PRELIMINARY DRAFT – NOT TO BE CITED

THE NEW FOREST CODE AND GREENHOUSE GAS EMISSIONS REDUCTIONS IN BRAZIL[1]

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1. Introduction

Forests conversion to land use has been object of law in Brazil as early as 1965, when the Brazilian Forest Code (FC) was first issued. According to Figueiredo and Leuzinger (2001), at that time the law granted to land owners legal certainty on exploitation of their farms, since there were still large areas of continuous forest stocks in different ecosystems, like the Cerrado (Savannah), the Pantanal, the Atlantic Forest and the Amazon Forest.

The rapid expansion of the Brazilian agriculture in the ensuing years, however, drastically modified that scenario, causing the previous environmental regulation to be regarded as an element restricting agricultural expansion. As a result, the law started to be overlooked by a large number of landowners, who benefited from very little official effort for law enforcement. The surge in environmental concerns worldwide in the nineties, however, led the Brazilian government to promote in 2008 the "Law of the Environmental Crimes" which, among other measures, stablished a 180 day deadline for every farm to officially register it´s Legal Reserve of natural vegetation (Reserva Legal, RL). With this the majority of the Brazilian farms could be considered illegal, and suitable to prosecution (Diniz, 2012).

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A lively debate about the appropriateness of the Forest Code started, with agricultural producers and environmentalists lobbies pressing the Brazilian Congress either for the law relaxation or its enforcement. The political reactions led to the creation of a Congress Commission that proposed changes to the old FC, which was approved by the congress in 2012 and sent for the Presidential approval. The law received further presidential amendments and was finally approved in May, 2012. Although approved almost 3 years ago, the FC is still in the first stages of implementation, since many of its instruments still depend on institutional ordinary legislation and adaptation.

The FC provisions cover basically two types of land areas to be protected: the Legal Reserve (RL) and the Permanent Preservation Areas (APP). Legal Reserve is that part of a farm which must be preserved for keeping a representative share of the natural environment of each region, and necessary for maintenance of the local biodiversity. The APP, on the other hand, has the purpose of preserving fragile environments, as hilltops, slopes, and river banks.

According to Soares-Filho et al (2015) roughly 53% of Brazil´s native vegetation occurs in private properties. Native forests and savannahs on these lands store about 105 billion tons of CO2, a critical stock to be managed for the global efforts to mitigate climate change through REDD. In spite of that, few studies exist to the moment trying to quantify the economic and environmental impacts of the new FC. The purpose of this paper is to analyze the impacts of the new Brazilian Forest Code both in terms of the economic losses involved with the agricultural land area losses necessary to recompose both the APP and RL, and the GHG emission impacts associated. Additionally, considering the important regional differences in Brazil, this study will use a detailed inter-regional approach to the problem.

This paper contributes to the existing literature in many ways. To the best of our knowledge it´s the first time that the Brazilian Forest Code scenarios are analyzed in an integrated dynamic economic framework. Second, it´s the first time the accounting of emissions associated with the different scenarios is performed, both for APP and RL.

2. Literature review[5]

Few studies exist in the literature trying to analyze the impacts of the Brazilian Forest Code. Most of the existing literature focuses on its economic impacts, frequently of just one of the two mechanisms (RL and APP). Many studies appeared during the FC discussion process, aiming to subsidize the discussions, with many different focuses. SBPC (2011), for example, reviews the role of the FC in preserving the biodiversity and in supplying ecosystem services, while ICONE (2011) and Metzger (2010) focus on juridical and scientific basis of the FC (Diniz, 2012). Miranda (2008) evaluated the remaining availability of agricultural areas in different FC scenarios, showing that there are important variations across different biomes.

Sparovek et al (2011) did a detailed evaluation of the FC scenarios[6], using satellite imagery in conjunction with information of FC regulations, showing that 100 million hectares (Mha) would be necessary to attend RL and 236 Mha requirements. However, part of those totals can be supplied by existing natural areas, resulting in a net requirement of 42 Mha for RL and 43 Mha for APPs.

Other studies on economic impacts of the FC and which focused exclusively on the RL mechanism are Oliveira (2011), in a study for Brazil; Padilha Junior (2004), for Parana state only; Bacha (2005), for sugar cane and citrus production in the Piracicaba River basin; Rigonatto (2009), for the state of Goias; Fasiaben (2010), on a particular micro basin in the Sao Paulo state. In terms of studies that analyzed both the RL and APP mechanisms, only Brancalion and Rodrigues (2010) reported results for the cost of compliance with the former FC environmental regulations for the sugar cane producers in Sao Paulo state. And, finally, Borner et al (2014) estimated the cost and income effects of enforcing the FC in the Brazilian Amazon.

