ECONOMIC EVALUATION OF PUBLIC POLICIES AIMING THE REDUCTION OF GREENHOUSE GAS EMISSIONS IN BRAZIL

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1 Introduction

According to the International Panel on Climate Change (IPCC 2001a) the change in the concentration of greenhouse gases in the atmosphere can cause an increase in the average temperature of the Earth of 1.4 to 5.8° Celsius in the next one hundred years. The United Nations, through the Framework Convention on Climate Change is aiming the "stabilization of concentration of greenhouse gases in the atmosphere at a level that avoid a dangerous human interference in the clime system". In the Conference of the Parts meetings (COP) international agreements between countries are discussed, in order to meet the targets established in the Convention. Among these agreements is the Kyoto Protocol (UNFCCC, 2001b), which establishes reductions targets for emissions for countries in the Annex I, for the first period of commitment, from the year 2008 to 2012.

Although Brazil is not included in the Annex I, and so does not have reduction targets for emissions in the first period, the present state of negotiations in the Climate Conventions brought to the discussions the need for some developing countries, like Brazil, China and India to have some kind of emissions reductions targets in the future. An initial assessment of the impacts upon the Brazilian economy of eventual targets on emissions reductions is the objective of this paper.

2 Objective

The main goal of this paper is to quantify the effects on the Brazilian economy of the introduction of public policies aiming to the reduction of greenhouse gases emissions. For this purpose a general equilibrium model of the Brazilian economy is developed to simulate the effects of that kind of policies, namely the quantitative restrictions of emissions. The model has a gas emissions module, which interacts with the core model equations. The next sections describe the main characteristics of the model, as well as the database used.

3 Literature review

The Brazilian literature has only a few studies that tried to evaluate quantitatively the effects of greenhouse gases' emissions reduction policies. Among them, Tourinho et all (2003) analyzed the main economic impacts of a policy of emissions reductions, using a general equilibrium model. The authors analyzed three different scenarios, with different values of a carbon tax. The results showed a small impact over total emissions, with the reduction falling between 0.198% and 1.36%. Transport, energy and sugar are the sectors

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that show the highest reductions in emissions levels, while construction is the sector that shows the largest increase in emissions. In this paper, however, emissions are calculated as CO2 emissions, and not in CO2 equivalents, which is the most appropriate measure for greenhouse effects analysis.

Lopes (2003) also used a general equilibrium model to analyze the effects of taxing emissions on the Brazilian economy. This author focused more specifically over the use of primary factors in this context, and also on the issues of energy substitution between capital and labor. The results of a preliminary version of the model the author showed that a reduction in emissions is related to a fall in aggregated country's activity level, as well as a fall in emissions, which were mainly caused by energy sources substitution.

Hilgemberg et al (2005) used an inter-regional input-output to quantify the CO2 emissions in the use of natural gas, alcohol and petroleum products in six Brazilian regions, and the impacts of emissions reductions policies. Their analysis had a regional focus, and concluded that the northeast regions would be specially affected by those policies.

None of the previous cited studies used the new database issued by the Ministry of Science and Technology used here, which constitutes the official Brazilian Initial National Communication to the United Nations Convention about Global Climate Change.

4 Methodology

A general equilibrium model of the Brazilian economy is used for the abovementioned analysis. It is a static, inter-regional bottom-up model, derived from the MMRF-GREEN model of Australia (Adams, Horridge and Witwer, 2002). The model was adapted and modified for the Brazilian economy, being the main modification the introduction in the model of mechanism for substitution alcohol/gasoline, a characteristic feature of the Brazilian fuel market which was magnified recently by the introduction in the country of the flexfuel engines[3] for vehicles. In this section the main characteristics of the model are described.

4.1 The general equilibrium model

The model has two main equations blocks: the core AGE model block, describing the core economy, and the gas emissions block. This separation, of course, is merely expositive, since the two blocks operate as one. Optimizing agent's behavior determines the equilibrium in product and factor markets, in a perfectly competitive setting. Labor demand at national level is determined by demographic variables (outside the model), and capital supply depends on rates of return of activities. Labor and capital are allowed to flow between regions in such a way that the factor stocks in each region reflects labor demands and relative capital returns. The perfect competition hypothesis implies the equality of prices and marginal costs in each sector inside each region. Demand equals supply in all markets, except the labor market, where disequilibrium conditions can occur.

In the production side, input demand and primary factors are combined to produce goods. A nested production tree uses a Leontief formulation for combining the

[3] Flexfuel engines can use as fuel gasoline, alcohol, or any blend of both.

composite/imported composite input and the composite primary factor. In the second level of the production tree the usual Armington formulation applies for imported and domestically produced inputs, while primary factors land, labor and capital are combined by a CES function to produce the composite primary factor. And, finally, the domestic products are also CES aggregates of products from 27 domestic origins.

Household demands are modeled through the Linear Expenditure System. Again, the products are CES aggregates between domestic and imported products, and the domestic products are a CES aggregate of the 27 regional origins inside the country. Exports face a negatively sloped demand curve.

4.2 The greenhouse emissions equations block

This block of equations links the gas emissions in the economy to the general economic system. Broadly speaking this set of equations comprises:

- A module of energy accounting and gas emissions, which accounts in details the gas emissions in each industry and each region;
- Mechanisms that allow the endogenous treatment of the effects of abatement actions in response to the introduction of specific policies;
- A mechanism that allows the explicit treatment of the alcohol/gasoline substitution in the Brazilian economy.

The model distinguishes the emissions in details, according to the emitting agent (industries plus the residential sector), the emitting region, and the emitting sector. The emissions can be associated to the energy consumption in each sector, or to the activity level of sectors (not linked to energy consumption, or fuel use), which is an important source of emissions for the Brazilian economy. Agriculture is the most important sector in emissions linked to the activity level in Brazil.

The emissions in fuel use are modeled as directly proportional to fuel use. To deal with the recent introduction in Brazil of the flexfuel technology, which allows vehicles to use gasoline, alcohol or any blend of both, a specific substitution module was introduced, for household consumption. In this module, households consume an alcohol/gasoline composite[4], whose composition depends on relative prices, and is intermediated by a substitution parameter. This parameter (the elasticity of substitution) is parameterized in the simulations, since its value is unknown.

5 Production activities and products in the model

The present version of the model has 38 activities and products, with each activity producing only one product. The aggregation focuses on the identification of the main fuels, namely gas, combustible oil, gasoline, alcohol, coal and gas for domestic use (GLP), included in the model in Other Refined Products. The sectors in the model can be seen in Table 1 bellow.

Table 1. Sectors and activities in the model.

No.	Sector in the model	Sector Description

[4] This composite is a CES aggregate between alcohol and gasoline, with a specific substitution elasticity parameter. Note that by gasoline it's meant actually the gasoalcool, which is the fuel used in Brazil, a mixture of alcohol and gasoline at fixed coefficients. The abovementioned substitution, then, is actually between gasoalcool and alcohol.

