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ENDOGENOUS LAND USE AND SUPPLY, AND FOOD SECURITY IN BRAZIL

by

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Abstract

Agriculture area and production has expanded greatly in Brazil during the last 40 years. The area of annual crops almost doubled, while the area planted for pastures and forestry tripled. However, the rate of deforestation has considerably reduced since 2004. In this paper we analyze the effect of slower forest clearing on food supply and the economy in Brazil, in the presence of increasing world food prices. A multi-period computable general equilibrium model, based on previous work of the authors, is used to analyze the importance of endogenous land supply for agriculture in Brazil. The model 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 36 sectors, 10 household types, 10 labor grades, and a land use change (LUC) module which tracks land use in each state. The core database is based on the 2005 Brazilian Input-Output model. The LUC model is based on a transition matrix calibrated with data from the 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, for the period 2005-2025. Results show that a halt in deforestation would decrease Brazilian GDP by about 0.5% in 2025, compared to a baseline which allows deforestation to continue. But there are redistributive effects that policies may need to counteract: regional GDPs would decrease by as much as 6% for states on the agricultural frontier, and food prices rise by around 2%, slightly raising the cost of living for poorer households.

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ENDOGENOUS LAND USE AND SUPPLY, AND FOOD SECURITY IN BRAZIL

1 Introduction

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

Recent food price increases have benefited commodity-exporting countries such as Brazil. It has enjoyed GDP growth rates as high as 7%, well above the observed world averages over 2000-2005. 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. 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. This 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 to what extent a freezing of the agricultural frontier may affect domestic food prices, agriculture-based exports, and other economic variables.

2 The agricultural expansion in Brazil

Planted area accelerated in the early seventies, with technological developments that allowed the exploitation of the vast cerrado (savanna) areas in central Brazil. The total planted area grew from 65.4 Mha (million hectares) in 1970 to 165.8 Mha in 2006 (Brazilian Agricultural Censuses 1970 and 2006), as shown in Table 1.

Table 1. Land use variation in Brazil, 1970-2006, Mha (million hectares).

	1970	1975	1980	1985	1995	2006
Perennial crops	8.0	8.4	10.5	9.9	7.5	11.6
Annual crops	26.0	31.6	38.6	42.2	34.3	48.2
Planted pastures	29.7	39.7	60.6	74.1	99.7	101.4
Planted forests	1.7	2.9	5.0	6.0	5.4	4.5
Total planted	65.4	82.6	114.7	132.2	146.8	165.8
Natural pastures	124.4	126	113.9	105.1	78.1	57.3

Source: Brazilian Agricultural Censuses, various years.

The area of annual crops almost doubled in the period, and the area of planted pastures tripled — at the expense of natural vegetation. But while new pasture mostly arises from forest clearing, most new cropland was previously pasture. Hence pastures, which represent most of the total area under production, are a traditionally important reservoir of potential new cropland.

As seen in Figure 1, the rate of deforestation has reduced considerably: from 27,772 km^2 in 2004 to 6,541 km^2 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, Pará, Amapá, Tocantins, Maranhão and Mato Grosso. But the agricultural frontier is mainly located in Mato Grosso, Rondonia and Pará, the states on the so-called "Arch of deforestation[3]".