In terms of GHG emissions impacts of the FC, Fearnside et al (2009) evaluated the deforestation and emissions in the region of influence of the Manaus-Porto Velho road; and IPEA (2011) analyzed different scenarios for RL recovery for above the ground carbon

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[5] Part of this chapter is based on Diniz and Ferreira Filho, forthcoming.

[6] The results are part of the AgLue (*Agricultural Land Use and Expansion Model*) project.

stocks, calculating the loss of carbon stocks due to the change in the law and evaluating those stocks using parameters derived from the willingness to pay from the international community.

A distinctive feature of the abovementioned studies is that either only part of the FC mechanisms (RL or APP) was analyzed in each study, or either the economic or the emissions impacts are analyzed. This paper tries to contribute to this the existing gap in the literature using an integrated model to analyze simultaneously the economic, as well as the environmental effects of the new Brazilian Forest Code. It contributes to the existing literature in two ways. First, it distinguishes the biome dimension in dealing with land use modeling. This is crucial for emissions analysis, due to the different rate of emissions associated to different biomes.

Second, our model associates emissions to an endogenous module of deforestation, according to different biomes, by state. This is done through the use of a transition matrix between land uses obtained from satellite imagery, by biome and region, and which is linked to a corresponding emissions matrix and to the core economic model. As it will be discussed later on the text, this is crucial for the analysis of one of the (polemic) mechanisms provided in the FC for RL recovery, the RL compensation, which requires the biome dimension.

3. Methodology[7]

The analysis will be performed using TERM-BR, a computable general equilibrium (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 (Horridge et. al., 2005), and a summary is provide here.

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

[7] The methodology follows closely the description provided by Ferreira Filho et al (2015).

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).
- 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.

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 is different across industries.

Guided by prices, each industry in each region chooses inputs to minimize unit production costs subject to a production function. The production technology for a representative industry is modeled through a series of 'nesting' assumptions, which 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 CES (constant elasticity of substitution) combination of individual commodities — although the elasticity of substitution is quite low. Each commodity is itself a CES combination of Brazilian and imported varieties. Finally, at bottom level of the decision tree each region's total demand for each commodity is supplied by a CES combination from different regions. The primary factor composite used by each industry is a CES combination of industry-specific capital, labor and land; with labor itself 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. Similar nesting assumptions (without the primary factor part) govern final demands, except that household demands for goods follow the linear expenditure system.

The supply of land to each state is described in what follows. 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 the GEMPACK suite (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 (Brasil, 2010). We processed this data to distinguish land areas used for three broad types of agriculture, Crop, Pasture, and Plantation Forestry, and one residual type we call 'Unused', which is mainly natural forest. We distinguished regional land use by state, and, within each state by 6 soil/vegetation zones called 'biomes'. The data shows how many hectares of, say, 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.

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 1.

Table 1. Transition Matrices between different land uses, 1994-2002, Million hectares.

			Amazonas		
TRANS	Crop	Pasture	PlantForest	Unused	Total 1994
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		
TRANS	Crop	Pasture	PlantForest	Unused	Total 1994
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		
TRANS	Crop	Pasture	PlantForest	Unused	Total 1994
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: Ferreira Filho et al (2015).

The final, row-total column in each sub-table of Table 1 shows initial land use (1994), 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, during 1994-2002. 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. And finally the transition matrix presented above has still another dimension, the biome dimension. The biome dimension distinguishes six different biomes in Brazil, namely Amazonia (Amazon forest), Cerrado (Savannahs), Caatinga, Mata Atlantica (Atlantic Forest), Pampa, and Pantanal, in each state.

Together with the observation on land use transition, Brasil (2010) also showed the emissions associated to those transitions, for the same land use dimensions (region and biome). This turns it possible to simulate the amount of emissions released (or saved, in the case of natural vegetation recovery) by state and biome, as land use changes. Emissions associated to deforestation, for example, become endogenous to the model and are driven by LUC. As mentioned before, this is important for the FC simulations.

The transition matrices were converted 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, so 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. We use the model to construct a base forecast for future states of the economy, to which different policy scenarios can be compared.

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). 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, different versions of the FC are imposed. In all scenarios, land moves endogenously between Crop, Pasture and Plantation Forest uses.

4. The scenarios to be analyzed

The scenarios to be analyzed are based on the calculations performed by the *AgLue Project* (Sparovek et al, 2010) and Diniz (2012). The database construction required the matching of satellite imagery information with economic data from the Brazilian Agricultural Censuses (Diniz, 2012). With this information it was possible to compute the required reduction in each agricultural activity, by state, needed to comply with the FC legislation, by each FC mechanism (RL or APP). Two scenarios are simulated, described in Table 2

Table 2. Main aspects of different versions of the Brazilian Forest Code.