1	Arroz	Rice production
2	Algodao	Cotton production
3	Soja	Soybean production
4	CanaAcucar	Sugar cane production
5	GadoCorte	Livestock production
6	GadoLeite	Raw milk production
7	Avicultura	Poultry production
8	OutAnimais	Other animals production
9	Silvicultura	Forestry production
10	OutAgricolas	Other agricultural products
11	ExtratMiner	Mineral extraction
12	ExtPetrGas	Oil and gás extraction
13	CarvaoOut	Coal extraction
14	FabMinNonMet	Non metallic minerals
15	Siderurgia	Siderurgy
16	MetalurNFerr	Non Ferrous Metallurgy
17	OutMetalurg	Other metallurgical products
18	FabMaqVeic	Machines and vehicles
19	MaterEletric	Eletric material
20	FabEqEletric	Eletric Equipment
21	PapelGrafica	Paper and graphic
22	IndQuimica	Chemical Industry
23	OutQuimicos	Other Chemical Products
24	Alcool	Alcohol
25	Gasolina	Gasoline
26	OleoCombust	Combustible Oil
27	OutProdRefin	Other Refined Products, includes GLP*
28	PetroqBasica	Basic Petrochemicals
29	Gasoalcool	Gasoalcohol
30	Fertilizante	Fertilizers
31	IndTextil	Textiles
32	AlimBebida	Foods and Beverages
33	IndDiversas	Other Industries
34	ConstCivil	Civil Construction
35	SIUP	Public Utility Industrial Services
36	Comercio	Trade
37	Transporte	Transport
38	Serviços	Services

* - gas for residential use.

6 The core model and the gas emissions database

As mentioned previously, the model has two main databases: the core database and the gas emissions database. The core model database uses information from the Brazilian 1996 input-output table[5] and other surveys, like the 1996 Brazilian Agricultural Census (IBGE, 1996) and the 1996 Brazilian Household Survey (IBGE, 1996a). The gas emissions database is elaborated based on the Brazilian Initial National Communication to the United Nations Convention about Global Climate Change (Ministério da Ciência e

[5] This is the last official input-output table in Brazil.

Tecnologia, 2004) for the 1994 reference year. The consolidation of those two databases is an important part of this project, and is described in more detail bellow.

The gas emissions database is organized by kind of gas and emitting sector. From an emissions originating perspective by each productive sector, part of the emissions are originated in fuel use, and part related to the level of activity of each sector. This is an important distinction from a modeling point of view, since fuel use is intermediate consumption of industries, while emissions related to the activity level are not related to any specific input. The first step in the database preparation, then, consisted in allocating the emissions to each sector in the input-output (IO) matrix, according to its origin (intermediate consumption or activity). Then the emissions linked to fuel use were distributed to each sector according to its proportion in the use of each fuel, information gathered directly from the input-output tables.

For the emissions linked to the activity level of the sectors, however, an agreement between the information from the National Communication and the IO tables had to be done. In some cases the allocation is clear, as is the case of fugitive emissions in the Mining sector, which can be allocated directly to the correspondent sector in IO table. In other cases, however, the allocation it's much less clear, and required many different assumptions in several different situations[6].

The emissions originating in fossil fuels burning were associated basically to five different fuels: gas, coal, combustible oil, and gas for residential use (Other Refined Products). The different production activities in the model, then, having different energy use matrices, have also distinct emissions patterns. Besides the productive sectors in the model, another emitting sector is the final demand, which encompasses both the household and the government[7] demands, aggregated under the Residential use. And, finally, it should be stressed that emissions related to land use change (deforestation) were not accounted for in this paper, since they are not associated to the productive sectors in the IO table.

Table 2 brings the result of the allocation of the CO2 equivalent emissions by sector in the model[8]. In this table each specific gas[9] emissions was transformed in CO2 equivalent through the use of technical coefficients of transformation. As it can be seen from the table, most of the emissions in the Brazilian economy are related to the sector's activity level, and not to fuel use. In terms of emissions originating in fuel use, the combustible oil is the main emitting fuel. It should also be noted that the emissions in the use of gasoline do not appear associated to the final demand (Residential), but mainly to the Gasoalcool sector. This is due to the fact that in Brazil the final demand uses Gasoalcool, produced from Gasoline and Alcohol[10].

Table 2. Emissions matrix by production sector. Gg of CO2 equivalent.

	Oil and Gas	Coal	Gasoline	Combustible	Other	Total

[6] The details about this process were omitted to avoid clutter, but can be obtained with the authors upon request.

[7] Note, however, that the government just uses Services.

[8] Equivalent tables with emissions by type of gas are also available, but now shown here.

[9] The gases accounted for are: CO2, CH4, N2O, HFC23, HFC134a, CF4, C2F6, and SF6

[10] Actually, in the IO tables gasoalcohol is produced by the Trade sector. However, this is a margin sector, and this formulation wouldn't be appropriate. The database was then adjusted in order to make the intermediate consumption of gasoline appear mainly in the gasoalcohol producing sector, which combines alcohol and gasoline to produce gasoalcohol sold to the households (Residential).

SECTOR	Extraction (Gas)			Oil	Refined Products	Activity	
1 Arroz	0	0	0	368.0	11.7	15828.5	16208.1
2 Algodao	0	0	0	87.2	2.8	850.4	940.4
3 Soja	0	0	0	997.1	31.6	22058.7	23087.5
4 CanaAcucar	0	0	0	1068.2	33.9	10821.5	11923.5
5 GadoCorte	0	0	0	1347.5	42.7	220275.9	221666.2
6 GadoLeite	0	0	0	935.0	29.6	39438.4	40403.1
7 Avicultura	0	0	0	780.7	24.7	2893.0	3698.4
8 OutAnimais	0	0	0	526.8	16.7	22956.9	23500.4
9 Silvicultura	0	0	0	236.3	7.5	-46473.9	-46230.2
10 OutAgricolas	0	0	0	6219.0	197.6	34038.6	40455.2
11 ExtratMiner	0	44.3	0	3482.4	125.4	0	3652.1
12 ExtPetrGas	0	601.4	0	588.3	22.2	4884.7	6096.5
13 CarvaoOut	0	34.4	0	20.8	0.8	2472.2	2528.2
14 FabMinNonMet	4.5	686.2	0	6320.0	160.4	13489.0	20660.1
15 Siderurgia	0	37964.6	0	2393.2	142.8	0	40500.6
16 MetalurNFerr	0	19.0	0	546.5	28.9	4447.3	5041.7
17 OutMetalurg	0	1136.9	0	1468.6	119.8	0	2725.2
18 FabMaqVeic	0	38.1	0	2023.4	398.8	162.5	2622.9
19 MaterEletric	0	2.8	0	360.8	189.4	0	553.0
20 FabEqEletric	0	0.2	0	203.4	21.2	0	224.7
21 PapelGrafica	0	0	0	2793.6	97.6	0	2891.2
22 IndQuimica	5642.8	215.2	0.1	2406.2	1062.5	7326.0	16652.9
23 OutQuimicos	236.9	366.5	0	1377.0	197.7	250.0	2428.0
24 Alcool	0	0.3	0	1179.9	43.0	0	1223.3
25 Gasolina	6920.1	0	0	1568.0	1090.8	0	9578.9
26 OleoCombust	8038.9	0	0	1821.5	1267.1	0	11127.5
27 OutProdRefin	6961.7	16.6	0	1593.4	1098.6	0	9670.3
28 PetroqBasica	7585.2	46.5	0	1772.7	1199.1	0	10603.5
29 Gasoalcool	0	0	27221.6	0	0	0	27221.6
30 Fertilizante	65.5	210.6	0	300.8	101.8	0	678.8
31 IndTextil	7.8	0	1.0	1178.8	55.5	0	1243.1
32 AlimBebida	0	4.2	0	6379.4	194.0	0	6577.7
33 IndDiversas	369.4	8.1	272.2	3702.7	201.6	0	4554.0
34 ConstCivil	0	0	0	5368.1	804.4	0	6172.6
35 SIUP	37.8	658.6	0	2555.7	55.0	20626.0	23933.1
36 Comercio	0	80.2	66.2	4993.0	172.2	0	5311.6
37 Transporte	0	0	40.8	37909.6	2934.9	0	40885.2
38 Servicos	48.3	55.3	2042.1	8476.8	732.3	0	11354.8
39 Residencial	0	0	0	27.7	4246.4	0	4274.1