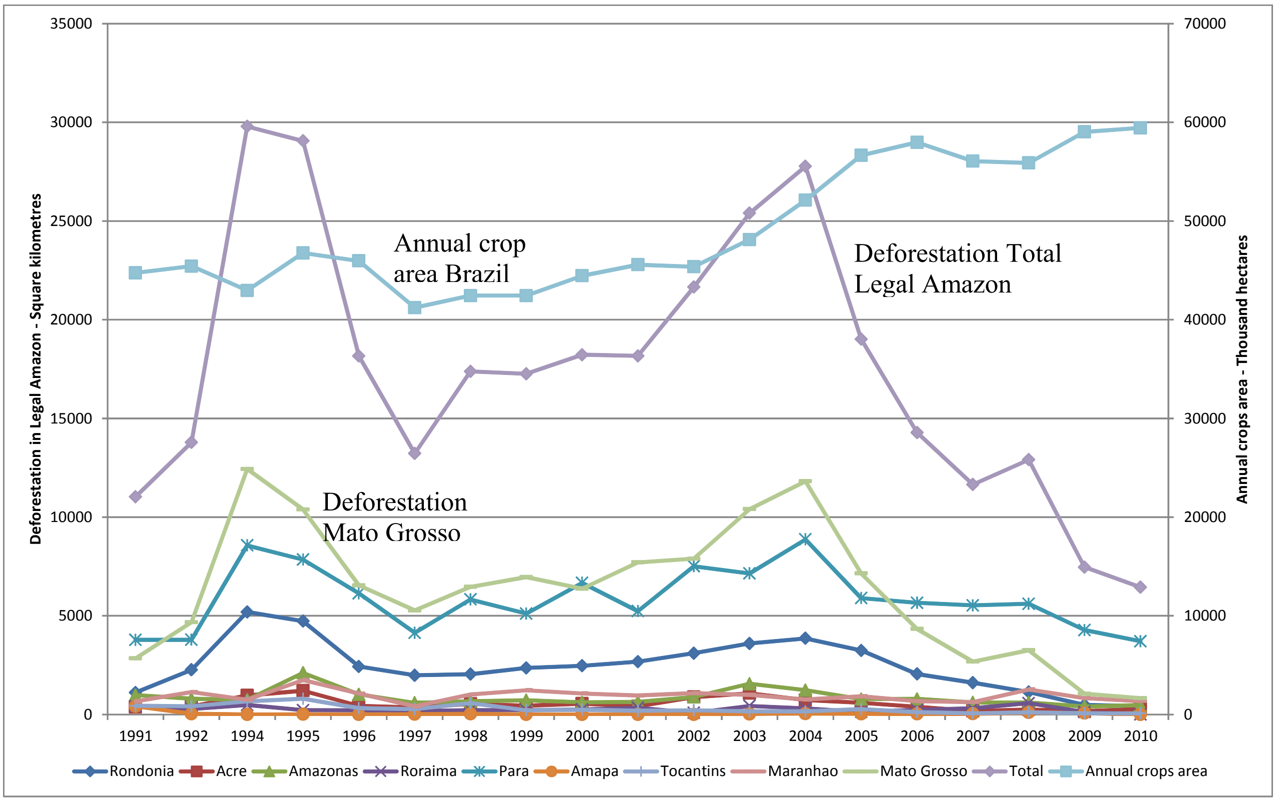


Figure 1. Deforestation in Legal Amazon and annual crops area (total) in Brazil, 1991-2010.

Source: PRODES (INPE) and Pesquisa Agrícola Municipal (IBGE). 1 km^2 = 100 ha.

Macedo et al (2012) relate the observed fall in deforestation to fluctuations in commodity prices, as well as to the implementation of several measures introduced by the Brazilian government for monitoring and enforcing deforestation controls. 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. The same authors observe that after 2005 soy production kept increasing, despite the fall in deforestation. However this trend is not restricted to soybean production — other crop areas have also increased. The crop area increases point to substitution of land from livestock to crop sectors. This is a well-known stylized fact of 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; Barona et al, 2010). Ferreira Filho and Horridge (2011) have used this important "prior" in their analysis of ethanol expansion in Brazil.

[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", this is indicated on Figure 3.

This increase in agriculture production causes food prices in Brazil to be fairly stable. Even the recent increase in world food prices did not reflect strongly on local food prices. 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.

