DEFORESTATION CONTROL AND AGRICULTURAL SUPPLY IN BRAZIL

JOAQUIM BENTO DE SOUZA FERREIRA FILHO, LUIS RIBERA, AND MARK HORRIDGE

Brazil has dramatically increased its agricultural area under cultivation, in the process becoming a major food exporter at the cost of natural forests. A new challenge is to meet the food demands of an expanding world population in the face of pessimistic climate change scenarios and the increasing scarcity of land. Can Brazil help meet rising world food demand while conserving its tropical rainforests? To address this question we simulate outcomes using a large dynamic multiregional computable general equilibrium model of Brazil to model land use over 20 years in 90 zones and 14 agricultural sectors. The model features a land-use change module based on a transition matrix obtained from satellite imagery. We analyze two scenarios of deforestation reduction, both linked to actual policy proposals. Model results indicate several mechanisms that allow food output to increase without expanding land supply. In particular, we stress the role of Brazil's vast, low-yield pasture area as a source of future cropland. Thus, we find that controlling deforestation leads to rather small decreases in food output—which could be neutralized by tiny exogenous productivity improvements. We conclude that the decrease in deforestation will not significantly compromise Brazilian agricultural supply capacity in the foreseeable future.

Key words: Deforestation, land-use change, agricultural supply, Brazil, CGE model.

JEL codes: Q230, Q240, Q280.

World food demand is projected to rise, driven by increases in population and income per capita. Although population growth is slowing, and richer people spend relatively less on food, the pressure on agriculture will stay high. Still, the world's population is forecast to increase by 2 billion in the next four decades, which will require global agricultural production to increase by 60% from its 2005–2007 level (United Nations 2013). The same study shows that the expansion of agriculture in the past fifty years demanded 67 million ha (Mha) of extra arable land, the result of a 107 Mha increase in the developing world and a 40 Mha decrease in developed countries. A study by the United Nations (2002) suggests that "in the coming 30 years developing countries will need an extra 120 Mha for crops, an overall increase of 12.5 percent", and that "more than half the land that could be opened up is in just seven countries of tropical Latin America and sub-Saharan Africa". Brazil is a prominent member of this group.

As table 1 shows, Brazil is an important global supplier of several agricultural commodities, especially oil crops (mainly soybeans), sugar, cotton, and meats.

Brazil is also one of the few countries that still has a vast stock of natural forests suitable for conversion to agricultural land. However, forest clearing threatens biological diversity and emits large amounts of CO_2. Consequently, the government is trying to control deforestation. Will controls limit future growth in agricultural output and exports? This article addresses that question, via counterfactual simulations performed with a computable general equilibrium (CGE) model of Brazil designed to analyze land-use change.

Although deforestation has recently attracted much attention in the economic literature, few quantitative studies focus on its role in the future of Brazilian agricultural supply.

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Table 1. Brazil's Share in World Production and Exports: Selected Commodities, 2010

Commodity	Share in world production (%)	Share in world exports (%)
Cereals	3.0	3.7
Oil crops	8.0	21.3
Sugar	23.0[a]	38.5
Cotton	4.7	7.8
Beef	13.5	14.2[a]
Pork	2.9	19.6[a]
Poultry	11.3	11.6[a]

Source: FAO (2013), except where marked (a), which indicates the OECD-FAO Agricultural Outlook (2010).

We know of only two studies that do so, both of which use CGE models to simulate the economic effects of reductions in forest clearing, Cabral and Gurgel (2014) and Ferreira Filho and Horridge (2012).

This article contributes to the literature on the importance of deforestation for food supply in two main ways. First, the transition matrix concept used by Ferreira Filho and Horridge (2012) with partially synthetic data is now supported by more comprehensive data from satellite imagery—the first time (to our knowledge) that this data has been so used.

Second, Ferreira Filho and Horridge (2012) assumed that Amazon deforestation rates would be driven by market forces: rising food demand would force up land rents, thereby causing deforestation to accelerate. For this article we have constructed a deforestation baseline consistent with recently observed deforestation rates, allowing us to project a more plausible path for the future. We compare that baseline path with alternative, reduced-deforestation scenarios. As observed by Hertel, Ramankutty, and Baldos (2014), this circumvents a common difficulty of statistical studies, namely the effects on agricultural supply of counterfactual scenarios.

This article is organized as follows. First we discuss recent trends in Brazilian agriculture and their relation to deforestation. Then the CGE methodology is presented, and the transition matrix concept discussed. The model baseline and alternate scenarios come next, followed by a results section. The next section measures the robustness of results with respect to a key parameter value. Finally, we present our conclusions and directions for future research.

Agricultural Expansion and Land-use Changes in Brazil: Recent Trends

The total area of annual crops in Brazil has expanded steadily in the last 20 years (see figure 1). Most of this expansion can be attributed to five main crops: cotton, rice, sugarcane, corn, and soybean, which together accounted for about 85% of Brazil's annual crop area in 2012. Soybean, corn, and sugarcane areas have increased fastest. From 2000 to 2012 the area under crops increased by 18.5 Mha, while the forested area in the Amazon region decreased by 19.5 Mha.

Figure 1 also shows that the rate of deforestation in the Brazilian Legal Amazon[1] fell markedly since 2004. According to Assunção et al. (2012), two government policies have mainly contributed to reductions in forest clearing. The first, instituted in 2004, was the Action Plan for Deforestation Prevention and Control in the Legal Amazon (Plano de Ação para a Prevenção e Controle do Desmatamento na Amazônia Legal – PPCDAm), which coordinates environmental monitoring and land management tasks performed by several government agencies. The second, from 2008, was credit-linked: that is, rural credit became conditional on compliance with local environmental regulations.