As it can be seen from the table, Agriculture is one of the most important emitting sectors in Brazil, and inside it the Livestock sector (Pecuária de Corte), which has its emissions associated to the level of activity. The above table was constructed through the use of technical coefficients of transformation[11] of gases in CO2 equivalents, whose values can be seen in Table 3 . One of the simulations to be developed in this paper involves the conversion coefficient of CH4 from a value of 21 to 6.

Table 3. Technical coefficients of conversion to CO2 equivalents.

Gases	Technical coefficient of conversion to Equivalent CO2 (GWP)*
1 CO2 Gg	1
2 CH4 Gg	21
3 N2O Gg	310
4 HFC23 ton	11700
5 HFC134a ton	1300
6 CF4 ton	6500
7 C2F6 ton	9200
8 SF6 ton	23900

* - Global Warming Potential

And, finally, regarding the above information, it should be stressed again that emissions from deforestation are not covered here. These emissions are actually the most important source of emissions in Brazil, accounting for about 80% of total CO2 emissions in 1994, or 58% of total emissions in terms of CO2 equivalents in the same year.

7 The simulations

The simulations done in this paper involve the introduction of a carbon tax in the economy, in different scenarios, to be described bellow. First, however, it is necessary to address the mechanisms by which this tax feeds into the main core model. AS noted before, the emissions in the model are basically of two types: those originating in the burning of fossil fuels, and those linked to the level of activities of sectors. In the case of a tax being introduced in the use of fuels, it is translated by the model into a tax on fuels. In the case of a tax being introduced on emissions originating on the sector’s activity level, the carbon tax is converted into a tax on each emitting sector’s product. In both cases this procedure is necessary since all taxation in the model is done through an indirect tax system over products flows.

8 Model’s closure

The main aspects of the closure used in this paper are as follows:

- The capital stock of the economy is endogenous, and adjusts to equalize the rate of return across activities. If the rate of return increases in one activity, the capital stock also accumulates, to reduce that rate.
- The investment by sector is proportional to the capital stock variation.
- The household consumption is endogenous, in real terms.
- The aggregated employment is fixed, being the real wage the variable that adjusts between the productive sectors to ratify the fixed total labor employment.

[11] The coefficient of conversion if the Global Warming Potential (GWP). There is no general agreement about the value of the coefficients for the CH4.

However, labor is free to move between sectors and regions, guided by real wage differentials.

- The government deficit is exogenous at national level.
- Considering the simulations involve the introduction of a tax over emissions, the government budget neutrality is obtained through the devolution of the equivalent tax collection to the society, via a subsidy to the household consumption.
- The trade balance, as a share of the GDP, is endogenous.
- The Consumer Price Index is the numeraire.

This closure gives the simulations a long run flavor, in the sense that the time period is enough for capital to accumulate, as well as for the real wages to adjust.

9 The scenarios to be simulated

Six different scenarios were analyzed, as described bellow:

- Scenario 1 (CARBTAX1): introduction of a carbon tax of R$10/ton[12] of carbon equivalent emissions, on fuel use only. Elasticity of substitution between gasoalcohol/alcohol with value 1.0.
- Scenario 2 (CARBTAX05): the same scenario as above, with elasticity of substitution between gasoalcohol/alcohol with value 0.5.
- Scenario 3 (CARBTX05x): R$10/ton carbon equivalent emissions, with incidence both on fuel use and activity level. Elasticity of substitution between gasoalcohol/alcohol with value 0.5.
- Scenario 4 (CARBTXAT): R$10/ton carbon equivalent emissions, with incidence on activity level only. Elasticity of substitution between gasoalcohol/alcohol with value 0.5.
- Scenario 5 (CARBTXETS): R$10/ton carbon equivalent emissions, with incidence on the level of activity of the sectors included in the European Trade Scheme (EU/ETS). In terms of the sectoral classification of the model, they comprise the following sectors: ExtratMiner, ExtPetrGas, CarvaoOut, FabMinNonMet, Siderurgia, MetalurNFerr, OutMetalurg, PapelGrafica, PetroqBasica, SIUP. Elasticity of substitution between gasoalcohol/alcohol with value 0.5.
- Scenario 6 (CARBMET6): R$10/ton carbon equivalent emissions, with incidence both on fuel use and activity level. Elasticity of substitution between gasoalcohol/alcohol with value 0.5. GWP coefficient for the CH3 (methane) gas with value 6 (as opposed to 21 in the other simulations).

As noticed previously, there are no estimates do the date for the substitution parameter gasoalcohol/alcohol. For this reason, its value was parameterized in one of the simulated scenarios. In most of them, however, the option was to use a value of 0.5, since the fleet of cars that use exclusively gasoline in Brazil is still large. The value of this parameter is expected to increase with the size of the fleet of flexfuel cars.

Throughout the text the simulations will be identified by code names. Then, for example, CARBMET6 is the simulation where the coefficient GWP assumes value of 6, and so on.

[12] R$10 is equivalent to approximately US$9.63, in 1996 values.

10 Results

In what follows, the results of the simulations are presented and discussed. Initially, Table 4 shows some macroeconomic results in order to establish a basis to analyze the sectoral results.