Old (original) Forest Code (Law 4771 of 1965)	New Forest Code (Law 12,651 of 2012)
Scenario 1	Scenario 2
• Total compensation of APP deficit; • No discounts on the RL computations; • RL in the Amazon region: 80% • RL required to be compensated inside the property.	• Compensation of 50% of the riparian APP deficit and 100% of hilltop APP deficit; • Four fiscal modules and natural vegetation existent on APPs discounted of the RL computation; • RL in the Amazon region: 50% • RL required to be compensated inside the property

Obs: fiscal module is a unit of land area used for fiscal purposes.
Source: Dinis (2012).

The resulting agricultural and livestock area reductions, once computed the scenarios above, can be seen in Table 3 and Table 4, by region and by economic activity.

Table 3. Scenarios 1 and 2. Agricultural area reduction in 2005 required to comply with the FC regulations in Brazil, by state. Million hectares.

	Scenario 1 (old FC)			Scenario 2 (New FC)		
Region	APP	RL	Total	APP	RL	Total
1 Rondonia	0.46	1.96	2.42	0.27	1.58	1.85
2 Amazon	0.56	1.57	2.13	0.29	0.35	0.64
3 ParaToc	3.24	5.82	9.05	1.82	4.32	6.14
4 MarPiaui	2.15	2.15	4.30	1.37	1.45	2.82
5 PernAlag	1.78	0.41	2.19	1.16	0.21	1.37
6 Bahia	4.02	1.70	5.72	2.36	1.09	3.46
7 RestNE	2.32	0.54	2.86	1.25	0.23	1.48
8 MinasG	5.67	2.20	7.87	3.81	1.34	5.16
9 RioJEspS	1.42	0.87	2.29	0.92	0.80	1.73
10 SaoPaulo	1.76	2.91	4.67	1.09	2.74	3.82
11 Parana	2.36	1.29	3.65	1.81	1.10	2.91
12 SCatRioS	5.68	2.42	8.09	3.59	1.96	5.55
13 MtGrSul	2.32	1.23	3.55	1.30	0.98	2.27
14 MtGrosso	2.93	9.11	12.03	1.72	5.64	7.36
15 Central	2.70	1.24	3.94	1.65	0.87	2.52
Total	39.33	35.42	74.75	24.42	24.66	49.07

Source: compiled with data from Diniz (2012).

It can be seen that the New Forest Code (NFC) considerably reduced the land requirements, from 74.75 Mha from 49.07 Mha. Even though the total area required for APP and RL is not very different, they assume different importance in different regions. In Santa Catarina and Rio Grande do Sul states (SCatRioS), for example, the area reduction due to the APP requirements in the old FC (5.68 Mha) is higher than for RL (2.42 Mha), while in Mato Grosso (MtGrosso) the respective values are 2.93 Mha and 9.11 Mha. This happens because the StaCatRioS are older regions in terms of occupation for agriculture, and with hilly lands, which require more permanent protection.

As explained before, the land area losses are computed from satellite imagery, at municipal level, which allows the calculation of land loss by agricultural activity at municipal level. This information once aggregated for the broad land use groups of the model, can be seen in Table 5 .

Table 4. Old Forest Code (Scenario 1). Agricultural area reduction in 2005, required to comply with different versions of the Brazilian FC, by broad agricultural sector. Million hectares.

	APP			RL		
State/region	Crop	Pasture	PlantForest	Crop	Pasture	PlantForest
1 Rondonia	0.002	0.454	0.000	0.000	1.962	0.000
2 Amazon	0.096	0.453	0.006	0.147	1.427	0.001
3 ParaToc	0.316	2.907	0.014	0.003	5.811	0.001
4 MarPiaui	0.270	1.873	0.004	0.000	2.154	0.000
5 PernAlag	0.907	0.868	0.001	0.035	0.378	0.000
6 Bahia	0.473	3.537	0.008	0.000	1.698	0.000
7 RestNE	0.102	2.219	0.001	0.000	0.541	0.000
8 MinasG	0.794	4.751	0.125	0.000	2.195	0.000
9 RioJEspS	0.301	1.096	0.021	0.042	0.822	0.004
10 SaoPaulo	0.580	1.066	0.114	0.220	2.690	0.001
11 Parana	1.448	0.867	0.041	0.083	1.208	0.000
12 SCatRioS	2.516	2.891	0.269	0.236	2.179	0.002
13 MtGrSul	0.169	2.148	0.001	0.000	1.228	0.000
14 MtGrosso	0.350	2.577	0.001	0.096	9.010	0.000
15 Central	0.324	2.370	0.001	0.000	1.242	0.000
Total	8.647	30.077	0.606	0.863	34.545	0.009

Source: compiled from original data by Diniz (2012).