Will recent success in controlling Brazilian deforestation prevent further increases in agricultural output? The key to this question is the role of pasture in agricultural expansion in Brazil. The evolution of pasture area is not included in figure 1 since there is no available time series. The Brazilian Agricultural Censuses of 1995 and 2006, however, show that total pasture area decreased from 177.7 Mha in 1995 to 151.8 Mha in 2006. Cropland can expand at the expense of this vast pasture area (the intensive margin), much of which has low yields.

In Brazil most new cropland was previously pasture, and most new pasture comes from forest clearing. This sequence implies that cropland expansion is related to deforestation through pasture expansion, which is an indirect land-use change (ILUC) effect. However, this process is empirically difficult

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[1] The Legal Amazon is an administrative region in Brazil that includes the states of Rondônia, Acre, Amazonas, Roraima, Pará, Amapá, Tocantins, Mato Grosso, and the western part of Maranhão. This region covers about 61% of Brazil's area, and contains about 12% of the population. The agricultural frontier is mainly located in Mato Grosso, Rondônia, and Pará, which are the states located on the so-called Arc of deforestation.

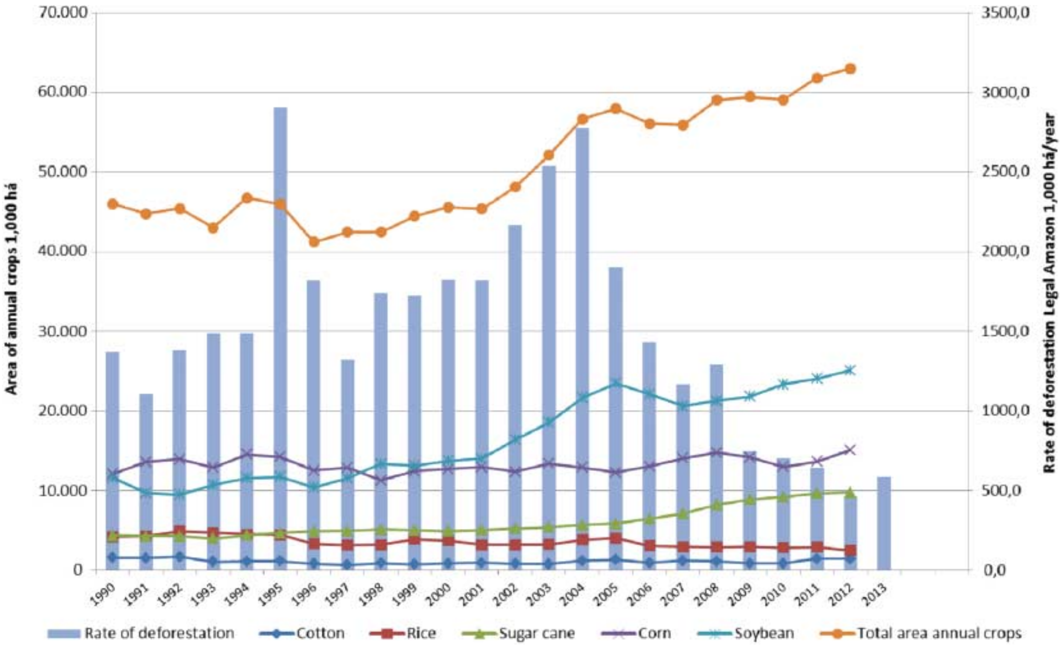

Figure 1. Crop area (1,000 ha) and rate of deforestation (1,000 ha/year), 1990–2012

Sources: Crop area from IBGE Produção Agrícola Municipal online database, available at: www.ibge.gov.br/home/estatistica/economia/pam/2012/. Deforestation from PRODES (cited in footnote 7).

to measure, and has recently been debated intensely (Nassar et al. 2010; Ferez 2010; Sá, Palmer, and Falco 2013; Lapola et al. 2010; Barona, Ramankutty, and Coomes 2010; Arima, Walker, and Caldas 2011; Macedo et al. 2012; Taheripour et al. 2010; Ferreira Filho and Horridge 2014).

The ILUC effect is captured by a simulation model, described below, which incorporates detailed satellite data on land-use changes. The model is used to estimate the effect that a halt in Brazilian deforestation would have on agricultural outputs and other economic variables.

Methodology

Our analysis uses TERM-BR, a CGE model of Brazil tailored for land-use analysis, and built on previous work by Ferreira Filho and Horridge (2012; 2014). The basic model structure is described elsewhere[2] (Horridge et al. 2005); we provide here a brief summary.

TERM-BR may be thought of as a collection of CGE models (one for each region), linked by trade and labor movements between regions. Each regional CGE model is fairly conventional: industries and final demanders follow cost-minimizing behavior to choose an input mix of commodities and (for industries only) primary factors. The industries have constant-returns-to-scale technology and price at marginal cost. In principle, the model distinguishes between activities (industries) and commodities: an industry can produce a range of commodities, but in simulations reported below each industry produces one commodity only. The core of each regional database is a USE matrix with dimensions COM*SRC*USER where COM is the set of commodities, SRC has two elements, domestic (Brazilian) and imported (from outside Brazil), and USER is the set of industries plus household, government, investment, and export final demanders.

Trade between regions is represented by a matrix of commodity flows, valued at basic prices, of size COM*SRC*REG*REG, where COM and SRC are defined as above, and the two REG subscripts denote source and destination regions. For Brazilian goods, the source region is where the commodities are produced; for imports, the source region is the port of entry.