Table 4. Model results. Selected macroeconomic variables. Percent variation

Variable	carbtax1	carbtax05	carbtax05x	carbtxat	carbtxets	carbtmet6
Real GDP	-0.32	-0.32	-0.39	-0.05	0.36	-0.28
Capital stock	-0.60	-0.60	-0.88	-0.27	0.29	-0.70
Household real consumption	-0.05	-0.05	-0.54	-0.48	0.05	-0.29
Real investment	-0.60	-0.60	-0.88	-0.27	0.29	-0.70
Balance of Trade/GDP	-1.02	-1.02	1.47	2.55	1.86	0.66
Exports (quantum)	-2.78	-2.77	2.39	5.32	3.95	0.76
Imports (quantum)	-0.45	-0.45	-0.83	-0.36	0.27	-0.61
Terms of trade	0.34	0.34	-0.76	-1.11	-0.21	-0.31
Real devaluation	0.30	0.30	2.34	2.04	0.35	1.52
Real wage	-0.25	-0.25	-1.03	-0.79	-0.42	-0.75
Total emissions of CO2 eq.	-0.84	-0.82	-4.96	-4.12	0.84	-3.27

The values in Table 4 represent percentage changes results in the selected variables, caused by the policy shock introduced (the carbon tax). In the first two scenarios the carbon tax incidence is just on emissions originating in burning fossil fuels, while in the third scenario the tax incidence are both on combustibles and the activity. As it can be seen, these first two scenarios present the second largest fall in GDP, around o.32%. These values don't differ much across the first two simulations, which means that the value of the elasticity of substitution between gasoalcohol/alcohol, the only differential in the simulations, has little effect upon that variable (GDP). However, it will be seen that it has important consequences for sectoral results. Regarding emissions reductions, it can be seen that the first two scenarios would cause the smallest reduction, around 0.84%. Here, a slightly smaller value is seen in the second scenario, what is caused by the higher difficulty to substitute between gasoalcohol and alcohol when the tax on gasoalcohol is introduced.

The analysis of the third scenario make it clear that, for the particular emissions matrix of the Brazilian economy any policy to reduce emissions via taxation must also include the taxation on emissions linked to activities. As it can be seen, the third scenario (CARBTAX05x), which differs from the second scenario just for the taxation on activity emissions, would result in a 4.96% reduction in total emissions, at an almost identical cost in terms of GDP loss.

These results are strongly linked to the behavior of household consumption and investment demands in the model. It is worth to notice that the carbon tax is introduced on fuel use emissions as a tax on fuel prices, which affects the economy as a whole, and especially the sectors which are more intensive in fuel use. Notice also that in the next simulation (scenario CARBTAXAT), where the tax incidence is just on activity emissions, the GDP almost does not change, but emissions fall by 4.12%.

It is also interesting to notice that, contrary to the other scenarios, the scenario CARBTXETS results in a GDP increase. In this case, the tax is introduced just on emissions linked to the activity level of sectors included in the EU/ETS lists. These are basically industrial inputs producing sectors used domestically, causing the effect of the tax do be distributed along the producing chains, with an impact relatively smaller in the general economy. The redistribution of the tax to the consumers in the form of a subsidy, however, raises household demands, and the GDP by 0.36%. These general equilibrium effects are related to a CO2 equivalent emissions increase of 0.84%, on the contrary of what was observed in the other scenarios. This result, of course, is associated to the treatment given to the tax neutrality (or government budget neutrality) in this paper, namely the paying back to households the tax collection on emissions, in the form of a subsidy.

Table 5 shows model results for the productive sector’s activity level variation. This table allows verifying in more details the effects of the hypothesis about the value of the gasoalcohol/alcohol substitution elasticity. A smaller value for that parameter makes it harder to substitute between those fuels in response to changes in relative prices. The introduction of the carbon tax on fossil fuels makes gasoalcohol relatively more expensive than the alcohol, leading to substitution towards alcohol, which is more intense the higher the value of the substitution parameter (higher in CARBTAX1 than in CARBTAX05). As it can be seen from Table 5, the imposition of the tax on emissions linked to fuels use reduces the activity level of the alcohol producing industry less in scenario CARBTAX1 (-0.41%) than in scenario CARBTX05 (-0.81%), and inversely for the gasoline producing industry, with values respectively of -1.67% and -1.43%. These results point to the fact that the sensibility of the alcohol producing sector will become less sensible to the introduction of carbon tax on fuel use to the extent that the flexfuel engine vehicles fleet increases (what will increase the easy of substitution between gasoalcohol/alcohol).

Table 5. Model results. Production sectors' activity level. Percent variation.

Production sector	carbtax1	carbtax05	carbtax05x	carbtxat	carbtxets	carbtmet6
Arroz	-0.20	-0.20	-5.53	-5.37	1.13	-2.99
Algodao	0.01	0.01	3.05	3.01	0.82	1.78
Soja	-0.29	-0.29	-3.47	-3.20	1.01	-2.37
CanaAcucar	-0.42	-0.53	-1.51	-0.99	0.51	-1.04
GadoCorte	-0.16	-0.16	-8.07	-7.96	1.29	-4.27
GadoLeite	-0.20	-0.20	-2.93	-2.75	1.03	-1.52
Avicultura	-0.07	-0.07	-3.06	-3.03	-0.40	-1.88
OutAnimais	-0.15	-0.14	-7.22	-7.13	0.91	-3.89
Silvicultura	-0.23	-0.23	12.75	12.98	0.38	13.03
OutAgricolas	-0.24	-0.24	-1.31	-1.07	0.55	-0.87
ExtratMiner	-2.84	-2.85	4.12	7.23	0.99	1.29
ExtPetrGas	-1.20	-1.15	-0.47	0.72	0.22	-0.75
CarvaoOut	-2.98	-2.98	-1.38	1.48	-1.95	-2.02
FabMinNonMet	-0.75	-0.75	-0.48	0.30	0.13	-0.61
Siderurgia	-5.80	-5.80	-1.15	5.14	0.83	-2.61
MetalurNFerr	-0.72	-0.72	1.66	2.43	-0.13	0.47
OutMetalurg	-0.86	-0.86	0.82	1.73	0.66	0.23
FabMaqVeic	-0.79	-0.79	3.46	4.34	1.07	1.78
MaterEletric	-0.44	-0.44	0.29	0.75	0.32	0.03
FabEqEletric	-0.26	-0.26	-0.48	-0.21	0.17	-0.34
PapelGrafica	-0.21	-0.21	0.63	0.85	0.49	0.36
IndQuimica	-0.58	-0.58	0.59	1.21	0.57	0.09
OutQuimicos	-0.74	-0.74	0.72	1.50	0.62	0.11
Alcool	-0.41	-0.81	-1.53	-0.73	-0.11	-1.30
Gasolina	-1.67	-1.43	-1.88	-0.45	0.11	-1.66

OleoCombust	-0.86	-0.87	-0.36	0.54	0.54	-0.47
OutProdRefin	-1.09	-1.07	-0.65	0.45	0.39	-0.76
PetroqBasica	-1.16	-1.13	-0.12	1.04	0.48	-0.51
Gasoalcool	-1.74	-1.47	-2.10	-0.64	0.08	-1.81
Fertilizante	-0.32	-0.33	-1.46	-1.13	0.69	-0.93
IndTextil	0.16	0.16	3.01	2.81	0.81	1.84
AlimBebida	-0.22	-0.21	-4.95	-4.78	1.14	-2.64
IndDiversas	-0.28	-0.28	3.16	3.46	1.06	1.86
ConstCivil	-0.58	-0.58	-0.84	-0.24	0.29	-0.66
SIUP	-0.41	-0.41	-0.40	0.04	0.06	-0.31
Comercio	-0.33	-0.32	-0.23	0.11	0.61	-0.15
Transporte	-0.83	-0.83	0.06	0.93	0.52	-0.22
Servicos	-0.09	-0.09	-0.26	-0.16	0.20	-0.14

Another interesting point to be noted from Table 5 is related to the Forestry sector. As it can be seen, the activity level of this sector increases considerably in the simulations where the carbon tax incidence is on emissions linked to the activity level. That happens because this sector is actually a carbon sink, that’s to say, it has negative emissions on the initial database. The equivalent tax on this sector, then, is actually a subsidy, what raises its use and, consequently, its activity level.