Table 5. New Forest Code (Scenario 2). Agricultural area reduction in 2005, required to comply with different versions of the Brazilian FC, by broad agricultural sector. Million hectares.

	APP			RL		
State/region	Crop	Pasture	PlantForest	Crop	Pasture	PlantForest
1 Rondonia	0.001	0.269	0.000	0.000	1.583	0.000
2 Amazon	0.061	0.229	0.003	0.000	0.345	0.000
3 ParaToc	0.216	1.593	0.009	0.000	4.323	0.000
4 MarPiaui	0.223	1.141	0.004	0.000	1.452	0.000
5 PernAlag	0.662	0.496	0.000	0.000	0.210	0.000
6 Bahia	0.334	2.026	0.005	0.000	1.090	0.000
7 RestNE	0.063	1.184	0.001	0.000	0.229	0.000
8 MinasG	0.603	3.112	0.098	0.000	1.342	0.000
9 RioJEspS	0.224	0.685	0.015	0.015	0.786	0.002
10 SaoPaulo	0.364	0.641	0.081	0.184	2.551	0.001

11 Parana	1.151	0.631	0.032	0.046	1.050	0.000
12 SCatRioS	1.639	1.760	0.188	0.213	1.750	0.001
13 MtGrSul	0.102	1.197	0.001	0.000	0.975	0.000
14 MtGrosso	0.226	1.495	0.001	0.061	5.579	0.000
15 Central	0.244	1.408	0.001	0.000	0.866	0.000
Total	6.113	17.868	0.437	0.520	24.130	0.005

Source: compiled from original data by Diniz (2012).

Pasture is by far the agricultural activity which would require most of the area reduction, in any scenario. This is in part due to the hypothesis used during the satellite imagery data collection, that pasture will be the first areas to be occupied by either APP or RL, due to its lower rate of return when compared to agriculture. This hypothesis is based on land productivity differentials between pastureland and cropland, which justifies the occupation of pastures beforehand. But pasture is also the activity with the largest area in the base year, around 160.5 Mha against 62.8 Mha of crops.

The area reductions reported in Table 3 and Table 4 above are in relation to the 2005 agricultural area in Brazil. Those figures have to be recalculated for the sake of this analysis in relation to the 2016 agricultural area, which is generated by the model´s base run simulation. This and other simulation details will be discussed further in what follows.

5. Baseline and simulation strategy

A dynamic model requires a baseline which describes the “business as usual” path of the economy in time, and which will be used as the base for the counterfactual (policy shocks) analysis. As explained before, 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 2013 through a historical simulation, which imposes the observed aggregate land use and macroeconomic changes during 2005-2013 to the model. After this the baseline simulation assumes moderate economic growth of the Brazilian economy until 2025 (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 monitoring project, i.e., to around 660 thousand hectares per year until 2025 . The model allocated this extra land to agricultural sectors via the transition matrix mechanism discussed above.

Our simulation entails the hypothesis that the FC implementation would start in 2016, and would last for ten years, in a simulation until 2025. The model was shocked with one tenth of the total APP and RL every year, for both scenarios. The results are presented in the next section.

6. Results and discussion

The loss of land areas dedicated to agriculture and livestock implies a reduction of the production possibilities frontier of the economy. The macroeconomic results associated with this loss can be seen in Table 6.

Table 6. Model results. Macroeconomic aggregates, % deviation from the baseline, accumulated in 2025.

	Old FC			New FC		
	APP	RL	TOTAL	APP	RL	TOTAL
Real Consumption	-0,06	0,13	0,05	0,00	0,09	0,06
Real Invest.	-4,98	-4,75	-12,48	-2,20	-3,14	-7,03
Exports (quantum)	-1,16	-1,06	-2,14	-0,60	-0,75	-1,54
Imports (quantum)	-0,94	-0,89	-1,73	-0,40	-0,63	-1,27
Real GDP	-0,92	-0,72	-2,16	-0,40	-0,48	-1,18
Aggreg employ.	0,01	0,00	0,01	0,00	0,00	0,01
Realwage	-2,07	-1,46	-4,47	-0,90	-0,97	-2,54
Capital stock	-0,98	-0,89	-2,28	-0,40	-0,60	-1,32

Source: model results.

The macroeconomic impacts of the FC scenarios on the macroeconomic aggregates of the economy are not large. The more severe restrictions of the old FC would imply a 2.16% loss of GDP accumulated in 2025, while the new FC would reduce GDP by only 1.18%. This is the economic loss associated with the policy, and considers that land necessary to recompose the APP and RL areas would just be set aside, with no further costs involved[8].

[8] Considering that in some cases other costs would be involved, like building new fences to isolate the protected areas, for example, those figures should be considered a floor for the total costs involved.