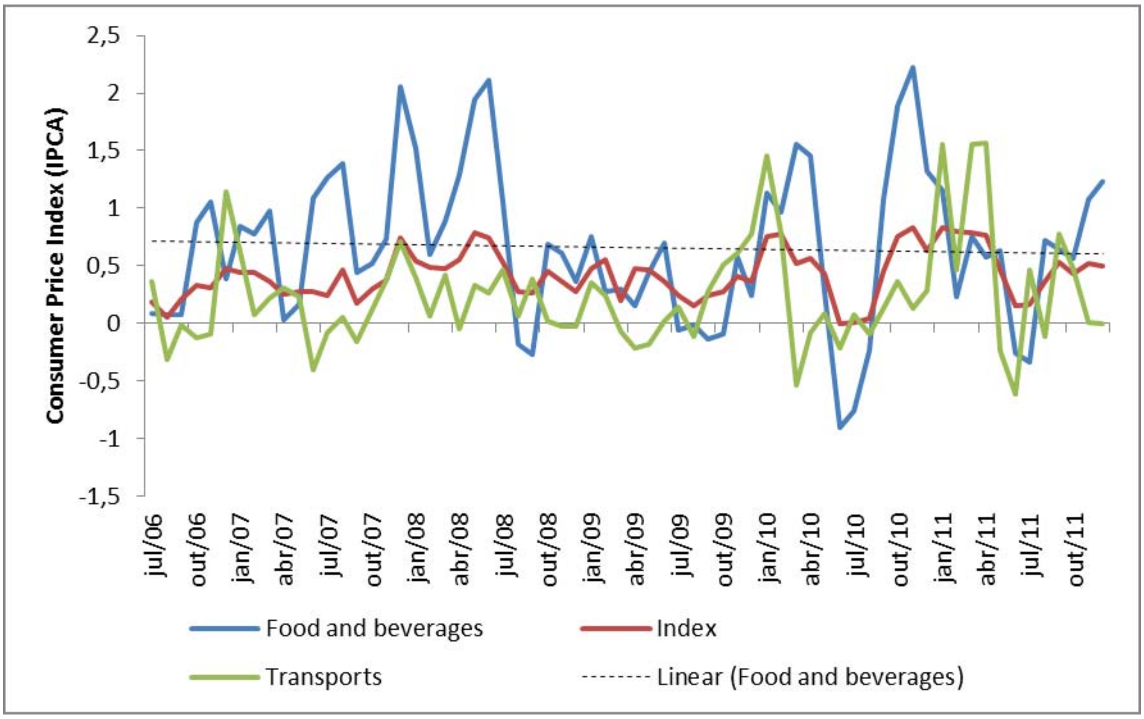


Figure 2. Evolution of the Extended Consumer Price Index (IPCA), 2006 – 2011.

Source: IBGE.

Part of the reason for this relative stability of food prices is that, within the household 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 household food bundle. Ferreira Filho and Vian (2011) showed that the Brazilian exchange rate appreciation in the period also helped to stabilize local prices while external prices rose. But the increase in agriculture acreage certainly also contributes to that stabilization effect, since the food production system had to adapt to the competition for land generated by rising agricultural export demand. 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, who tried in different ways to evaluate the indirect land use change (ILUC) caused by various 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:

- Real wage changes drive the movement of labor between regions and activities (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 divide 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.

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

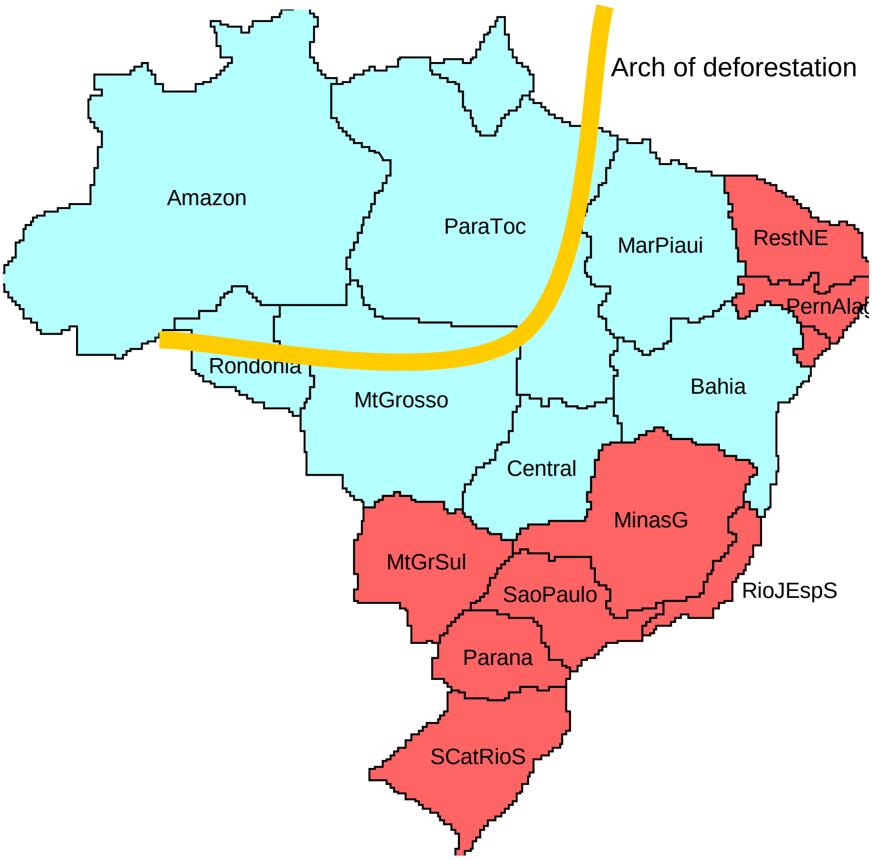


Figure 3. Frontier (blue) and Land-constrained (red) regions of the model

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 Estatística (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, natural or planted 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. However the latter areas are expected to change much less than the natural forests, so the change in "Unused" is used here as a proxy for deforestation, or land clearing for agricultural use. Note that the share of Unused in the total area of land-constrained states averages around 50% — an approximate lower bound for this share.

Table 2. Initial data: land use by region, Mha (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 [the top-left cell in this and other tables names the model variable that is reported].

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.