The scenario CARBMET6 compares directly to the scenario CARBTX05x, with the only difference between them the GWP coefficient used for the methane gas (CH4), which in this scenario has the value of 6[13]. This causes the emissions associated to the level of activity of the Livestock sector (GadoCorte), the main emitting sector of CH4 and one of the main emitting sectors in the Brazilian economy, to be smaller in this scenario. As it can be seen from the results, the scenario where the GWP of the methane gas is higher would cause a larger fall in the level of activity of the Livestock sector, since the equivalent tax on production required would be considerably smaller. The same type of effect, in smaller proportions, can be seen in the raw milk production sector (GadoLeite). This simulation, then, emphasize the importance of the value of certain parameters for the analysis, especially if the focus is on particular sectors of the economy.

In the CARBTXAT scenario, where the carbon tax is introduced only on emissions linked to the activity level, there are still other results that should be noticed. Initially, a strong reduction on the activity level of livestock and a rise in forestry is observed, by the very same reasons discussed above. Other sectors, however, like the mining (ExtratMiner) and siderurgy (Siderurgia) also show an increase in production. These are sectors where the emissions are mainly associated to fuel use, and not to the activity level. In these cases, the increase in exports, caused by the real exchange rates devaluation, causes the increase in the activity level.

In other cases, as is the case of the metallurgy of non-ferrous metals (MetalurNFerr), although there are emissions associated to the level of activity, the effect of the introduction of the tax is compensated by the increase in exports, since they represent a share of approximately 20% of total use in the economy in the base year. This is an example of case where opposing forces combine to give the final result, and are adequately computed by the model.

[13] As seen previously, in the scenario CARBTAX05x the GWP for the CH4 gas has value 21.

Another useful way of looking to the results is to analyze the variation of emissions according the emitting source, what can be seen in Table 6.

Table 6. Model results. Percent variation in emissions of CO2 equivalent, according to the emitting source.

Fonte emissora	carbtax1	carbtax05	carbtax05x	carbtxat	carbtxets	carbtmet6
ExtPetrGas	-1.08	-1.03	-0.48	0.58	0.39	-0.67
CarvaoOut	-5.33	-5.33	-1.00	4.81	0.89	-2.37
Gasolina	-1.61	-1.37	-1.90	-0.54	0.11	-0.37
OleoCombust	-0.77	-0.77	-0.33	0.47	0.55	-0.41
OutProdRefin	-1.03	-1.02	-0.67	0.38	0.38	-0.75
Activity	-0.26	-0.26	-7.69	-7.46	1.05	-6.06

It can be seen from Table 6 that the reductions in emissions originating in fuel use are larger, in general, in the scenarios where the carbon tax is imposed only fuel use, being the exception gasoline, whose emissions reduce more in CARBTAX05x than in the first two scenarios. To see why this happens, it is necessary to go back to the results in Table 4, which shows the macroeconomic results from the model. It can be seen there that the household consumption falls more in the simulations which involve only the tax over the level of activity than in those where the tax is over fuel use only. The product gasoline is sold basically for gasoalcohol production, which is consumed almost entirely (81.9% of total use) by the households. The fall in household consumption, then, causes an additional fall in the use of gasoline, derived from the fall in the consumption of gasoalcohol. The same doesn't happen to the other fuels in the model[14]. The larger reductions in emissions associated to the level of activity appear, of course, when activity is also taxed, with the exception of the CARTXETS scenario. But this last scenario, however, is associated to an increase in emissions, as seen previously.

The percent variations in emissions levels, by production sector in the model, can be seen in Table 7. In this table, attention should be called to the fact that the results showed for the forestry sector (Silvicultura) should be interpreted with a opposite signal, since this sector is actually a "carbon sink", and have negative emissions in the initial database. In this way a 12.75% variation in this sector's emissions in scenario CARBTAX05X means that variation over a total of -46,230Gg of CO2 equivalent in the base year, or a reduction of 5,984.33 Gg of CO2 equivalent in that scenario. Whenever forestry (Silvicultura) increases its activity level, it will be reducing the associated emissions.

Table 7. Model results. Percent variations in CO2 equivalents, by sector.

Production sector	carbtax1	carbtax05	carbtax05x	carbtxat	carbtxets	carbtmet6
Arroz	-0.20	-0.20	-5.53	-5.38	1.13	-3.00
Algodao	0.01	0.01	3.05	3.01	0.82	1.78
Soja	-0.29	-0.29	-3.47	-3.20	1.00	-2.37
CanaAcucar	-0.42	-0.53	-1.52	-1.00	0.51	-1.04
GadoCorte	-0.16	-0.16	-8.08	-7.97	1.29	-4.27
GadoLeite	-0.20	-0.20	-2.94	-2.76	1.03	-1.52
Avicultura	-0.07	-0.07	-3.06	-3.03	-0.40	-1.88

[14] Even the product Other Refined Products, which is basically gás used for cooking (GLP) has its consumption considerably more distributed in the economy, being the households responsible for just 26% of its total consumption.

OutAnimais	-0.15	-0.14	-7.23	-7.14	0.90	-3.90
Silvicultura*	-0.23*	-0.23*	12.75*	12.98*	0.38*	13.03*
OutAgricolas	-0.24	-0.24	-1.30	-1.07	0.55	-0.86
ExtratMiner	-2.85	-2.86	4.16	7.28	1.00	1.31
ExtPetrGas	-1.20	-1.15	-0.47	0.72	0.22	-0.75
CarvaoOut	-2.98	-2.98	-1.38	1.49	-1.95	-2.02
FabMinNonMet	-0.75	-0.75	-0.48	0.30	0.13	-0.61
Siderurgia	-5.83	-5.84	-1.13	5.23	0.93	-2.61
MetalurNFerr	-0.72	-0.72	1.66	2.43	-0.13	0.47
OutMetalurg	-0.89	-0.89	0.83	1.79	0.73	0.23
FabMaqVeic	-0.79	-0.79	3.49	4.37	1.08	1.80
MaterEletric	-0.44	-0.44	0.30	0.76	0.32	0.04
FabEqEletric	-0.26	-0.26	-0.47	-0.20	0.17	-0.34
PapelGrafica	-0.21	-0.21	0.63	0.85	0.50	0.36
IndQuimica	-0.59	-0.59	0.55	1.18	0.50	0.04
OutQuimicos	-0.74	-0.74	0.69	1.47	0.60	0.08
Alcool	-0.41	-0.81	-1.53	-0.73	-0.11	-1.30
Gasolina	-1.68	-1.44	-1.88	-0.45	0.10	-1.67
OleoCombust	-0.87	-0.87	-0.36	0.55	0.54	-0.47
OutProdRefin	-1.09	-1.08	-0.65	0.46	0.38	-0.77
PetroqBasica	-1.16	-1.14	-0.12	1.05	0.47	-0.51
Gasoalcool	-1.74	-1.47	-2.10	-0.64	0.08	-1.55
Fertilizante	-0.32	-0.33	-1.45	-1.12	0.69	-0.93
IndTextil	0.06	0.05	3.11	3.02	0.82	1.84
AlimBebida	-0.22	-0.22	-4.74	-4.56	1.16	-2.52
IndDiversas	-0.28	-0.28	3.16	3.46	1.04	1.85
ConstCivil	-0.58	-0.58	-0.83	-0.23	0.29	-0.66
SIUP	-0.41	-0.41	-0.40	0.04	0.06	-0.31
Comercio	-0.32	-0.32	-0.27	0.06	0.61	-0.19
Transporte	-0.84	-0.84	0.06	0.94	0.52	-0.22
Servicos	-0.13	-0.13	-0.08	0.06	0.32	-0.03
Residencial	-1.49	-1.49	-2.20	-0.71	0.07	-1.87

