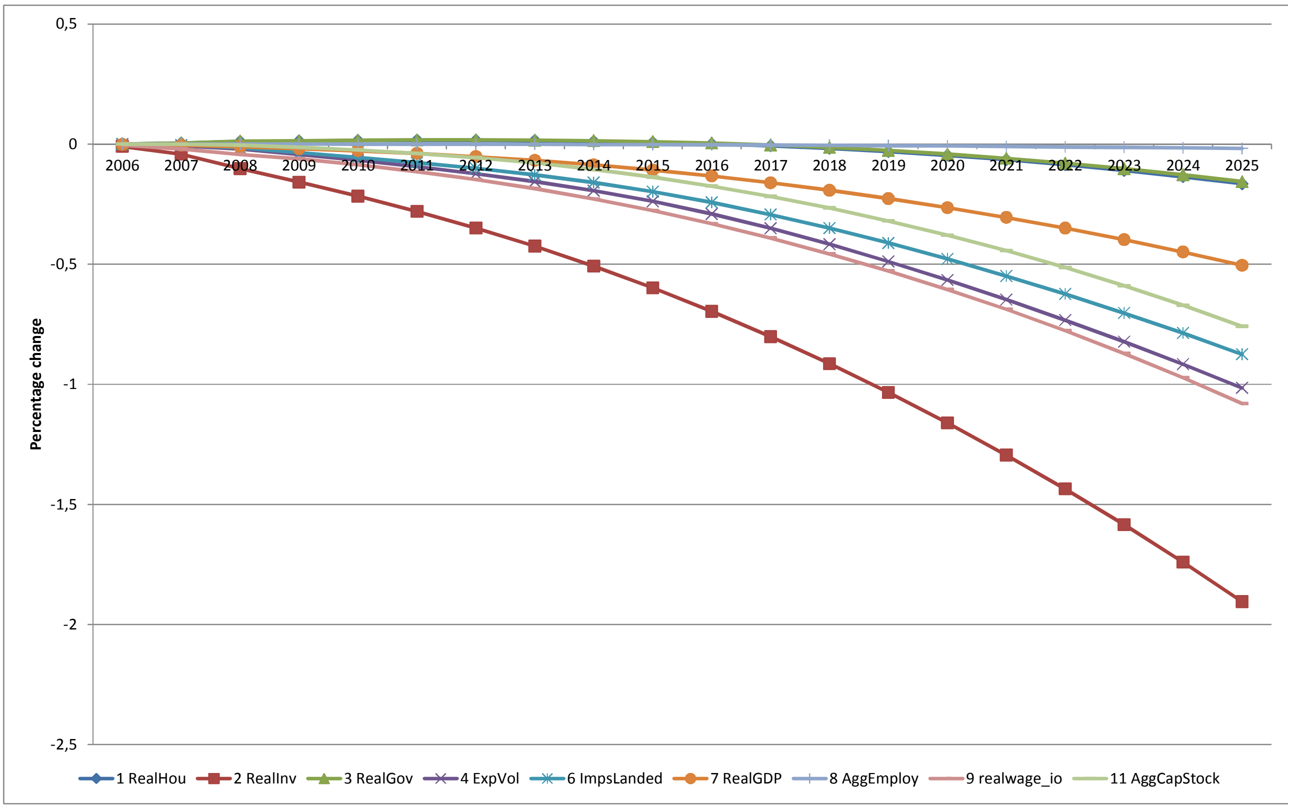


Figure 7. Macro variables, deviation from the baseline. Percentage change, accumulated.

There are, naturally, important regional differences. The regional real GDP in the agricultural frontiers states would decrease by value as high as 6.1% in Mato Grosso and 5.5 % in Rondonia, two states in the arch of deforestation, highlighting the higher dependence of those states on land expansion through deforestation.

In terms of agricultural production and use of land, Table 11 shows that soybeans and livestock, activities usually associated with the frontier, would strongly decrease both land use and production, but this would happen also with cassava and cotton, both important crops in the cerrados area. Sugar cane, on the other hand, depends less on land use expansion, since the bulk of it is produced in Southeast Brazil, far from the agricultural frontier.

Table 9. Model results. Agricultural output, Percent deviation from baseline accumulated to 2025.