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[2] Links to various papers and resources can be found at: www.copsmodels.com/term.htm.

Partner matrices of similar dimensions show commodity tax revenue levied on each flow, and also the value of margin services (transport, retail) needed to deliver each good from producer to user. Other satellite matrices allow expenditure shares to vary between household type (usually arranged by income) and according to the destination industry of investment, since the composition of the investment good varies across industries.

Guided by prices, each industry in each region chooses inputs to minimize unit production costs subject to a production function of the general form:

$$\text{(1)} \qquad \mathrm{Output} = \mathrm{A_0 F(A_1 X_1, A_2 X_2, \ldots, A_n X_n)}$$

where the $\mathrm{X_1}$ to $\mathrm{X_n}$ represent quantities of the various inputs to production (primary factors and commodities), and the A variables are exogenous technological coefficients that can be shocked to simulate technical progress. For example, an increase in $\mathrm{A_0}$ corresponds to an all-input-enhancing or neutral productivity improvement. Our base scenario includes changes over time in various A variables, representing expected technical progress. The same A shocks are used in our alternate scenarios, so that differences in yield (or output per hectare) between alternate and base scenarios are not due to different assumptions about technological change.[3] Instead, yields can increase by increasing the proportion of other inputs, or, in the case of national average yields, by relocating production to regions where yields are higher.

Figure 2 illustrates the production technology for a representative industry, for example, Soybean in Mato Grosso. A series of "nesting" assumptions, shown as lozenge shapes, constrain and simplify input substitution. At the top level, inputs of a goods composite and a primary factor composite are demanded in proportion to output (Leontief assumption). The goods composite is a constant elasticity of substitution (CES) combination of C individual commodities—although the elasticity of substitution is quite low. Each commodity is itself a CES combination of Brazilian and imported varieties (the so-called Armington assumption). Finally, at bottom left of figure 2, each region's total demand for, say, Brazilian fertilizer, is supplied by a CES combination of fertilizer from different regions.

Again, the primary factor composite used by each industry is a CES combination of industry-specific capital, labor and land, with labor itself being a CES combination of several different labor types.

Although all sectors in all regions share this input structure, substitution elasticities and input proportions differ across sectors and regions (figure 2 shows representative elasticity values). Similar nesting assumptions (without the primary factor part) govern final demands, except that household demands for goods follow the linear expenditure system.

The bottom right quadrant of figure 2 depicts the supply of land to Mato Grosso Soybean growers. We describe this further below.

The TERM-BR database is mainly based on the 2005 Brazilian National Input-Output tables, along with other regional data sources. The database separately represents 108 sectors and the 27 Brazilian states, as well as 10 household types and 10 labor grades. For the simulations reported below we sped up computations by aggregating the database to 38 sectors and 15 regions.

TERM-BR is a multi-period model with recursive-dynamic mechanisms inherited from the MONASH CGE model (Dixon and Rimmer 2002). These mechanisms are: (*i*) a stock-flow relation between investment and capital stock, which assumes a one year gestation lag; (*ii*) a positive relation between investment and the rate of profit; and (*iii*) a relation between wage growth and regional employment—implying that unemployment rates vary, at least in the short run. The model is solved using GEMPACK (Horridge et al. 2012).

We turn now to TERM-BR's land-use change (LUC) module, which tracks land use in each state. The LUC module is based on data from satellite imagery of Brazilian land-use changes between 1994 and 2002.[4] We

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[3] Exceptions are the additional TFP shocks used for Scenarios 1a and 2a, reported in columns 4 and 7 of table 5.

[4] The transition matrices used previously in Ferreira Filho and Horridge (2012 and 2014) were for the 1996–2005 period, and were not based on satellite imagery observations. Rather, they were based on agricultural census data which corresponded to the "Total" rows and columns shown in table 2. The interior (or transition) parts of the matrices were made up following rules of thumb (but added to the known row and column totals). The new satellite data include the complete transition matrices, and adds a biome dimension that is lacking in the agricultural census data.