* - the emissions of Silvicultura (Forestry) should be interpreted with opposite signal.

The results analyzed so far raise important questions for the introduction of a carbon tax on the Brazilian economy. As discussed previously, the introduction of the carbon tax on emissions linked both to fuel use and the level of activities are more effective in terms of emissions reductions, due to the importance of emissions linked to activities on Brazil. It was also shown that the agriculture sector is one of the most important emitting sectors of the economy. The imposition of a carbon tax on these emissions, then, being implemented through an equivalent tax on products, would probably have important distributive consequences, since the burden of the tax on agriculture would have to be transmitted to food prices. This effect can be evaluated in Table 8. As it can be seen from the table, the increase in prices of raw agricultural products would reflect in an increase in the price of food (AlimBebidas) of 3.93% and 3.84% respectively in scenarios CARBTAX05x and CARBTAXAT, where the emissions linked to the activity level are taxed. Food prices show the largest price increase after fuel prices and some raw agricultural prices.

Table 8. Model results. Consumer prices variation.

Product	carbtax1	carbtax05	carbtax05x	carbtxat	carbtxets	carbtmet6
Arroz	0.46	0.46	1.79	1.33	0.12	1.57

Algodao	0.51	0.51	1.45	0.93	0.12	1.25
Soja	0.55	0.55	1.09	0.53	0.24	1.20
CanaAcucar	0.10	0.03	0.03	-0.00	0.18	1.01
GadoCorte	0.49	0.49	10.37	9.86	0.33	5.00
GadoLeite	-0.01	-0.01	4.12	4.13	0.42	2.09
Avicultura	0.12	0.12	0.88	0.77	0.45	0.72
OutAnimais	0.61	0.61	4.42	3.81	0.16	3.29
Silvicultura	-0.06	-0.06	-27.33	-27.28	0.02	-26.78
OutAgricolas	0.01	0.01	-0.20	-0.22	0.13	0.23
ExtratMiner	0.74	0.74	0.78	0.04	0.10	0.78
ExtPetrGas	3.34	3.35	7.49	3.47	-0.04	4.15
CarvaoOut	13.71	13.72	14.20	0.75	1.84	12.98
FabMinNonMet	0.71	0.71	1.58	0.87	1.17	1.58
Siderurgia	1.84	1.85	2.07	0.22	0.22	1.89
MetalurNFerr	0.20	0.20	0.92	0.72	0.82	0.84
OutMetalurg	0.73	0.73	0.41	-0.32	0.03	0.52
FabMaqVeic	0.20	0.20	-0.11	-0.31	-0.03	0.03
MaterEletric	0.21	0.21	-0.04	-0.25	0.03	0.11
FabEqEletric	0.04	0.04	0.03	-0.01	0.08	0.08
PapelGrafica	-0.05	-0.05	-0.48	-0.43	0.05	-0.27
IndQuimica	0.30	0.30	0.43	0.13	0.07	0.48
OutQuimicos	0.24	0.24	0.35	0.11	0.17	0.43
Alcool	0.16	0.14	0.40	0.26	0.39	0.55
Gasolina	1.55	1.55	1.34	-0.12	0.06	1.51
OleoCombust	10.09	10.09	10.12	0.04	0.28	10.14
OutProdRefin	2.08	2.08	2.09	0.01	0.20	2.14
PetroqBasica	1.22	1.22	1.27	0.06	0.33	1.34
Gasoalcool	2.73	2.73	2.95	0.25	0.52	2.97
Fertilizante	0.19	0.19	-0.04	-0.22	0.02	0.11
IndTextil	-0.09	-0.09	-0.41	-0.32	-0.06	-0.25
AlimBebida	0.10	0.10	3.93	3.84	0.36	2.13
IndDiversas	0.08	0.08	0.34	0.26	0.15	0.24
ConstCivil	0.57	0.57	0.74	0.17	0.17	0.71
SIUP	-0.13	-0.13	0.43	0.56	1.10	0.15
Comercio	-0.36	-0.36	-1.02	-0.66	-0.02	-0.72
Transporte	0.83	0.83	0.29	-0.54	0.03	0.55
Servicos	-0.38	-0.38	-0.99	-0.61	0.08	-0.70

11 Allowing endogenous technological changes in the simulated scenarios

No technological change is considered in the abovementioned scenarios. As noted by Adams et alii (2002), however, this is not a very realistic hypothesis in a long run scenario. It can be relaxed to consider that the change in relative prices introduced by the carbon tax would cause a reaction from the agents in relation to the production technology. In this section the results of scenarios that take into account two different types of endogenous technological changes are presented.

The first type of technological change would reduce the fugitive emissions (those not associated to fuel use) when the carbon tax is introduced. This change is modeled as directly proportional to the carbon tax, through a proportionality parameter. There are no estimates for this parameter for the Brazilian economy. In the international literature Adams et alii (2002) used, for the Australian economy, values for that parameter which would determine a reduction in emissions associated to the level of activity of 60% for agriculture; 70% for black coal mining; 40% for crude oil extraction; 25% for aluminum production and refineries; and 10% for natural gas extraction and brown coal, chemicals (except petroleum), cement and other services, for each A$100 of tax for CO2 equivalent ton[15]. In the simulations here performed, then, values adapted from those used by Adams et alii 2002) will be used, shown in Table 9, bellow.

Table 9. Percent reduction in emissions linked to the activity level, by each R$100 of carbon tax by ton of CO2 equivalent.