	Frontier regions							Land-constrained regions							
agricxtota	Amazon	Rondonia	ParaToc	MarPiaui	Bahia	MtGrosso	Central	PernAlag	RestNE	MtGrSul	MinasG	RioIEspS	SaoPaulo	Parana	SCatRioS
Rice	-31.8	-34.2	-22.9	-15.1	-3.4	-12.9	4.7	9.1	8.4	3.0	5.7	5.5	6.4	7.0	4.0
Corn	-36.5	-39.6	-25.3	-16.7	-7.2	-15.6	-0.8	1.9	1.7	0.7	0.2	-0.2	-0.3	0.4	-1.0
Wheat	-35.2	-35.9	-24.2	-18.6	-11.4	-13.2	-4.3	-2.8	-3.8	-4.8	-3.2	-3.0	-1.4	-1.3	-2.9
Sugarcane	-46.4	-46.5	-33.0	-20.4	-14.8	-19.3	-2.3	-0.4	-0.9	-1.7	-0.3	-1.4	-0.8	0.8	-0.9
Soybean	-41.3	-36.9	-30.4	-23.0	-9.7	-19.2	-2.1	4.1	1.6	-2.6	1.2	-0.3	0.8	0.3	0.1
Other agric	-30.2	-25.5	-17.3	-14.1	-7.0	-10.9	-0.9	0.8	0.5	-0.7	0.2	-0.2	0.2	1.0	-0.2
Cassava	-28.7	-31.1	-18.5	-13.6	-3.4	-6.3	8.2	4.6	4.4	8.1	8.8	7.9	8.5	7.1	5.7
Tobacco	-39.1	-46.2	-33.8	-26.3	-8.7	-26.4	-4.3	-1.5	-1.9	-4.8	-1.9	-2.1	-0.7	0.4	-1.5
Cotton	-29.9	-30.7	-17.8	-12.0	0.6	-7.6	9.2	11.8	10.9	9.8	14.4	14.9	15.9	17.2	15.1
Citrus fruits	-37.6	-39.6	-24.8	-18.7	-8.6	-21.4	-0.4	1.2	0.8	-1.1	0.4	-0.6	-0.3	1.7	-0.3
Coffee	-41.2	-41.6	-31.0	-24.5	-14.0	-22.7	-4.3	-2.5	-2.9	-4.6	-2.5	-3.1	-2.0	-0.6	-2.4
Forestry	-29.1	-29.6	-26.7	-19.0	-14.5	-31.8	-3.0	9.7	7.8	0.8	3.3	3.6	3.2	1.3	0.8
Meat cattle	-31.7	-24.1	-19.0	-11.1	-4.5	-23.3	5.5	6.8	6.1	6.6	8.5	11.5	11.4	13.1	10.8
Milk Cattle	-33.7	-26.0	-22.6	-13.9	-8.1	-26.2	-2.0	1.4	1.4	0.2	0.7	-0.5	0.1	-0.2	-0.6

Source: simulation results

Table 10. Model results. Land areas, deviation from base scenario, cumulative ordinary change 2005- 2025. Million hectares.

	Frontier regions							Land-constrained regions								
del_AREAS PLUS	Amazon	Rondonia	ParaToc	MarPiaui	Bahia	MtGrosso	Central	PernAlag	RestNE	MtGrSul	MinasG	RioIEspS	SaoPaulo	Parana	SCatRioS	**All Brazil**
Rice	-0.1	-0.1	-0.2	-0.2	0.0	-0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0
Corn	-0.1	-0.1	-0.2	-0.2	-0.1	-0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.4
Wheat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
Sugarcane	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	-0.4
Soybean	0.0	0.0	-0.3	-0.2	-0.2	-3.7	-0.2	0.0	0.0	-0.1	0.0	0.0	0.0	-0.1	-0.1	-4.9
Other agric	-0.1	-0.1	-0.1	-0.1	-0.4	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.9
Cassava	-0.1	0.0	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.4
Tobacco	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cotton	0.0	0.0	0.0	0.0	0.0	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2
Citrus fruits	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
Coffee	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.3
All Crops	-0.3	-0.4	-1.0	-0.8	-0.9	-5.2	-0.3	0.0	-0.1	-0.2	-0.1	0.0	-0.2	-0.1	-0.2	-9.7
Forestry	-0.1	0.0	-0.1	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.4
Meat cattle	-1.9	-3.0	-7.1	-2.1	-1.7	-9.8	0.0	0.0	0.1	0.2	0.3	0.1	0.2	0.2	0.3	-24.3
Milk Cattle	-0.2	-0.3	-0.5	-0.2	-0.2	-0.5	-0.2	0.0	0.0	0.0	-0.2	0.0	-0.1	-0.1	-0.1	-2.5
All Pasture	-2.1	-3.3	-7.6	-2.3	-1.9	-10.3	-0.2	0.0	0.1	0.2	0.1	0.0	0.2	0.1	0.2	-26.8
Unused	2.5	3.7	8.7	3.2	2.8	15.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.9
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 11. Model results. Percent changes in national agricultural production, prices and land use caused by the halt in deforestation. Percent deviation from baseline accumulated in year 2025.