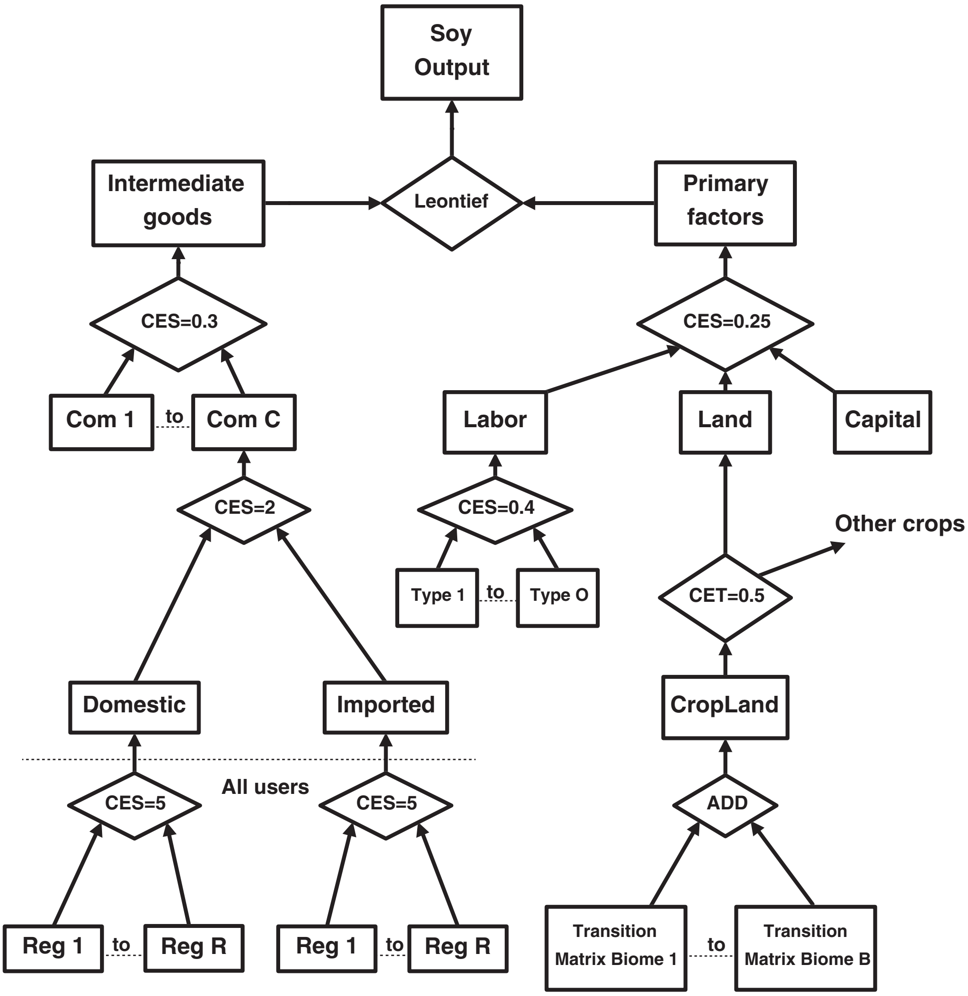

Figure 2. Production nesting structure, with typical elasticities

processed this data to distinguish land areas used for three broad types of agriculture—Crop, Pasture, and Plantation Forestry—as well as one residual type we call "Unused", which is mainly natural forest.[5] We distinguished regional land use by state, and within each state by 6 soil/vegetation zones called "biomes". For example, the data shows how many hectares of the Cerrado biome in Mato Grosso was Unused in 1994, and also how much of that 1994 Unused area was used in 2002 for say, Crops, or was still Unused. Thus, the data comprises, for each of 6 biome zones within each state, a full *transition matrix* between the 4 broad land uses.[6]

The observed values for the transitions for two selected states (i.e., aggregated over biomes) in the Brazilian agricultural frontier (Amazonas and Mato Grosso), and the national total can be seen in table 2.

The final, row-total column in each subtable of table 2 shows initial land use (1994),

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[5] Areas used for cities and roads are also included in the Unused category, but they account for only a small fraction of the Unused area in states where most deforestation is occurring.

[6] Land cannot move between states or biomes. Hence, the biome dimension adds some useful extra regional detail. However, the biome dimension is included for another purpose, not explored here. Parallel to the transition matrices showing areas of land that changed use is another series of matrices which show the emissions of CO_2 and other greenhouse gases associated with each land use change. Clearing a hectare of Amazonia (rainforest) biome releases far more CO_2 than clearing a hectare of Cerrado (savanna) biome. We intend in future to relate deforestation to emissions, for which the biome distinction will be important.

Table 2. Transition Matrices between Different Land Uses, 1994–2002, Million Hectares

TRANS	Crop	Pasture	PlantForest	Unused	Total 1994
Amazonas					
Crop	0.08	0	0	0	0.08
Pasture	0	3.68	0	0.07	3.74
PlantForest	0	0	0	0	0
Unused	0.04	0.67	0	151.19	151.89
Total 2002	0.12	4.35	0	151.26	155.72
Mato Grosso					
Crop	7.95	1.61	0	0.04	9.60
Pasture	1.30	18.28	0	0.27	19.84
PlantForest	0	0	0	0	0.00
Unused	2.08	5.88	0	53.23	61.20
Total 2002	11.33	25.77	0.01	53.53	90.64
Brazil					
Crop	97.6	3.2	0.1	0.3	101.1
Pasture	5.1	171.7	0.1	1.3	178.2
PlantForest	0.1	0.1	5.6	0	5.8
Unused	7.7	25.9	0.1	531.2	564.9
Total 2002	110.3	200.9	5.9	532.8	850.0

Source: Original data from Brasil (2010), adapted by the authors to match IBGE agricultural census data.

while the final, column-total row shows year-end land use (2002). The numbers within the table show the observed transition of one type of land to another from 1994 to 2002. The pattern of transitions differs substantially between states. In Amazonas state, for example, 0.67 Mha of the natural forests (Unused) were converted to Pasture, with only 0.04 Mha converted directly to Crops. By contrast, in Mato Grosso 2.08 Mha were converted directly from forests to Crops, and 5.88 Mha from forests to Pasture. At the same time, no Pasture was converted to Crops in Amazonas, while 1.3 Mha of Pasture were converted to Crops in Mato Grosso. In total we see that nationally, there was a 9.2 Mha increase in Crop area and a 22.7 Mha increase in Pasture area in the period, with 7.7 Mha of Unused land being converted directly to Crops and 25.9 Mha to Pasture, while 5.1 Mha of Pasture were converted to Crops.

We converted the transition matrices into shares which show Markov probabilities that a particular hectare of land used in one year for some use would be in another use in the next year. In the model, these Markov share matrices drive movements of land between uses, thereby determining agriculture land supply in each year.