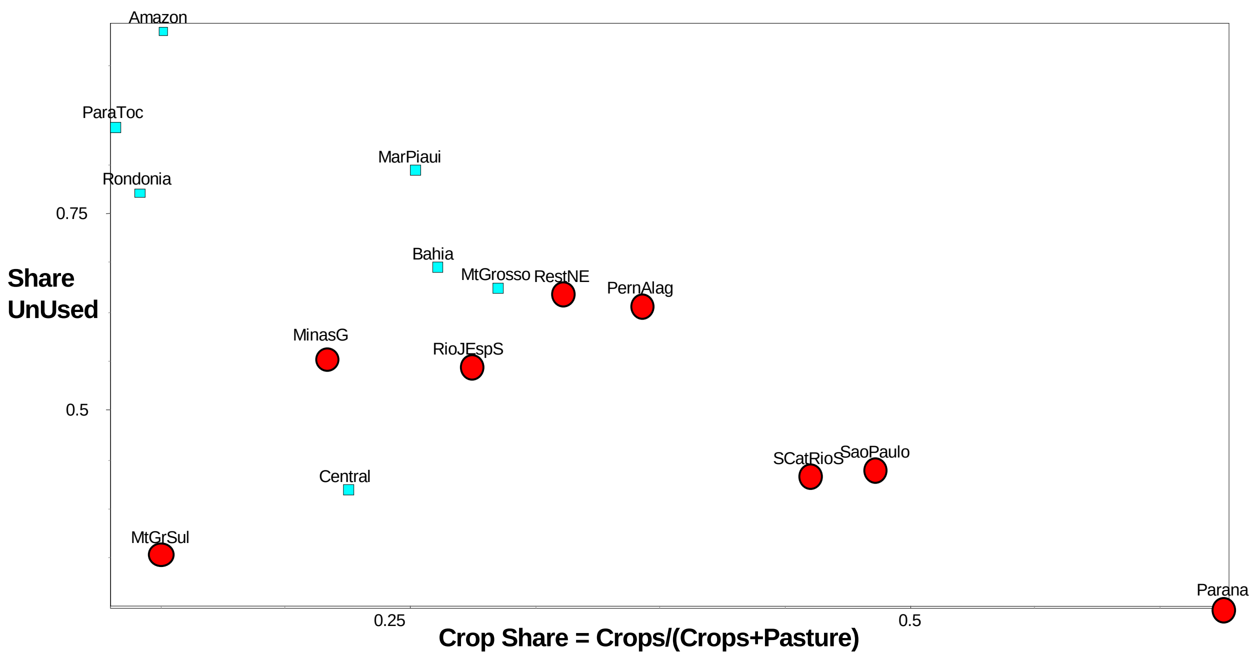


Figure 4. Emptier regions (blue) prefer Pasture; full regions (red) prefer Crops

Notice also the potential for expansion in the intensive margin in states like São Paulo and Santa Catarina (with Rio Grande do Sul), states where the stock of unused land for conversion has run out long ago. Paraná, on the other hand, has the smallest share of crops in (crops plus pasture) area, suggesting that for this state the possibilities of agricultural expansion on the intensive margin are 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)

Agricultural per-hectare productivity varies between regions, as shown in Table 3. This suggests that redistribution of the agricultural output mix towards more productive regions offers another route to increase output without increasing farmed area. This effect turns out to be important (see the discussion of Table 12 below).

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 totals 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:

$$S_{pqr} = \mu_{pr} . L_{pqr} . P^{\alpha}_{qr} . M_{qr} \qquad = \text{(alternatively)} \quad L_{pqr} . P^{\alpha}_{qr} . M_{qr} / \sum_{k} L_{pkr} . P^{\alpha}_{kr} . M_{kr}$$

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

[5] The Brazilian Agricultural Census of 1996 refers to the period between August 1, 1995 and July 31, 1996. The 2006 Agricultural Census has a 2006 reference year (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).

A CET (of 0.5[6]) mechanism allocates Crop land between the 11 crop types distinguished by the model.

In summary, the model allows for (say) Soybean output in a region 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 [CET];
- 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. We chose to highlight the role played by the expansion of the agricultural frontier. 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.

[6] Keeney and Hertel (2008) use the same 0.5 number, which they attribute to the FAPRI model.