The fact that the economic aggregated costs are low should not be a surprise. Agriculture and livestock activities account for just 4.5% of total value of production in the Brazilian economy in 2005, and for about 6% of GDP at factor costs. The reduction in land availability, then, even though can be more expressive in regional terms for some states, represents a small shock for the whole economy, generating a small loss in aggregate. Regional results, however, are very different, and can be seen in Table 7.

Table 7. Model results. Regional GDP % deviation from the baseline. Accumulated in 2025.

	Old Forest Code			New Forest Code		
State (region)	Total	APP	RL	Total	APP	RL
1 Rondonia (N)	-9,43	-0,79	-5,76	-5,59	-0,37	-4,13
2 Amazon (N)	-1,12	-0,25	-0,57	-0,30	-0,13	-0,12
3 ParaToc (N)	-4,56	-1,16	-2,04	-2,40	-0,59	-1,36
4 MarPiaui (N)	-3,94	-1,39	-1,30	-1,99	-0,82	-0,77
5 PernAlag (NE)	-3,81	-2,57	-0,58	-1,92	-1,44	-0,30
6 Bahia (NE)	-1,66	-0,82	-0,34	-0,77	-0,42	-0,20
7 RestNE (NE)	-2,19	-1,27	-0,31	-0,87	-0,58	-0,13
8 MinasG (SE)	-2,48	-1,29	-0,52	-1,32	-0,79	-0,31
9 RioJEspS (SE)	-0,77	-0,32	-0,25	-0,45	-0,19	-0,18
10 SaoPaulo (SE)	-1,31	-0,48	-0,56	-0,79	-0,28	-0,41
11 Parana (S)	-2,94	-1,29	-1,04	-1,90	-0,86	-0,77
12 SCatRioS (S)	-3,24	-1,74	-0,85	-1,85	-0,99	-0,61
13 MtGrSul (CW)	-3,41	-1,44	-1,02	-1,78	-0,72	-0,72
14 MtGrosso (CW)	-7,85	-1,64	-4,19	-3,84	-0,91	-2,31
15 Central (CW)	-2,52	-1,05	-0,82	-1,34	-0,57	-0,54

Source: model results

The state of Rondonia would have the larger GDP loss, followed by Mato Grosso. Those states are in the deforestation frontier of Brazil, and it can be seen that both would be more affected by the need to recompose RLs then APPs. It can be seen from the table that different states would be affected differently by the APP or RL mechanisms, depending on a range of local characteristics. But in most cases the main effects is due to the need to recompose APP in the more traditional agricultural areas of the South and Southeast Brazil. The pressure to expand food supply in those regions led producers to expand their activities in areas like hilltops or former river edges, areas not allowed for agriculture. The new agricultural areas in the North region, on the other hand, tend to have a higher deficit of RL, and therefore are more affected by this mechanism.

In terms of the production composition changes, activities extensively grown in areas like hilltops or lowlands, like coffee in Southeast region, or rice. Table 8 displays the variation in production by agricultural product.

Table 8. Model results. Production % deviation from the baseline. Accumulated in 2025.

	Old Forest Code			New Forest Code		
	TOTAL	APP	RL	TOTAL	APP	RL
Rice	-21,56	-18,62	-2,86	-14,05	-9,68	-1,92
Corn	-11,02	-6,45	-3,37	-6,86	-3,19	-2,30
Wheat	-4,19	-5,73	1,24	-2,94	-3,01	0,90
Sugar cane	-5,61	-3,08	-1,80	-3,37	-1,32	-1,27
Soybean	-7,55	-7,91	0,11	-5,53	-4,69	0,05
Other agric	-6,89	-6,51	-0,30	-4,48	-3,07	-0,18
Cassava	-10,63	-6,87	-2,66	-6,35	-3,49	-1,58
Tobacco	-8,26	-8,37	0,40	-5,07	-3,86	0,19
Cotton	-4,61	-2,66	-1,38	-2,85	-1,31	-0,97
Citrus fruits	-9,82	-6,04	-2,78	-6,13	-2,94	-1,95
Coffee	-13,82	-13,70	-0,26	-10,01	-7,36	-0,01
Forestry	-6,59	-6,94	0,24	-4,55	-3,85	0,23
Livestock	-30,28	-11,75	-13,06	-17,62	-5,16	-8,86
Raw milk others	-28,59	-13,17	-12,22	-18,01	-5,95	-8,74

Source: model results.

It´s interesting to note that most of the fall in production of agricultural activities happens in the traditional production areas, as can be seen in Table 9, which highlights the complexity of the FC potential impacts. A few points are worth stressing here. First, APP shocks (not shown in the table) explain most of the result in the non-frontier region. This happens because in the more traditional and old agricultural regions, closer to the consumption regions in South and Southeast regions, the value of land is higher, driving producers to try to use all the available land. Considering that the FC wasn´t enforced until recently, areas now targeted for environmental preservation were previously occupied with agriculture and livestock activities. The restoration of those areas to APP causes a larger impact in those regions than in the frontier regions, where the APP deficits are smaller.