Although initially calibrated from observed data, the model's Markov matrices are subsequently modified endogenously according to simulated changes in the average unit rentals of each land type in each region. The changes follow the rule:

$$S_{pqrb} = \mu_{prb} \cdot L_{pqrb} \cdot P_{qr}^{\alpha} \cdot M_{qrb} \tag{2}$$

where the r and b subscripts, respectively, denote region and biome zones, S_{pqrb} is a share of land type p that becomes type q, μ_{prb} is a slack variable adjusting to ensure that $\sum_q S_{pqrb} = 1$, L_{pqrb} is a constant of calibration that equals the initial value of S_{pqrb}, P_{qr} is average unit rent earned by land type q, α is a sensitivity parameter with a value set to 0.28 (chosen to mimic recent history), and M_{qrb} is a shift variable with an initial value of 1.

Following rule (2), if Crop rents rise relative to Pasture rents, the rateof conversion of Pasture land to Crops will increase.

As shown in the bottom right portion of figure 2, the land supplies implied by biome transition matrices are summed, over biomes, to determine in each region and year the total area of each broad type of land use. Then the model allocates the total among different crops or livestock uses according to a CET-like rule:

$$A_{jr} = \lambda_r \cdot K_{jr} \cdot R_{jr}^{0.5} \tag{3}$$

where A_{jr} is the area of crop land in region r used for industry j, and R_{jr} is the unit land rent earned by industry j. Further, K_{jr} is a constant of calibration while the slack variable λ_r adjusts so that

$$\sum_{j} A_{jr} = A_r \tag{4}$$

where A_r is the pre-determined area of each broad land type (Crop or Pasture).

We use the model to construct a base forecast for future states of the economy, to which different policy scenarios can be compared. The new scenarios differ from the base only via shocks on policy variables, which generate deviations from the base that can be interpreted as the effect of the policy change.

Other details of the model closure are as follows. The national supply of each labor skill type increases according to official projections. Inter-regional real wage differentials drive labor movement between regions. Within a region, labor of each skill type flows freely between activities. Regional household consumption is linked to regional wage income and to national household consumption. Nationally, the nominal trade balance as a fraction of GDP is fixed; national household and government consumption adjust together to meet this external constraint.

In all scenarios, areas of unused land (natural forests) in each region are exogenous. This implies that regional deforestation rates are also externally determined. Regions are divided into two broad groups: frontier and land-constrained, based on their proportion of unused land (natural forests).[7] All scenarios prevent further conversion of unused land in the land-constrained regions. In the Base scenario, deforestation is allowed to continue in the frontier regions at recently observed rates, while in the alternate (Policy) scenarios, deforestation is reduced in frontier regions. In all scenarios, land moves endogenously between Crop, Pasture, and Plantation Forest uses.

Model Baseline and Scenario Simulation

The model database is for year 2005, the starting point for our scenarios. The first step in the simulation is to update the database to year 2012 through a historical simulation, which imposes on the model the observed aggregate land use and macroeconomic changes between 2005–2012. After this, the baseline simulation assumes moderate economic growth of the Brazilian economy until 2030 (2.5% annual increase in GDP), together with population projections by state from the Brazilian official statistical agency (IBGE).

After the historical period, baseline regional deforestation rates were set to the average observed for 2009–2013 by the PRODES[8] monitoring project, that is, to around 660,000 hectares per year until 2025.[9] The model allocated this extra land to agricultural sectors via the transition matrix mechanism discussed above.

For the counterfactual analysis of the post-historical period, we consider two policy scenarios. The first scenario imposes the target proposed in the abovementioned PPC-DAm plan. According to this target Brazil should reduce its yearly deforestation rate by 80% in relation to the average yearly rate observed during 1996–2005 (1,965,500 hectares). This means that the targeted yearly deforestation rate in 2020 is about 392,500 hectares.

The second scenario models a complete halt in deforestation, starting in 2015. This scenario, although extreme, matches the target proposed by the New York Declaration on Forests, issued in the United Nations Climate Summit 2014 (United Nations 2014), which Brazil has not endorsed.[10]

In summary, our simulations consist of the following scenarios:

Baseline (Base): Shocking our model with the commodity (average) price shocks in international markets for the historical period (2005 to 2012), and projecting the economy until 2025 based on past observed trends for GDP, population, and other variables. After the historical period we assume

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[7] The model's frontier regions are Amazon, Rondonia, ParaToc, MarPiaui, Bahia, and MtGrosso.

[8] The PRODES project (Monitoramento da Floresta Amazônica Brasileira por Satélite) monitors deforestation in the Brazilian Amazon region through satellite imagery. Available at: www.obt.inpe.br/prodes/index.php.

[9] The actual last five years' average rate is 627,000 hectares. We have used a slightly higher value because there are some areas not covered by PRODES in which deforestation occurs, such as the southern part of Maranhão and Piaui states, and western Bahia.

[10] The United Nations Climate Summit 2014 scenario proposes to halve deforestation from 2015 until 2020, and to halt deforestation after 2020. We choose to apply the total halt in deforestation starting in 2015 because our first scenario already deals with a partial halt in deforestation. Thus, our scenario 2 is somewhat more severe than the UN Summit proposal.

that world commodity prices grow annually 1% faster than manufacturing prices, and that the Brazilian economy grows by 2.5% per year. Deforestation rates follow those observed for 2009–2013, thus determining how much new land is available for agriculture.

Policy Scenario 1: The same as the baseline, plus the PPCDAm (Brasil 2013) targets for deforestation reduction, that is, annual deforestation of 392,500 hectares, starting in 2015.

Policy Scenario 2: The same as the baseline, plus the total halt in deforestation, starting in 2015.

We compare these two policy simulations with the baseline to highlight the effect of deforestation controls on Brazilian economic growth.[11]

Results

Simulation results are shown in tables 3 to 5 below. Results for selected macroeconomic aggregates, accumulated to 2025, are shown in table 3. In the table, Base refers to baseline growth between 2005 and 2025, while Scenario 1 and Scenario 2 refer, respectively, to the 2025 deviation from the baseline caused by the extra policy shocks of scenarios 1 and 2. Tables 4 and 5 follow a similar pattern.