Agricultural product	Production	Prices	Land use	Land use frontier states	Land use other states
Rice	-4.0	7.2	-19.1	-28.3	1.0
Corn	-3.8	3.9	-10.9	-25.0	-2.1
Wheat	-2.0	0.5	-3.6	-11.4	-3.4
Sugarcane	-2.0	3.3	-5.6	-22.9	-2.8
Soybean	-9.9	5.9	-16.0	-26.5	-2.3
Other agriculture	-2.6	4.1	-10.9	-19.7	-2.2
Cassava	-4.9	7.8	-16.9	-25.6	2.3
Tobacco	-1.3	2.1	-3.4	-21.3	-2.8
Cotton	-4.2	10.7	-13.5	-18.5	7.3
Citrus fruits	-2.5	3.7	-5.6	-23.8	-2.4
Coffee	-4.9	2.4	-10.6	-35.9	-4.4
Forestry	-7.6	8.7	-7.9	-30.8	-1.1
Meat cattle	-5.1	13.8	-15.2	-24.9	2.6
Milk cattle	-3.7	6.6	-10.0	-21.6	-3.3
Other livestock	-1.34	-0.5			

Source: simulation results

It can be seen from the data above that the decrease in land use is greater than the decrease in production, as a rule. This is partly due to productivity differences in the frontier, which is normally lower when compared to production in the traditional agricultural regions.

Table 12. Model results. Sources of land productivity change: Policy relative to Base, 2025

RPT	(1) Area 2025 Base	(2) Output 2025 Base	(3) Frontier share of output	(4) % diff Area	(5) % diff Productivity	(6) % diff Output	(A) National Area Effect	(B) Area shift Effect	(C) Productivity Effect	(D) Interactive term
Rice	5.1	10430	0.4	-19.1	18.7	-4.0	-19.1	7.9	9.5	-2.3
Corn	13.2	18001	0.3	-10.9	8.0	-3.8	-10.9	2.6	5.8	-1.3
Wheat	2.2	1839	0.0	-3.6	1.6	-2.1	-3.6	0.1	1.5	-0.1
Sugarcane	6.9	25546	0.1	-5.6	3.7	-2.0	-5.6	0.7	3.2	-0.4
Soybean	30.9	51067	0.6	-16.0	7.3	-9.9	-16.0	-1.0	9.9	-2.8
Other agric	8.7	39786	0.3	-10.8	9.3	-2.6	-10.8	3.6	5.6	-0.9
Cassava	2.6	7692	0.5	-16.9	14.4	-4.9	-16.9	3.4	11.6	-3.0
Tobacco	0.5	7117	0.0	-3.4	2.2	-1.3	-3.4	0.4	1.8	-0.1
Cotton	1.5	9752	0.9	-13.5	10.8	-4.2	-13.5	-6.4	20.5	-4.8
Citrus fruits	1.1	8596	0.2	-5.6	3.3	-2.5	-5.6	-0.2	4.0	-0.6
Coffee	2.4	12585	0.1	-10.6	6.4	-4.9	-10.6	3.1	3.3	-0.7
Forestry	5.0	16854	0.4	-7.9	0.3	-7.6	-7.9	-5.4	7.5	-1.9
Meat cattle	159.8	65200	0.6	-15.2	11.9	-5.1	-15.2	2.0	10.3	-2.2
Milk Cattle	25.1	26634	0.3	-10.0	6.9	-3.7	-10.0	1.4	5.7	-1.0

Source: simulation results

This increase in land productivity (output per hectare) is further analyzed in Table 12. There, columns 1 and 2 show crop areas and output at the end of the base scenario. Column 3 shows what share of output is produced by Frontier regions (where land expansion was prevented). Column 4 shows the percentage difference in crop area at 2025 of the policy (no land-clearing) scenario relative to the base scenario. Similarly Column 6 shows the percentage deviation (policy/base) in output. As observed previously, output falls by much less than does area. Comparing columns 4 and 6 enables us to compute column 5, the induced increase in land productivity. We can understand the source of this productivity increase by splitting the output result of Column 6 into 4 parts A-D:

A = a = the percent change in national area (= column 4). This is the decrease that would occur if land shrunk equally in all regions and if land productivities remained unchanged.