Second, notice that both wheat and sugar cane actually increase in the frontier, in both scenarios. Those products are mostly produced in Southeast and Southern Brazil, the traditional agriculture areas. The pressure on those cultures in the traditional areas would cause a stimulus to increase their production in the other regions located in the frontier[9].

Table 9. Model results. Production % deviation from the baseline, according to regional location. Accumulated in 2025.

	Old Forest Code		New Forest Code	
	FRONTIER	NON FRONTIER	FRONTIER	NON-FRONTIER
Rice	-7.20	-28.75	-3.77	-19.27
Corn	-9.23	-11.42	-4.84	-7.33
Wheat	2.51	-4.20	0.95	-2.95
Sugar cane	7.66	-6.36	4.30	-3.81
Soybean	-3.76	-10.17	-2.75	-7.45
Other agric	1.39	-9.50	0.76	-6.14
Cassava	-5.98	-15.67	-2.14	-10.92
Tobacco	-1.53	-8.34	-0.33	-5.13
Cotton	-4.21	-6.46	-2.58	-4.07
Citrus fruits	-1.83	-11.08	-0.09	-7.09
Coffee	0.88	-15.82	0.63	-11.46
Forestry	-2.75	-8.62	-1.52	-6.15
Livestock	-32.47	-28.42	-17.61	-17.63
Raw milk others	-27.30	-28.82	-15.52	-18.47

Source: model results.

In the frontier regions, on the other hand, the RL shocks tend to affect more severely agricultural production, mostly in the livestock activities. This happens because the legal requirements for RL are higher in the frontier than in the non-frontier regions, and many producers didn´t comply with the existing legislation so far.

The land use change (LUC) promoted by the FC scenarios will have impacts on emissions, being natural vegetation recovery the most important source. The other, non-LUC emissions in the model can be associated to two main sources: emissions linked to fuel burning, and emissions associated to “activity”. The emissions associated to “activity”

[9] Wheat (plus other cereals except corn) is basically produced in Southern Brazil. There are very little areas of wheat production in the frontier states in the database. The increases in the frontier, hence, represent increases over a negligible area in the base, and should be disregarded.

are those generated in other sources but fuel burning, like in fertilizer degradation in soils, CH4 emissions by livestock and manure management, fugitive emissions in mining and refineries, etc.

The emissions associated to the transitions of natural forests to agricultural uses (deforestation), as well as LUC between different agricultural and livestock uses are calculated attaching the observed GHG emissions matrix to the land use transition matrix shown in Table 1, generating emissions matrices in the transitions (Silva, 2015). Those transition matrices follows the format shown in the Second Brazilian Inventory of Anthropogenic Emissions by Sources and Removals by Sinks of Greenhouse Gases (Brasil, 2010), built by state and biome, for 15 land use categories:

- Non-managed forests,
- Managed forests,
- Secondary forests,
- Forests with selective timber extraction,
- Reforestation,
- Non-managed fields,
- Managed fields,
- Field with secondary vegetation,
- Planted pastures,
- Crops, Urban areas,
- Rivers and lakes,
- Reservoirs,
- Other uses, and
- Non classified areas.

These 15 land use categories were aggregated into four broader categories (Crop, Pasture, Plantforest and Unused) in the model. As mentioned before, the emissions matrix incorporates the biome dimension, e.g., the model keeps track of emissions by type of transition, by state and by biome. For the sake of the present simulation, a further step in emissions accounting is still required. This happens because the emissions matrix displays observed emissions in transitions in the period 1994-2002. In this period, however, no transition was observed from natural forests to other uses in the non-frontier regions, since natural stocks were already used up. Considering the shocks will simulate a restoration of natural forest in those regions, using the observed emissions matrix would allow no emissions sinks in LUC from other uses to forests, or the reversal of the deforestation observed in the past.

To correct for this problem the average emissions by biome, calculated over regions where the transitions from forests to other uses were actually observed were imputed to the respective transitions in the non-frontier regions, such that the restoration of forests there now will generate a CO2 sink equivalent and opposite in sign to the deforestation which happened in that biome. Table 10 displays as an example the resulting emissions matrix for one region, São Paulo state, but one such matrix exists for each state in the model.

Table 10. Emissions in conversions of Unused lands in other uses, by biome. São Paulo state. Gigagrams of CO2/ha.