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

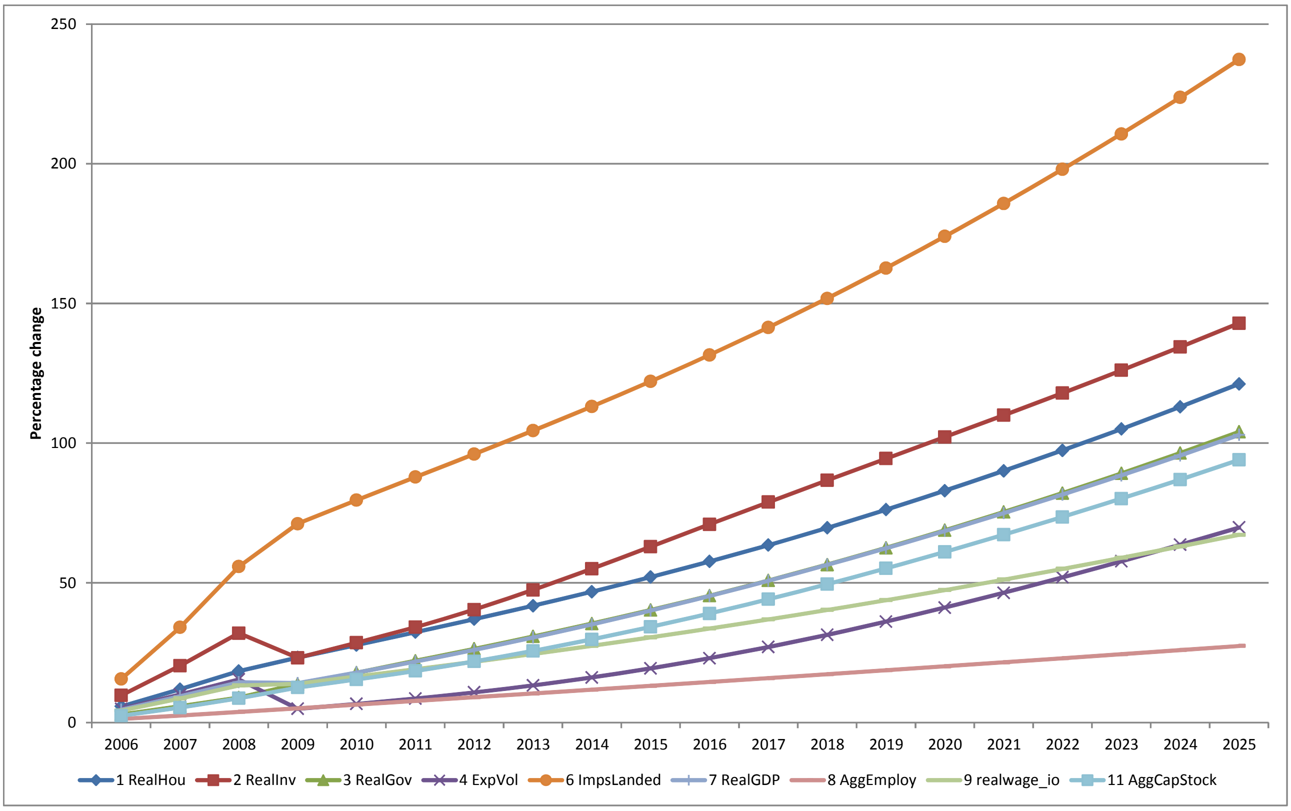


Figure 5. Macro variables, baseline. Percentage change, accumulated.

The results for agricultural output expansion implied by our baseline scenario can be seen in Table 6, while Table 7 shows the corresponding land use variation. We see that the growth scenario projected to 2025 would imply a strong increase in agricultural production in most Brazilian regions, and in land use in the frontier regions. The latter of course is due to our assumption that agricultural area expansion is only possible in frontier states. Table 7 shows that the total new land required, or deforestation, would amount to 37 Mha.

Although our scenario ends in 2025, we might ask, how long could deforestation continue before land supplies ran out? Noting from Table 2 that in 2005 Amazonas had 205.6 Mha of Unused land, of which 2.58 Mha is converted to farms by 2025, we see that there the limit is far off! Similarly ParaToc lost but 8.9 Mha of its 131 Mha. On the other hand, other more developed 'frontier' regions are starting to fill up: for example the unused share of total land in MtGrosso falls from 66% to 48% (compare: SaoPaulo=43%, MinasG=59%). Hence, if the base scenario was extended past 2025, we would see the "arch of deforestation" of Figure 3 moving north-west towards Amazonas.

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

	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, Mha.