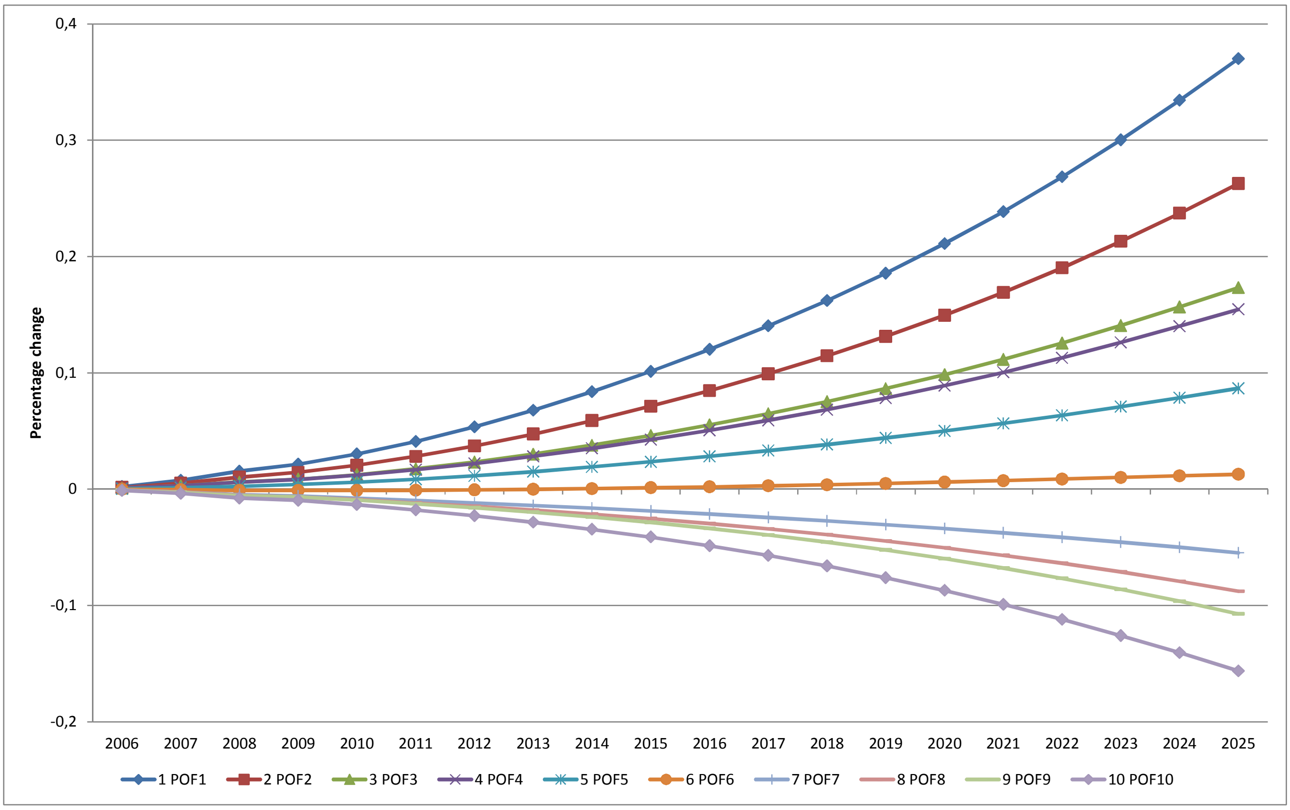
B = $\sum_r W_r[a_r-a]$ where a_r is the % change area in region r, so that $[a_r-a]$ is the % change in a region's share of crop area. W_r is the region share of 2025 base output. This component shows the (generally positive) effect of land areas expanding more where output per hectare is greater (ie, in the long-established non-Frontier regions, where productivity is generally higher). However, for soy and cotton, output per hectare is higher in the Frontier states (where expansion is constrained), leading to negative contributions.

C = $\sum_r W_r p_r$ where p_r is the % change (policy/base) in regional land productivity (output per hectare), arising from limited substitution (σ=0.25) between land, labor, and capital.

D = $\sum_r W_r p_r a_r/100$ is the interactive or second-order term. As areas shrink (negative % change), land rents rise, leading to substitution against land, and an increase in output per hectare. Thus the product term tends to be negative.