	São Paulo					
Land use	Amazonia	Cerrado	Caatinga	MAtlantica	Pampa	Pantanal
1 Crop	-	0.22	-	0.38	-	-
2 Pasture	-	0.10	-	0.27	-	-
3 PlantForest	-	0.00	-	0.11	-	-
	Amazon					
1 Crop	0.50	-	-	-	-	-
2 Pasture	0.49	-	-	-	-	-
3 PlantForest	-0.03	-	-	-	-	-

Source: Model database.

Notice that, in Table 10, only some conversions are possible, since not all biomes are present in all regions. In São Paulo state, for example, only the Cerrado and Mata Atlantica biomes are possible. The figure in the table show, for example, that the conversion of natural forest in the Mata Atlantica biome to crops generate emissions of 0.38 gG of CO2 per hectare, more than in the conversion of forests in the Cerrado biome to crops (0.22 Gg). Likewise, the conversion from natural forests to crops in Amazon generates emissions of 0.5 Gg of CO2, on Amazonia biome only. Notice that the rate of emissions on conversion to crops is the higher in the Amazonia biome, but also very high in the Mata Atlantica biome.

When the FC shocks are applied, then, the LUC will generate a change in total emissions. Considering that the effect of the LUC is to restore the original vegetation, the resulting afforestation will work as a carbon sink, reducing the emissions in the Brazilian economy. Other sources of emissions, however, may increase emissions, due to the rearrangement of the economy. In what follows, we present the results on emissions.

Initially, notice that the direct effect of the shocks are in agriculture and livestock activities, but the general equilibrium linkages generate changes in all sectors. Table 11 summarizes the results at national level.

Table 11. Model results. Emissions in CO2 equivalents, % deviation from baseline. Brazil, accumulated in 2025.

	Old Forest Code			New Forest Code		
	Total	APP	RL	Total	APP	RL
Mining	1.20	0.66	0.28	0.68	0.40	0.18
Gasoline (pure)	1.82	0.95	0.48	1.05	0.58	0.32
Gasoline C	1.11	0.47	0.39	0.58	0.24	0.23
Combustible oil	-1.51	-0.77	-0.57	-0.93	-0.46	-0.39
Other fuels	-0.74	-0.29	-0.38	-0.45	-0.17	-0.25
Activity	-19.59	-7.59	-8.52	-11.43	-4.18	-5.78

Obs: Gasoline C is pure gasoline with addition of anhydrous ethanol.

Table 11 shows that there is a strong reduction of emissions associated “Activity” in the model. Most of the emissions in Activity are associated to emissions by Livestock production, which would decrease, as seen in Table 9. Actually, livestock is the second most important emissions source in the Brazilian economy, after deforestation.

The results on emissions have a complex pattern, especially considering the biome dimension. Table 12 displays the change in emissions, in Gg of CO2 equivalents, by broad activity group and biome, aggregated by all states.

Table 12. Model results. GHG emissions by biome, deviation from the baseline. Total Gg of CO2 equivalents, accumulated in 2025.

	Old Forest Code (OFC)					
	BIOME					
Broad Activity	1 Amazonia	2 Cerrado	3 Caatinga	4 MAtlantica	5 Pampa	6 Pantanal
1 Crop	-251,212	-483,433	-119,035	-670,864	-1,473	-2,234
2 Pasture	-9,394,774	-2,667,850	-425,718	-4,677,973	-25,559	-302,836
3 PlantForest	-4,260	-13,370	45	-12,146	-70	0
4 UNUSED	-10,406	-2,572	-624	-7,643	-91	-83
Total	-9,660,651	-3,167,225	-545,332	-5,368,626	-27,193	-305,154
	New Forest Code (NFC)					
	BIOME					
Broad Activity	1 Amazonia	2 Cerrado	3 Caatinga	4 MAtlantica	5 Pampa	6 Pantanal
1 Crop	-130,996	-347,018	-84,680	-489,775	-991	-1,379
2 Pasture	-5,887,240	-1,725,667	-246,550	-3,248,738	-17,695	-190,965
3 PlantForest	-2,587	-10,479	31	-8,760	-49	0
4 UNUSED	-6,703	-1,687	-379	-5,763	-62	-52
Total	-6,027,527	-2,084,851	-331,577	-3,753,035	-18,797	-192,395

The figures in Table 12 represent the total emissions of each broad activity (Crop, Pasture, PlantForest, or Unused) in the transition to all other types of broad activity, accumulated in 2025, by biome. Let´s take Crops as an example. The change of Crops to all other activities (e.g., crops changing to pastures plus PlantForest plus Unused), driven by the transition matrix between years from 2016 until 2025, implied an emission reduction (negative emission) of 251,212 Gg of CO2 equivalents in the Amazonia biome, for the Old Forest Code scenario. Equivalently, the change of Pasture to all other uses (a negative change) in the period implied an emission of -3,248,738.0 Gg of CO2 equivalent, or a GHG sink, in the Mata Atlantica biome and for the NFC.