	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

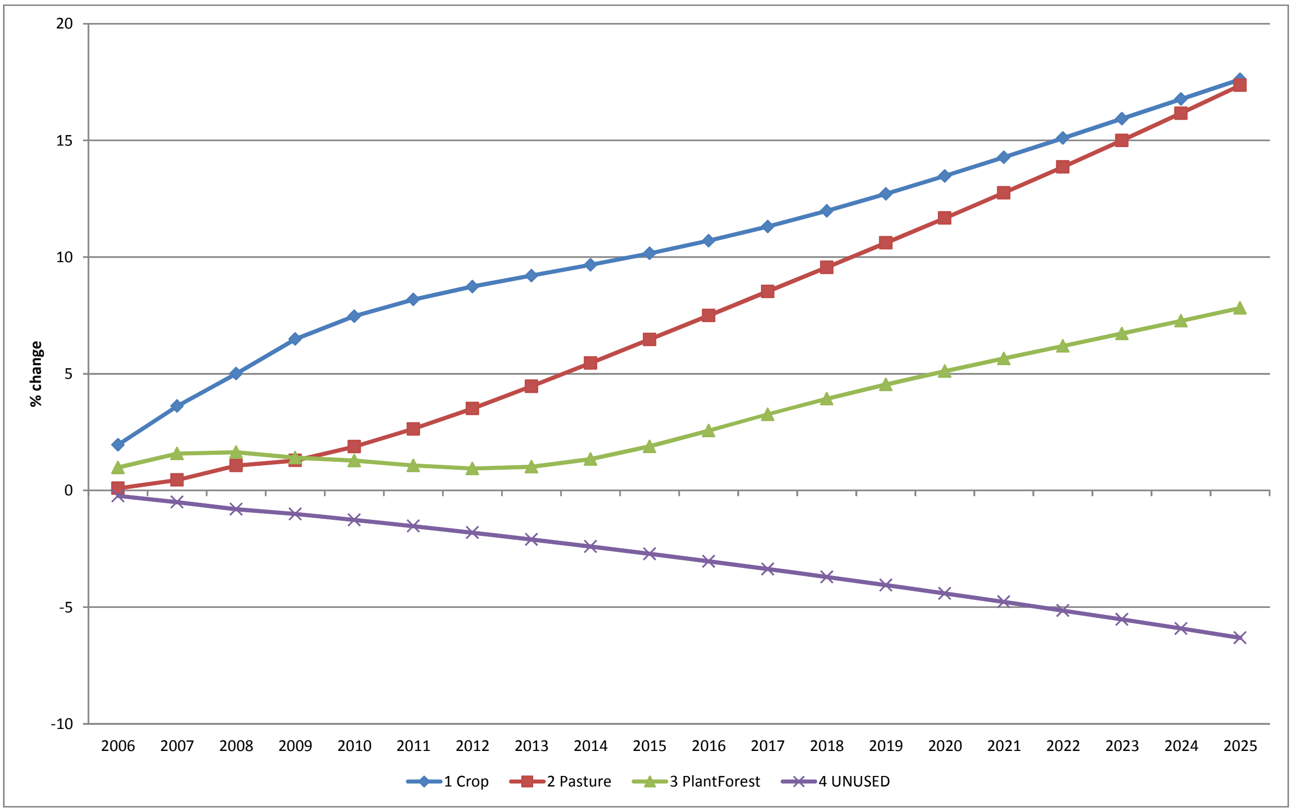


Figure 6. Model results. Broad land use type variation in the baseline. Percentage change, cumulative.

Figure 6 shows how broad land use grows in the baseline. The lines show the accumulated percentage change in the amount of each broad type of land use, namely crops, pastures, planted forests and unused (mainly natural forests) in the business-as-usual scenario. The stock of unused land (deforestation) shrinks, to a cumulated 6.3% fall by 2025. The counterpart of this fall in unused land area is an increase of 17.6% in total area under crops, a 17.4% increase in pasture area, and a 7.8% increase in planted forests. Together these amount by 2025 to an extra 37.0 Mha of land incorporated to production in 2025, with 12.3 Mha going to crops, 24.5 Mha for pastures, and 0.3 Mha for planted forests (see Table 7).

5 Results: effects of restricting deforestation

As explained before, the policy simulation imposes a no-deforestation scenario, under the same set of hypothesis used in the baseline. Results, then, show the impact on the economy caused by the halt of deforestation, or the "shadow value of deforestation" for the economy. Needless to say, this concept involves no environmental valuation, but only economic effects. The decrease in land supply shrinks back the production possibility frontier of the economy, decreasing the stock of a primary resource. Since the decrease is not uniform across regions, it also generates a change in the location and composition of production, both in the frontier regions where deforestation is halted and also in the other regions, through the change in market conditions. The results of the simulation are presented below.

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

The policy scenario would have macroeconomic impacts, some of which can be seen in Figure 7. The halt to 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%. The 0.5% fall in national GDP can be regarded as the "shadow value of deforestation" in the context of our baseline and policy assumptions, and is a small[7] sacrifice to avoid environmental damage or risks associated with continued deforestation.