Following the increase in agricultural prices, most food prices also rises by around 2%, accumulated in 2025. These results agree with DeFries and Rosenzweig (2010) who found only a minor contribution of deforested lands to food production at global and continental scales. These increases in food prices, however, would have different impacts on different household groups, depending on their expenditure patterns, meaning that the price variation can have different distributional effects. As Figure 8 shows, the group-specific consumer price index increases more for the poorest (POF1 stands for the poorest households, and POF10 for the richest). Our results, then, point to a regressive distributional effect associated with the halt of deforestation in Brazil, what follows from the greater food share in the poorer households' consumption bundles.

Figure 8. Consumer price index variation, by household group. Percentage change, accumulated.



6 Final Remarks

The increase in land supply in regions where it is still available, as is the case of Brazil, is usually regarded as an important element in food price stability. The results found in this paper, however, make a strong case against this assertion. Our simulation shows that the shadow value of deforestation in the context of the recent price increases would be around 0.5% of national GDP, accumulated in year 2025. This point to the fact that deforestation policies cannot be advocated based on economic growth considerations, especially in countries like Brazil where a vast intensive frontier, in the form of pasturelands is still available. The intensification effect (which, in this context should not be regarded as technological change, but just input use reallocation) plays an unexpected role in cushioning the fall in land availability. This effect could be greatly enhanced if agricultural research could speed up the rate of technological change, although this particular aspect has not yet been explored in this paper.

Another important point to be taken into consideration is that, although the aggregated fall in GDP is not high, it´s strongly concentrated on some states, namely those states located on the frontier. This is an important issue for regional development policies, since those states are highly dependent on the land use expansion for growth. Deforestation control policies should be accompanied by compensatory policies for those states, a discussion important to get compliance in policy management and enforcement.

And, finally, our results point also to a regressive income distribution effect associated to the halt of deforestation, which appears mostly from the expenditure side. In the absence of compensatory technological changes, the reduction of deforestation would tend to increase food prices, even though by a small amount. This comes in contrast to the potential environmental benefits associated to the fall in deforestation, a complex policy issue that should be incorporated to our policy agenda.

7 References

Arima, E.Y; Richards, P; Walker, R; Caldas, M.M. 2011. Statistical confirmation of indirect land use change in the Brazilian Amazon. s. Lett. 6 (2011) 024010 (7pp) doi:10.1088/1748-9326/6/2/024010 .

DeFries, R; Rosenzweig, C. 2010. Toward a whole-landscape approach for sustainable land use in the tropics. PNAS. Vol. 107, no. 46. November 16.

Ferreira Filho, J.B.S. 2010. World food prices increases and Brazil: an opportunity for everyone? In: Carlos de Miguel; José Durán de Lima; Paolo Giordano; Julio Guzmán; Andrés Scuchny; Masakazu Watanuki (orgs). Modeling Public Policies in Latin America and the Caribbean. 1 ed. Santiago, Chile: United Nations Publications. V1. P. 231-253.

Ferreira Filho, J.B.S. 2011. The rise in global demand for ethanol and poverty in Brazil. Project Document. CEPAL-AECID Project. 43 p. United Nations Commission to the Latin American and Caribbean – ECLAC.

Ferreira Filho, J.B.S; Horridge, M.J. 2009. The World Increase in Ethanol Demand and Poverty in Brazil. In: Twelfth Annual Conference on Global Trade Analysis, 2009, Santiago. Proceedings of the Twelfth Annual Conference on Global Trade Analysis.

Ferreira Filho; J,B,S; Horridge, J,M, 2010. Climate Change Impacts on Agriculture and Internal Migrations in Brazil. In: Thirteenth Annual Conference on Global Economic Analysis, 2010, Penang, Malasia.

Ferreira Filho, J.B.S; Horridge, M. 2011. Ethanol expansion and the indirect land use change in Brazil. In: 14th Annual Conference on Global Economic Analysis. Veneza. Proceedings of the 14th Conference on Global Economic Analysis.

Horridge, J.M., Madden, J.R. and G. Wittwer (2005), “The impact of the 2002-03 drought on Australia”, *Journal of Policy Modeling*, Vol 27/3, pp. 285-308.

Macedo, M. N; DeFriesa, R.S; Mortonb, D.C; Sticklerc, C.M; Galfordd, G.L; Shimabukuroe, Y.E. 2012. Decoupling of deforestation and soy production in the southern Amazon during the late 2000s. PNAS January 24, 2012 vol. 109 no. 4 1341-1346.

Morton, D.C; DeFries, R.S; Shimabukuro,Y.E; Anderson, L.O; Arai,E; Espirito-Santo,F.B; Freitas,R; Morisette,J. 2006. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. PNAS, September 26, 2006. vol. 103, no. 39. 14637–14641.