Notice that the most important reductions in emission would occur in Amazonia and in the Mata Atlantica biomes. A large part of Mata Atlantica occurs in the traditional agricultural regions of Minas Gerais, São Paulo, Paraná and Santa Catarina. As seen in Table 10, the rate of emissions in conversion of Mata Atlantica to crops (or conversely, from crops to Mata Atlantica) is very high, what, combined with the large area shock in those regions, generate that result. In both scenarios, however, the largest reduction in CO2 would occur in the Amazonia biome, almost twice as much in this case as the Mata Atlantica. Still, it´s worth noticing that the fall in emissions by biome are proportionately different in the scenarios, reflecting the different shocks composition by activities.

Finally, Table 13 shows a summary of total emissions change in the economy in both scenarios, in physical quantities (Gg) of CO2 equivalents.

Table 13. Model results. Emissions in Gg of CO2, deviations from the baseline. Accumulated in 2025.

	Old Forest Code			New Forest Code		
Sector	TOTAL	APP	RL	TOTAL	APP	RL
Mining	2,726	1,488	644	1,548	911	415
Gasoline	1,377	715	364	790	437	244
Gasoline C	225	96	79	117	48	46
Combustible oil	-3,365	-1,706	-1,277	-2,072	-1,028	-872
Other fuels	-185	-73	-95	-112	-41	-62
Activity	-152,349	-58,984	-66,230	-88,880	-32,515	-44,929
7 LUC	-19,074,180	-8,512,530	-10,561,608	-12,408,183	-5,236,328	-7,171,834
Total	-19,225,751	-8,570,994	-10,628,124	-12,496,793	-5,268,515	-7,216,993

Source: model results.

Notice that the net results of the shocks are a reduction in emissions, even though general equilibrium effects cause emissions to increase in some sources. Notice also that LUC accounts for the larger reduction of CO2, as expected, and that the RL shocks causes a greater reduction than the APP shocks.

For the sake of comparison, the emissions on LUC observed in Brazil in 2005 amounted to 1,258,626 Gg of CO2. The total reduction in emissions of 19,225,751 Gg for the Old Forest Code Scenario in ten years represent an average of 1,922,575 Gg of CO2 per year, showing that the shocks more than compensate for the emissions caused by deforestation as projected in the model baseline.

Finally, it´s worth to highlight an important aspect of our results. Our model considers that reforestation reduces emissions by the same amount that is released when deforestation occur. Even though it´s a reasonable assumption in the long run, there is a time difference between the two cases, because while emissions in deforestation occur immediately, forests take a long period to recover, as well as the emissions sinks. Our results, then, represent potential emissions savings, which start when reforestation starts, but would be completed only in the future.

7. Final remarks

The results found in this paper highlight some important aspects related to the implementation of the NFC in Brazil, when compared to its previous version.

First, the cost of implementation of both versions would not be high in terms of GDP loss, and is smaller in the NFC. This social cost would amount to about 2.16% and 1.18% of GDP respectively in the OFC and the NFC, accumulated in 2025. Note that our simulation does not take into account any exogenous technological change, which could easily offset that loss. The potential environmental gains associated with the policies are likely to be high, in terms of biodiversity conservation.

Second, results show that there would be a significant reduction in GHG emissions in both scenarios, which would be large enough to compensate for the rate of deforestation projected in the baseline. The difference is that while deforestation occur only in the agricultural frontiers, and mainly in the Amazonia and Cerrados biomes, the forests recovering due to the FC scenarios would occur all over Brazil, and in many different biomes. Actually, our model results show that in Forest Code versions the main emissions reductions would occur in the Amazon and Mata Atlantica biomes. Mata Atlantica is characteristic of the South and Southeast regions in Brazil, the richest and most populated regions in the country, and one of the richest biomes in terms of biodiversity, a gain not evaluated in this paper.

A final point is still worth stressing in this discussion. Even though the aggregated social cost in terms of GDP loss are small, the regional impacts can be much greater in some cases. This is true for states in the agricultural frontier, which would lose the most. Nevertheless, even for the states in the older regions of Brazil, and which would typically lose less, another issue arises: the impact on smaller properties located in hilly lands or too close to riparian areas. The compensation for RL and APP in these cases could easily make then economically non-viable, a problem that is likely to be very serious in states like Santa Catarina, for example, where a large number of small properties occur.

This became a very difficult problem in the implementation of the Forest Code Law, which is presently awaiting for the ordinary regulations and implementation details in the congress. The pressure of organized groups against the implementation of the FC is high, and there are presently serious doubts about how much of it will actually be at work in the near future, since the new mechanisms and rules proposed in the congress are likely to reduce the FC original scope.

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