Production sector	% reduction in emissions associated to the level of activity of industries, by each R$100 per ton of CO2 equivalent
1 Arroz	20
2 Algodao	20
3 Soja	20
4 CanaAcucar	20
5 GadoCorte	20
6 GadoLeite	20
7 Avicultura	20
8 OutAnimais	20
12 ExtPetrGas	30
13 CarvaoOut	40
14 FabMinNonMet	10
22 IndQuimica	20
23 OutQuimicos	20
35 SIUP	10

The results in Table 9 are percentage change reductions in emissions associated to the activity level of the production sectors, by each R$100 of carbon tax by ton of CO2 equivalent. Considering the simulations in this paper involve the introduction of a carbon tax of R$10 per ton of CO2 equivalent, the reductions in the model represent only a tenth of those showed in the table.

The reduction in carbon emissions due to the endogenous technological change would cause a reduction in cost for the involved sectors. Technological changes, however, demands investments to occur, what implies new expenditures to the enterprises. The model takes this into account through the introduction of an accompanying cost for this technological change, which exactly compensates the amount of tax to be saved via emissions abatement.

The second mechanism to be endogenously considered allows a reduction in the use of the input whose price is increasing. This mechanism affects mainly the use of fuels, which price is directly affected by the introduction of the carbon tax. This mechanism try to represent the fact that firms, when faced with an increase in the price of fuel, would try to use more efficient industrial methods to save that input. Again, this would be done at a cost, and the model treats this endogenous technological as cost neutral, that’s to say, the technological change happens to compensate exactly the cost increase caused by the tax. As in the previous case, this substitution between inputs is controlled by an elasticity of

[15] The authors emphasize that those values, calculated based on point estimates for Austrália, are quite speculative and, for the Australian economy, are really important just for agriculture.

substitution, whose value is assumed as 0.15 for all production sectors in the model[16]. Taking into account these new hypotheses about the economy's adjustment, the results for the scenarios are modified, and presented in what follows.

Table 10. Model results, selected macroeconomic variables. Percent variation. Endogenous technological change.

Variable	carbtax1	carbtax05	carbtax05x	carbtxat	carbtxets	carbtmet6
Real GDP	-0.32	-0.32	-0.34	-0.00	0.35	-0.25
Capital stock	-0.60	-0.60	-0.82	-0.20	0.28	-0.67
Household real consumption	-0.05	-0.05	-0.55	-0.50	0.05	-0.30
Real investment	-0.60	-0.60	-0.82	-0.20	0.28	-0.67
Balance of Trade/GDP	-1.01	-1.01	1.91	2.99	1.82	0.93
Exports (quantum)	-2.94	-2.93	3.05	6.14	3.84	1.08
Imports (quantum)	-0.59	-0.59	-0.97	-0.35	0.25	-0.75
Terms of trade	0.34	0.34	-0.78	-1.13	-0.20	-0.32
Real devaluation	0.29	0.29	2.34	2.05	0.33	1.52
Real wage	-0.25	-0.25	-1.04	-0.80	-0.41	-0.76
Total emissions of CO2 eq.	-1.68	-1.67	-8.50	-6.83	0.65	-5.56

As it can be seen comparing Table 10 and Table 4, the macroeconomic results don't change significantly. The same, however, doesn't happen to total emissions, whose reduction is considerably higher when technological change is incorporated to the model. This is an important point to be stressed. The efficiency of the carbon tax to reduce emissions can be considerably amplified through policies that facilitate the technological change in the relevant emission sectors. The introduction of the tax, then, should be accompanied by other policy instruments, like especial credit lines, facilitation of imports of equipment and services, and specific investments in research that can make it easier for the firms, for given value of the tax, maximize the reductions of emissions. As it can be seen, the reduction of emissions almost doubles in some scenarios, highlighting the importance of technological change in the discussions of emissions' reductions.

The reductions of emissions by production sector can be seen in Table 11.

Table 11. Model results. Activity level of industries. Percent variation. Endogenous technological change.

Setor	cbtax1a	cbtax05a	cbtx05xa	cbtxata	cbtxetsa	cbtmet6a
Arroz	-0.22	-0.22	-5.34	-5.17	1.09	-3.08
Algodao	-0.00	-0.00	2.81	2.78	0.76	1.56
Soja	-0.34	-0.34	-3.11	-2.80	0.95	-2.33
CanaAcucar	-0.36	-0.46	-1.33	-0.87	0.47	-1.04
GadoCorte	-0.19	-0.19	-11.88	-11.77	1.20	-6.14
GadoLeite	-0.21	-0.21	-3.01	-2.82	0.98	-1.54
Avicultura	-0.09	-0.08	-2.67	-2.62	-0.40	-1.68
OutAnimais	-0.20	-0.19	-8.17	-8.04	0.86	-4.78
Silvicultura	-0.22	-0.22	15.05	15.29	0.37	15.20
OutAgricolas	-0.24	-0.24	-1.20	-0.96	0.53	-0.83
ExtratMiner	-2.79	-2.80	4.28	7.33	0.94	1.41
ExtPetrGas	-2.39	-2.34	-1.77	0.59	0.09	-2.03
CarvaoOut	-7.09	-7.09	-5.84	1.06	-2.39	-6.08
FabMinNonMet	-0.75	-0.75	-0.49	0.28	0.00	-0.66
Siderurgia	-5.85	-5.85	-1.10	5.23	0.80	-2.60

[16] Adams et alii (2002) use the value of 0.25 for that parameter, for the Australian economy.

MetalurNFerr	-0.67	-0.67	1.70	2.41	-0.22	0.49
OutMetalurg	-0.88	-0.88	0.93	1.87	0.65	0.29
FabMaqVeic	-0.78	-0.78	3.54	4.41	1.04	1.84
MaterEletric	-0.42	-0.42	0.33	0.78	0.31	0.07
FabEqEletric	-0.26	-0.26	-0.47	-0.20	0.16	-0.34
PapelGrafica	-0.20	-0.20	0.74	0.95	0.49	0.43
IndQuimica	-0.58	-0.58	0.63	1.24	0.56	0.11
OutQuimicos	-0.74	-0.74	0.71	1.49	0.59	0.09
Alcool	-0.24	-0.64	-1.40	-0.77	-0.11	-1.15
Gasolina	-2.01	-1.78	-2.22	-0.46	0.08	-2.00
OleoCombust	-3.12	-3.13	-2.63	0.52	0.47	-2.74
OutProdRefin	-1.48	-1.47	-1.05	0.44	0.35	-1.16
PetroqBasica	-1.53	-1.50	-0.46	1.08	0.45	-0.86
Gasoalcool	-1.81	-1.54	-2.17	-0.64	0.07	-1.88
Fertilizante	-0.30	-0.31	-1.34	-1.03	0.68	-0.89
IndTextil	0.17	0.17	3.07	2.86	0.79	1.88
AlimBebida	-0.28	-0.27	-4.63	-4.41	1.12	-2.48
IndDiversas	-0.28	-0.28	3.24	3.54	1.03	1.91
ConstCivil	-0.58	-0.58	-0.77	-0.18	0.28	-0.63
SIUP	-0.36	-0.37	-0.41	-0.02	-0.08	-0.28
Comercio	-0.36	-0.35	-0.16	0.20	0.60	-0.13
Transporte	-0.90	-0.90	0.05	0.99	0.51	-0.26
Servicos	-0.09	-0.09	-0.25	-0.15	0.20	-0.13

It can be seen from the comparison of results in Table 11 and Table 5 that the activity level of some sectors, especially those with high share of emissions linked to the level of activity, and particularly coal (CarvaoOut) and livestock (GadoCorte) have a tendency to present a higher fall in emissions once introduced the technological change. It's worth to remind that the coal producing sector, besides having an important share of its emissions like fugitive emissions, has also the higher coefficient of emissions reduction. The results of emissions by emitting source can be seen in Table 12.