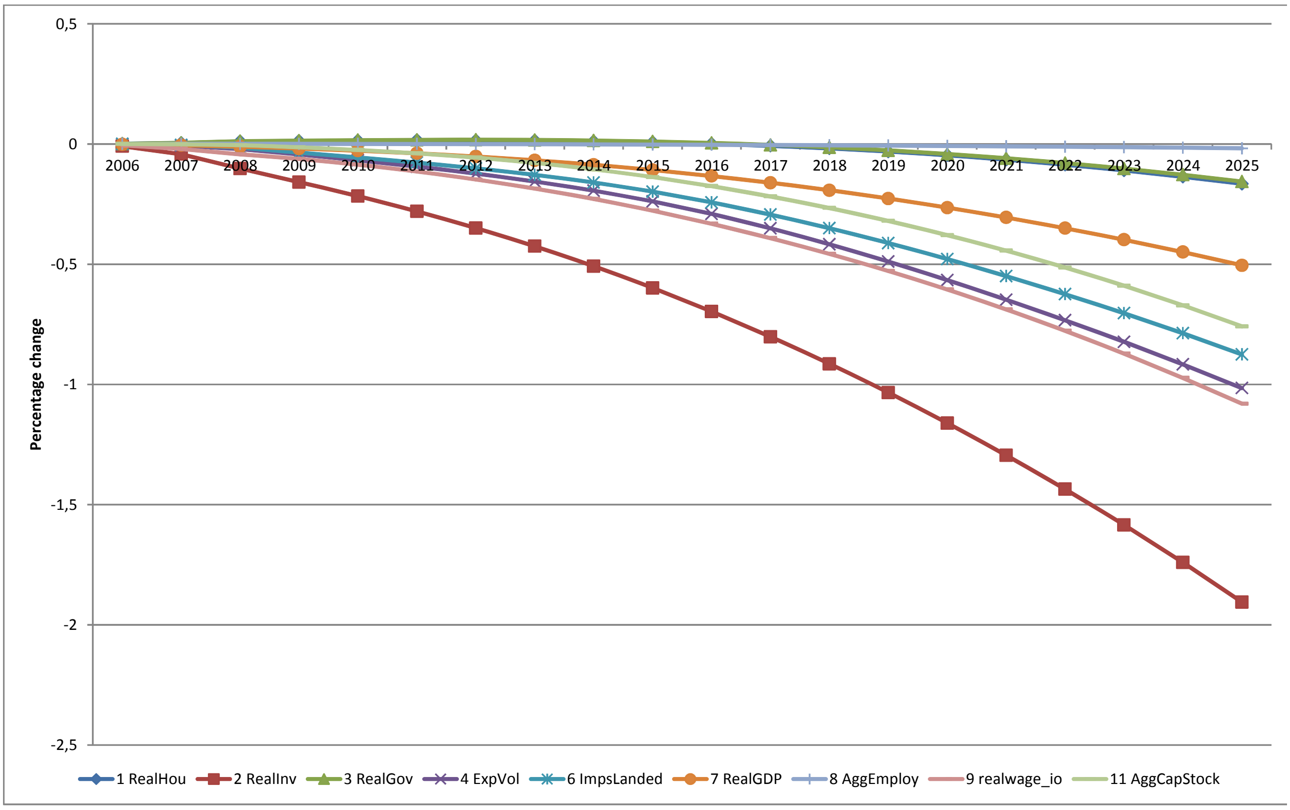


Figure 7. Macro variables, deviation from the baseline. Percentage change, accumulated.

Naturally there are important differences between regions. Regional real GDP in the agricultural frontier states would decrease, by as much as 6.1% in Mato Grosso and 5.5 % in Rondonia, two states in the arch of deforestation, highlighting the greater dependence of those states on land expansion through deforestation.

Table 9 and Table 10 report more detailed regional results for agricultural production and land use. They are summarized in Table 11, which shows that soybeans and livestock, activities usually associated with the frontier, would strongly decrease in both output and area. Cassava and cotton, both important crops in the cerrados area, also decline. 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.

[7] Recall from Table 5 that real GDP doubled during the 20-year base scenario, so that the 0.5% cumulative difference represents only 2 or 3 months of income growth.

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	RioJEspS	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, Mha.

	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	-0.1	-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

Table 11 shows that nationally the decrease in land use is generally greater than the decrease in production. This is partly due to productivity differences in the frontier, which is normally lower than that of the traditional agricultural regions (see Table 3).

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.