Although below we focus on the difference between policy and base scenarios, salient features of the base scenario are worth noting. Real GDP grows by 75%, but absorption grows by more, such that imports triple. This is made possible by an assumed increase in the terms of trade. On average, agricultural outputs (table 5) rise 50%, yet cropland area rises by only 12.4%. Pasture area increases by only 4.3% (table 3), constrained by the imposition in this scenario of recent low levels of deforestation. Consequently, land rents rise sharply, particularly for pasture (because of higher income elasticities for beef, and the ongoing conversion of pasture to cropland). The overall increase in output per hectare is possible because of the technological progress common to all scenarios, and because of two additional mechanisms explained below.

Table 3. Model Results, Selected Aggregates, Percentage Changes, Accumulated to 2025

	Percentage Change 2005–2025	2025 Policy relative to 2025 Base	
	Base	Scenario 1	Scenario 2
Real Consumption	101.38	0.00	0.00
Real Investment	88.65	−0.27	−0.52
Real Government	77.79	0.00	0.00
Exports	67.76	−0.07	−0.12
Imports	290.88	−0.05	−0.10
Real GDP	75.22	−0.05	−0.09
Employment	27.40	0.00	0.00
Real wage	48.01	−0.10	−0.19
Aggregate capital	77.58	−0.06	−0.11
Cropland area	12.41	−0.79	−1.45
Pasture area	4.26	−1.81	−3.31
Cropland unit rent	254.08	1.42	2.66
Pasture unit rent	646.95	4.81	9.28

Note: The first column (Base) shows cumulative percentage changes over the simulation period 2005–2025; for example, real GDP grows 75.22% over the period. The remaining columns show percentage deviations from Base in 2025; for example, in Scenario 2 real GDP in 2025 is 0.09% lower than in the Base in 2025 (i.e., GDP grew by 75.07% from 2005–2025, rather than 75.22% in the Base: 175.07 is 0.09% less than 175.22).

Table 4. Model Results, Land Use by Broad Categories, Ordinary Changes, Million Hectares, Accumulated to 2025

	Change 2005–2025	2025 Policy–2025 Base	
	Base	Scenario 1	Scenario 2
Crops	7.8	−0.6	−1.0
Pasture	6.8	−3.0	−5.5
Planted Forests	0.1	0.0	−0.1
Unused	−14.8	3.6	6.6
Total	0.0	0.0	0.0

Note: Numbers should be interpreted as in table 3. For example, in the Base scenario, Unused land area falls by 14.8 million hectares from 2005–2025, while in Scenario 2, Unused area in 2025 is 6.6 million hectares more than in the Base in 2025. Thus, Scenario 2 cuts baseline deforestation by nearly half.

The policy scenarios impose even tighter limits on forest clearing; scenario 2 nearly halves the baseline deforestation rate, reducing the supplies of cropland by 1.45% and pasture by 3.31%. However, land rents in the initial-year database account for just 1.8% of GDP, which suggests that the effect on the whole economy of a halt in deforestation should not be high. The national GDP decreases due to reduced deforestation are only 0.05% for Scenario 1 and 0.09% for the

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[11] Computer files are available to rerun simulations reported here. See archive item TPMH0144 at www.copsmodels.com/archivep.htm.

Table 5. Model Results, Land Use and Production, with Annual Productivity Increase Needed to Keep 2025 Production at the Base Level

	Base: Percentage Change 2005–2025	Scenario 1: Percentage variation relative to baseline in 2025			Scenario 2: Percentage variation relative to baseline in 2025		
	(1) Production	(2) Land use	(3) Production	(4) Extra TFP	(5) Land use	(6) Production	(7) Extra TFP
Rice	15.3	−2.28	−1.11	0.09	−4.16	−2.05	0.18
Corn	64.6	−0.83	−0.28	0.03	−1.53	−0.52	0.06
Wheat	−42.4	−0.02	−0.01	0.00	−0.04	−0.07	0.01
Sugarcane	103.7	−0.23	−0.10	0.00	−0.42	−0.19	0.01
Soybean	62.3	−0.68	−0.54	0.03	−1.25	−0.99	0.06
Other agric	42.6	−1.09	−0.17	0.02	−2.00	−0.31	0.03
Cassava	70.9	−2.39	−0.72	0.15	−4.34	−1.38	0.28
Tobacco	59.2	−0.10	−0.03	0.01	−0.18	−0.06	0.02
Cotton	64.7	−0.59	−0.25	0.04	−1.08	−0.47	0.07
Citrus fruit	57.4	−0.64	−0.26	0.02	−1.18	−0.50	0.03
Coffee	28.5	−0.72	−0.23	0.01	−1.33	−0.42	0.03
Forestry	42.2	−0.64	−0.52	0.04	−1.23	−1.00	0.09
Livestock	59.3	−1.90	−0.84	0.10	−3.48	−1.56	0.19
Milk Cattle	54.9	−1.28	−0.58	0.05	−2.36	−1.09	0.10

Note: Column 1 shows percentage output changes from 2005–2025 in the Base scenario. Remaining columns show 2025 percentage differences between a policy scenario and the Base. For example, in Scenario 1, 2025 Soybean output is 0.54% lower than in 2025 Base. The columns headed "Extra TFP" refer to two supplementary simulations (Scenario 1a and Scenario 2a); the numbers show what above-base annual increments to Total Factor Productivity (TFP, or all-input-reducing technological change) would be needed to hold crop output at the Base levels.

more aggressive Scenario 2; both are negligible values, especially when compared to the 75% growth of GDP in the baseline.[12]

Frontier regions (which lose the chance to clear forest) are of course more severely affected than the established regions. Corresponding to the 0.09% national GDP fall in Scenario 2 are regional GDP falls of around 0.6% for the frontier states compared with 0.05% decreases in for example, São Paulo and Paraná.