Table 12. Model results. Percent variation in CO2 equivalent emissions, by source. Endogenous technological change.

Emitting source	cbtax1a	cbtax05a	cbtx05xa	cbtxata	cbtxetsa	cbtmet6a
ExtPetrGas	-2.27	-2.22	-1.79	0.45	0.26	-1.95
CarvaoOut	-9.43	-9.43	-5.45	4.48	0.57	-6.40
Gasolina	-1.96	-1.72	-2.25	-0.55	0.09	-1.43
OleoCombust	-3.05	-3.05	-2.62	0.45	0.48	-2.68
OutProdRefin	-1.46	-1.44	-1.10	0.37	0.35	-1.18
Activity	-0.32	-0.33	-12.12	-11.85	0.81	-8.52

As it can be seen, the reductions tend to be greater in the alternative scenarios (with endogenous technological change), as it could be expected. It's worthwhile to note the strong reduction in emissions associated to the use of coal (CarvaoOut), which is cause by the technological change which saves coal, what can also be seen in the strong differential fall in the sector's activity level, as can be seen in Table 5.

And, finally, the variations in total emissions, by emitting sectors, can be seen Table 13. Again, the reductions tend to be higher in the alternative scenarios, when compared to those without technological change.

Table 13. Model results. Percent changes in CO2 equivalent emissions, by sector. Endogenous technological change.

Sector	cbtax1a	cbtax05a	cbtx05xa	cbtxata	cbtxetsa	cbtmet6a
Arroz	-0.27	-0.27	-7.27	-7.05	1.09	-4.10
Algodao	-0.22	-0.22	0.77	0.96	0.76	0.44
Soja	-0.44	-0.44	-5.08	-4.67	0.95	-3.37
CanaAcucar	-0.57	-0.67	-3.33	-2.67	0.47	-2.15
GadoCorte	-0.20	-0.20	-13.72	-13.60	1.20	-7.11
GadoLeite	-0.27	-0.27	-4.97	-4.73	0.98	-2.58
Avicultura	-0.58	-0.57	-4.68	-4.16	-0.42	-3.02
OutAnimais	-0.25	-0.25	-10.04	-9.88	0.86	-5.77
Silvicultura*	-0.21*	-0.21*	15.07*	15.29*	0.37*	14.12*
OutAgricolas	-0.60	-0.60	-1.57	-0.98	0.53	-2.04
ExtratMiner	-5.03	-5.04	1.86	7.25	0.90	-0.93
ExtPetrGas	-3.05	-3.00	-4.88	-1.92	-2.41	-3.56
CarvaoOut	-7.17	-7.17	-9.63	-2.83	-6.19	-7.12
FabMinNonMet	-1.60	-1.60	-2.02	-0.42	-0.68	-2.15
Siderurgia	-9.78	-9.78	-5.36	4.98	0.70	-6.46
MetalurNFerr	-0.96	-0.96	1.40	2.41	-0.21	-0.68
OutMetalurg	-3.96	-3.96	-2.45	1.54	0.41	-2.82
FabMaqVeic	-2.84	-2.84	1.39	4.36	0.99	-0.33
MaterEletric	-2.25	-2.25	-1.54	0.73	0.28	-1.78
FabEqEletric	-2.61	-2.62	-2.78	-0.17	0.14	-2.66
PapelGrafica	-2.67	-2.67	-1.86	0.82	0.42	-2.12
IndQuimica	-1.27	-1.27	-1.04	0.26	0.41	-1.10
OutQuimicos	-2.90	-2.90	-1.79	1.13	0.40	-2.19
Alcool	-2.63	-3.03	-3.67	-0.68	-0.13	-3.42
Gasolina	-2.65	-2.41	-2.93	-0.54	0.02	-2.69
OleoCombust	-3.76	-3.76	-3.33	0.44	0.41	-3.42
OutProdRefin	-2.13	-2.12	-1.78	0.36	0.29	-1.87
PetroqBasica	-2.20	-2.18	-1.21	0.99	0.38	-1.59
Gasoalcool	-2.02	-1.76	-2.38	-0.64	0.06	-1.78
Fertilizante	-2.86	-2.87	-4.15	-1.38	0.29	-3.49
IndTextil	-2.41	-2.41	0.59	3.01	0.73	-0.65
AlimBebida	-2.72	-2.72	-5.99	-3.39	1.12	-4.33
IndDiversas	-2.49	-2.50	0.97	3.53	0.95	-0.35
ConstCivil	-2.66	-2.66	-2.88	-0.22	0.27	-2.71
SIUP	-0.67	-0.67	-1.59	-0.90	-0.95	-1.62
Comercio	-2.77	-2.77	-2.79	-0.03	0.49	-1.59
Transporte	-2.66	-2.66	-1.85	0.83	0.44	-2.10
Servicos	-2.21	-2.21	-2.29	-0.08	0.22	-2.19
Residencial	-1.49	-1.49	-2.17	-0.68	0.07	-1.85

*- the emissions of the Silvicultura (forestry) activity should be interpreted with an opposite signal.

12 Conclusions

As it can be seen from the above discussion, then, the introduction of a carbon tax on the economy has complex impacts, with differentiated results upon different production sectors. The particular way of tax incidence, if either on fuels, activity of both, the sectors to be included in the policy and other structural details of the economy decisively affects the outcomes of the policy.

The results here presented highlight the importance of the emissions linked to the activity level of the firms for the Brazilian economy. Emissions taxation policies would be more effective if incident also on emissions linked to the activity level of the production sectors, instead of just on fossil fuels use. The results show that the social cost of these policies (in terms of GDP reduction) would be practically the same, with a reduction in emissions significantly higher in the second case. This kind of policy, however, would have important implications for the increase in price of food, with potential negative effects on poverty. This last aspect of the problem must be further evaluated in future works.

Another point to be noted is the results obtained with the taxation of selected sectors, as is the case of those listed in the EU/ETS. The general equilibrium results show that even a contrary result to the one pursued could be obtained, with an increase in emissions. Those results arise from the interconnections across the economic sectors, as well as from the economic adjustment hypothesis used, and illustrate the complexity of the policy under analysis.

And, finally, the scenarios with long run simulations and endogenous technological change induced by the taxation policy highlight the importance of this phenomenon in the process, and the use of complementary policies to the introduction of carbon tax arise as important points here. Industrial policies that facilitate the technological change in response to the change in relative prices introduced by the tax could strongly improve the efficiency of the taxation policy in terms of emission reduction. The estimates obtained here suggest that the reductions in emissions could be twice as bigger in this case, at a social cost practically identical, measured in terms of GDP loss.

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