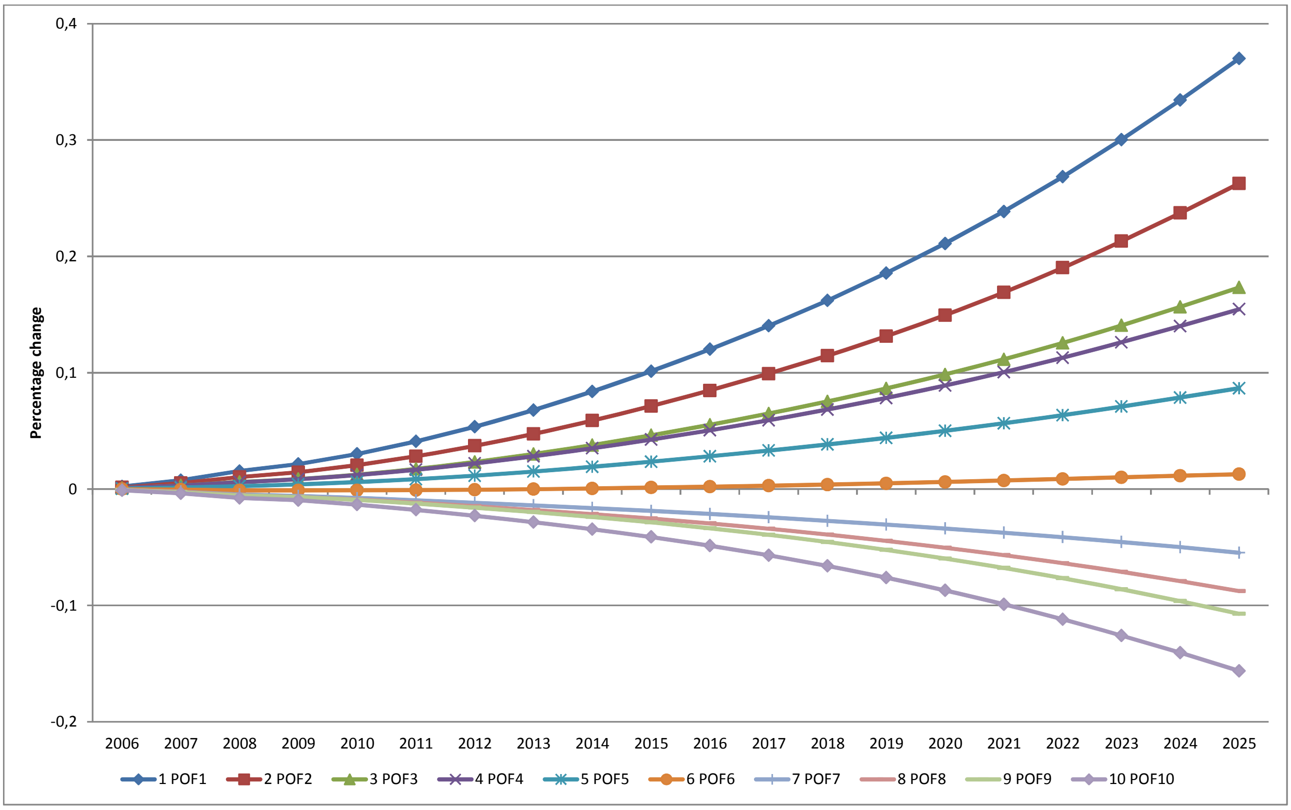
C = $\sum_r W_r p_r$ where p_r is the % change (policy/base) in regional land productivity (output per hectare), arising from limited substitution (σ=0.25) between land, labor, and capital.

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 rise[8] 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. But these food price rises impact differently on different household groups, depending on their expenditure patterns, causing 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, because of the greater food share in the poorer households' consumption bundles.

[8] CPI changes should be interpreted as relative to the GDP price index which is used as numeraire.

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, such as Brazil, is usually regarded as an important element in food price stability and economic growth. Our results argue against this assertion. Our simulation shows that the shadow value of deforestation in the context of world agricultural price increases would be around 0.5% of national GDP, accumulated in year 2025. Thus deforestation is not necessary for economic growth, especially in countries like Brazil where a vast intensive frontier, in the form of pasture-lands, is still available. The intensification effect (which, in this context should not be regarded as technological change, but as input use reallocation) plays an unexpected role in cushioning the fall in land availability. This effect could be greatly enhanced if agricultural research sped up the rate of technological change, a possibility not explored in this paper.

Although the national fall in GDP is not high, it is strongly concentrated in frontier states. This is an important issue for regional development policies, since those states are highly dependent on land use expansion for growth. Deforestation control policies may require compensatory policies for those states, in order to encourage compliance in policy management and enforcement.

Our results point also to a regressive distributive effect associated with the halt of deforestation, appearing mostly from the expenditure side. In the absence of offsetting technological changes, the reduction of deforestation would tend to slightly increase Brazilian food prices, harming poor more than rich.

However, against a backdrop of rising living standards, the negative economic effects of halting deforestation (less GDP, higher food prices) seem small, especially when compared to the potential environmental benefits associated with preserving forests.

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