Table 4 shows area changes for the broad land-use groups. Again, the last 2 columns show the 2025 effects of the policy shock for each scenario: our assumption that 3.6 Mha of forests are spared from clearing in Scenario 1 (and 6.6 Mha in Scenario 2) cause corresponding reductions in the amount of land available for Crops, Pasture, and Planted Forests compared to the baseline.

Most of the decrease in deforestation is compensated by the dip in areas under pasture, that is, 3.0 Mha and 5.5 Mha in scenarios 1 and 2, respectively. Crop area decreases much less, which is caused both by the relatively smaller area under cultivation and by the substitution of pasture by crops as the price of agricultural land goes up. Thus, the large pasture area acts as an "intensive frontier", that is, land which can be used instead by more profitable agricultural activities. This effect cushions the impact on crop supply of the fall in total available area (see table 5).

Comparing columns 2 and 3 of table 5 (or columns 5 and 6 for Scenario 2), we see that production falls by less than land use, implying an increase in national per-hectare yields. The yield increase arises from two mechanisms:

(1) Yields are often less in frontier regions than in the traditional, non-frontier regions. When land prices rise, trade between regions allows production to shift to higher-yielding regions, thus increasing national average yields.
(2) As the price of land goes up, input substitution occurs and agriculture substitutes away from land toward other inputs, thus increasing output per hectare.

The Scenario 2 output effects[13] are decomposed into area and the two yield effects in

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[12] Cabral (2014), using a different CGE model, estimated that laws restricting deforestation might reduce 2020 GDP by 0.15%, which is not very different from our 0.09% result.

[13] Due to space constraints, we use Scenario 2 to illustrate the effects. The results for Scenario 1 are similar, but smaller in magnitude. The program and formulas that produce the shift-share decomposition are included in the archive item mentioned in footnote 11.

Table 6. Model Results, Sources of Output Change, Policy Relative to Base, 2025, Scenario 2

	(A) National area	(B) Regional shift	(C) Input substitution	(D) Interactive term	(E) National output
Rice	−4.16	1.63	0.59	−0.12	−2.05
Corn	−1.53	0.53	0.53	−0.05	−0.52
Wheat	−0.08	0.01	0	0	−0.07
Sugarcane	−0.42	0.15	0.09	−0.01	−0.18
Soybean	−1.24	−0.23	0.51	−0.03	−0.99
Other agric	−2.00	0.97	0.77	−0.06	−0.31
Cassava	−4.34	0.15	3.39	−0.58	−1.37
Tobacco	−0.18	0.13	−0.01	−0.01	−0.06
Cotton	−1.08	−0.41	1.04	−0.02	−0.47
Citrus fruits	−1.17	0.15	0.60	−0.07	−0.50
Coffee	−1.33	0.61	0.33	−0.03	−0.42
Forestry	−1.23	−0.54	0.82	−0.05	−1.01
Meat cattle	−3.48	0.37	1.70	−0.16	−1.56
Milk Cattle	−2.36	0.23	1.11	−0.07	−1.09

Note: Column E (national output) is the same as column 6 of the preceding table. For example, 2025 national Soybean output in Scenario 2 is 0.99% lower than in 2025 Base. Columns A to D add up to column E; they show how the changes of column E may be decomposed into several different effects described in the text.

table 6, following a shift-share decomposition system used in Ferreira Filho and Horridge (2012).

In table 6, the change in national output (column E) is decomposed into four main components (columns A-D). Column A represents the percentage change in national area. This is the decrease that would occur if land areas shrunk equally in all regions and if yields remained unchanged. Column B is the (generally positive) effect of crop areas expanding more where output per hectare is greater (i.e., in the long-established non-frontier regions, where yields are generally higher). However, for soybean and cotton, output per hectare is higher in the frontier states (where expansion is constrained), thus leading to negative contributions. Column C is the percentage change in yields (output per hectare) arising from limited substitution ($\sigma = 0.25$) between land, labor, and capital. Finally, Column D is an interactive or second-order term. As areas shrink (negative percentage change), land rents rise, leading to substitution against land, and an increase in output per hectare. Thus, the product term tends to be negative.

The decomposition helps us to understand how relocation and input-substitution effects can dampen the effect of area reduction. Using corn as an example, the halt of deforestation would cause a 1.53% decrease in 2025 corn area (column A). However, the relocation of corn production to regions with higher yields would increase production by 0.53% (the area shift effect, column B), while the induced input-substitution against land would bring an extra 0.53% increase in yields (column C). This result is similar to DeFries and Rosenzweig (2010), who show that forest clearing contributes little to world food output growth. Thus, the simulations suggest that a decrease in deforestation has only a small impact on agricultural supply, which is due partly to increased average yields. Notice that this yield increase is a price-induced effect, and not technological change in the classic sense, which is exogenous to the model and could also compensate for area reductions, as discussed below.

Effects of Additional Technological Change

Agricultural research has contributed greatly to Brazilian farm output. It seems possible that more research might yield productivity gains that could offset the effects of deforestation control. To explore this idea, we performed two supplementary simulations (Scenario 1a and Scenario 2a) in which we imposed additional neutral technological progress (the A_0 variable in equation 1 above) on agricultural sectors. Individual A_0 shocks were chosen to allow each sectoral output to grow at the same rate as in the base scenario, in spite of reduced agricultural land supplies. The required extra shocks are shown in columns 4 and 7 of table 5; they are expressed as annual average percentage differences in A_0 relative to the base scenario.

Table 7. Sensitivity Analysis, Changes in National Land Use, Policy Relative to Base, 2025, Scenario 2

Product	(1) α = 0.14 (alternate)	(2) α = 0.28 (actual)	(3) α = 0.56 (alternate)
Rice	−4.00	−4.16	−4.45
Corn	−1.49	−1.53	−1.60
Wheat	−0.02	−0.04	−0.06
Sugarcane	−0.40	−0.42	−0.47
Soybean	−1.17	−1.25	−1.38
Other agric	−1.93	−2.00	−2.12
Cassava	−4.17	−4.34	−4.67
Tobacco	−0.17	−0.18	−0.20
Cotton	−1.04	−1.08	−1.16
Citrus fruits	−1.15	−1.18	−1.23
Coffee	−1.25	−1.33	−1.48
Forestry	−1.18	−1.23	−1.33
Meat cattle	−3.52	−3.48	−3.40
Milk Cattle	−2.39	−2.36	−2.30

Source: Model results. Column 2 repeats column 5 of table 5 and column A of table 6. It shows, for example, that 2025 Rice area in policy scenario 2 was 4.16% less than in the 2025 Base. Columns 1 and 2 report corresponding results, computed using alternate values of α.

For example, in Scenario 1, year 2025 livestock output fell by 0.84% (relative to base). If we had annually imposed an additional total factor productivity (TFP or A_0) increase of 0.10% for livestock, its output growth would have been the same as in the base scenario.

We can see that modest above-trend increases in TFP would be enough to stabilize agricultural outputs. By comparison, the TFP growth in Brazilian agriculture from 1995–2006 was around 2.13% per year (Gasques et al. 2011). Similarly, Martha, Alves, and Contini (2012) showed that 42.1% of the beef supply expansion in Brazil from 1996–2006 was due to the increase in the stocking rates, an average 9.1% per year increase.

Sensitivity of Results to Value of Parameter α

The CGE models typically rely on a large number of assumptions about data, functional forms, and parameter values. One way to see how these assumptions affect model results is to recalculate simulations using different assumptions. Results from such an exercise are presented in table 7 below, which shows alternative LUC results for two different values of the parameter α, which is the response of land-use change to land rents. We selected this parameter for sensitivity analysis because it appears in the land-use transition mechanism (equation 3 above) which is novel in our model. Therefore, other CGE modelers may have little sense of a plausible α value. The value of 0.28 used in our main simulations was chosen so that the model best tracked recent historical land-use changes. We computed alternate results with α set to either double or one half of the 0.28 value. The results in table 7 suggest that simulated long-run changes in agricultural land use are negatively correlated to α, but do not vary greatly with the alternate values.

Conclusions

In this article we have examined the consequences that a future slowing or halt in deforestation would have for Brazilian agricultural supply by comparing two alternate scenarios with a baseline where deforestation followed present trends. We obtain estimates of the economic costs of deforestation control policies. Model results suggest that even in the more extreme case, the national costs would be very small: for example, deforestation control would reduce 2005–2025 GDP growth from 75.22% (no control) to 75.07% (with control). The reduced supply of new land is offset by a more effective use of existing agricultural land.

Considering agriculture only, the effects are more noticeable: for example, we estimated that more stringent limits on forest clearing might reduce 2025 soy output by 1%. But we show that small increments in the rate of technological progress would neutralize such output falls. Such increments might arise through agricultural research and extension directed toward increasing productivity, especially in the pasture sectors (which use most of the agricultural land). Hence, one policy conclusion is that Brazil should build on an existing strength, namely the integration of science and agriculture. Even small research-driven productivity gains could offset the cost of preserving forests.

While the economic costs of controlling deforestation are small for Brazil as a whole, the effects on agriculture in frontier regions are more pronounced. Farmers in these regions have an incentive to clear forest, even illegally. Compensatory policies may be needed to make forest preservation more acceptable and enforceable. Given the marked differences among producers in terms of size, capital, and technology used, these policies would need to be tailored to target specific groups or areas since no single policy would work well for all. For example, in order to foster sustainable commercial agricultural production, policies should focus on improving transportation infrastructure, opening export markets, and reducing export paperwork. On the other hand, subsistence farmers are likely to require additional policies such as health care, subsidized inputs, and agricultural outreach.

Conclusions drawn from large simulation models, as used here, rest upon numerous modeling and data assumptions, and it is hard to quantify the uncertainties involved. Further work on improving data and re-estimating key elasticities is needed. But perhaps a larger yet unavoidable source of uncertainty is the set of assumptions about future world demands and about agricultural productivity (especially in light of climate change).

In this article we have treated forest preservation as an end in itself. However, the motive for forest preservation—perhaps habitat preservation, or perhaps reduced CO_2 emissions—affects policy choices. As mentioned in footnote 6, we now have data to show how CO_2 emissions from LUC vary by region and biome. Hence, if emission reduction is the aim, more focused policies seem advisable. We plan to explore this area in future research.

Presently, deforestation is slowing in Brazil, but a complete halt is not imminent. Our results suggest that further limits on deforestation will not compromise Brazilian agricultural supply capacity in the foreseeable future. Indeed, food exports may become linked to the pursuit of international forest protection goals, if environmental restrictions are incorporated into trade regulations.

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